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Development of regional flood frequency relationships using L moments for south Bihar

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Abstract
Estimation of magnitudes of likely occurrence of floods is of immense importance for solution of a variety of water resources problems. 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 regional flood frequency relationships or the flood formulae developed for the region are one of the alternative methods which may be adopted for estimation of design floods specially for small to moderate size catchments. In this study, regional flood frequency relationship has been developed using the L–moment based General Extreme Value (GEV) distribution utilizing the annual maximum peak flood data of 32 small to medium size catchments of South Bihar for estimation of floods of desired return periods for the small to medium size gauged catchments. The L-moment based regional flood frequency curves derived for the GEV distribution have been coupled with the relationship between mean annual peak flood and the catchment area and the regional flood formula has been developed for estimation of floods of desired return periods for the ungauged catchments of South Bihar.

INTRODUCTION

Information on flood magnitudes and their frequencies is often needed for design of hydraulic structures such as dams, spillways, road and railway bridges, culverts, urban drainage systems, flood plain zoning, economic evaluation of flood protection projects etc. A number of studies have been carried out for estimation of design floods for various structures by different Indian organizations. Prominent among these include the studies carried out jointly by Central Water Commission (CWC), Research Designs and Standards Organization (RDSO), and India Meteorological Department (IMD) using the method based on synthetic unit hydrograph and design rainfall considering physiographic and meteorological characteristics for estimation of design floods (e.g. CWC, 1985) and regional flood frequency studies carried out by RDSO using the USGS and pooled curve methods (e.g. RDSO, 1991) for various hydrometeorological subzones of India.

Use of a Generalised Extreme Value (GEV) distribution as a regional flood frequency model with an index flood approach has received considerable attention (Chowdhury et al., (1991). Some of the recent studies based on index flood approach include Hosking and Wallis (1988), Jin and Stedinger (1989), Potter and Lettenmaier (1990), Farquharson et al. (1992) etc. Based on some of the comparative flood frequency studies involving use of probability weighted moment (PWM) and L moments based at-site, at-site and regional and regional methods as well as USGS method, carried out for some of the typical regions of India (NIH, 1995-96, NIH, 1997-98) in general, at-site and regional GEV method is found to be robust. Farquharson et al. (1992) state that GEV distribution was selected for use in the Flood Studies Report (NERC, 1975) and has been found in other studies to be flexible and generally applicable. Karim and Chowdhary (1995) mention that both goodness-of-fit analysis and L-moment ratio diagram analysis indicated that the three-parameter GEV distribution is suitable for flood frequency analysis in Bangladesh while the two-parameter Gumbel distribuion is not. L-moments of a random variable were first introduced by Hosking(1986). They are analogous to conventional moments, but are estimated as linear combinations of order statistics. Hosking (1986, 1990) defined L-moments as linear combinations of the PWMs. In a wide range of hydrologic applications, L-moments provide simple and reasonably efficient estimators of characteristics of hydrologic data and of a distribution's parameters (Stedinger et al., 1992). The regional flood frequency curves derived by using the L-moment approach have been coupled with the relationship between annual maximum peak floods and catchment area for development of regional flood frequency relationships and flood formulas for the seven subzones of India (Kumar et al., 1999). In this study, regional flood frequency relationships have been developed for estimation of floods of desired return periods for the gauged and ungauged catchments of South Bihar.

STUDY AREA AND DATA USED

The state of Bihar comprises alluvial plains of Indo-Gangetic basin in the north and Kaimur-Chotanagpur Santhal Pargana plateau in the south. The alluvial plain is divided into two regions by the river Ganga flowing from west to east. South Bihar comprises the flat alluvial plains on the southern side of the river Ganga and the Kaimur-Chotanagpur Santhal Pargana plateau. The total areal extent of Bihar is 1,73,306.07 sq. km., out of which the South Bihar region covers an area of about 1,17,217.11 sq. km. Annual maximum peak flood data of 32 gauging sites of South Bihar have been used. Catchment areas of these sites vary from 11.70 to 3171.00 square kilometers. Mean annual peak floods of these sites vary from 29.15 cumec to 1293.20 cumec.

ANALYSIS AND DISCUSSION OF RESULTS

The station-year data of $Q_{i,j}/(\bar{Q})_j$ for the various gauging sites have been considered for the regionalization study; where, $Q_{i,j}$ is the annual mean peak flood for ith year at the jth site and $\bar{Q}_j$ is the mean annual peak flood for the jth site. A regional non-linear relationship between $\bar{Q}$ and A has been developed for estimating the mean annual peak flood for ungauged catchments, which is the scaling factor in the regional flood frequency analysis. The annual maximum peak flood data of the 32 gauging sites have been used for development of the regional flood frequency relationship and the regional flood formula for South Bihar. The details of catchment area, sample size and sample statistics are given in Table 1.

Table 1. Catchment area, sample statistics and sample size for the gauging sites of South Bihar.

Sl. No.	Name of River	Name of Site	A	Q	SD	CV	CS	SS
1	Darua	Gandhitanr	42.74	45.15	19.02	.421	.386	6
2	Bagdaro	Loharjori	32.63	48.97	52.63	1.075	1.422	6
3	Ajay	Punasi	292.67	567.04	159.99	.282	1.742	7
4	Ajay	Ghasko	673.40	829.82	499.60	.602	.416	10
5	Pathro	Burhai	349.65	579.60	265.11	.457	-.817	11
6	Jam	Bhuiyadih	240.87	321.54	241.49	.751	1.843	5
7	Dhanarji	Rajauli	194.25	194.23	76.91	.396	.465	6
8	Khuri	Akbarpur	150.22	78.67	47.55	.604	-.197	8
9	Sakari	Gobindpur	1424.50	861.67	529.92	.615	1.309	6
10	Tilayia	Phulwaria	194.25	234.19	133.31	.569	-.443	6
11	Kiul	Lakhisarai	2619.00	628.41	409.55	.652	1.033	24
12	Falgu	Gaya	3171.00	346.67	190.70	.550	.419	7
13	Sakri	Kadarganj	1590.00	131.36	84.03	.640	1.731	6
14	Batane	Dhobidih	218.34	542.56	219.03	.404	.095	30
15	Jamuna	Vishnuganj	246.05	94.49	55.79	.590	.360	24
16	Dardha	Kolchak	715.00	185.18	132.83	.717	.359	33
17	Kharkai	Mahudilodha	2805.00	1293.2	824.79	.638	1.430	5
18	Su-barnarekha	Getalsood	828.80	732.85	377.95	.516	.834	7
19	Sakari	Amgachi	36.26	267.11	424.50	1.589	2.126	5
20	Gumani	Petkasa	1105.93	1163.28	1221.83	1.050	2.232	6
21	Gumani	Kushma	432.53	849.40	618.03	.728	.455	7
22	Rajoya	Mero	42.22	87.89	66.21	.753	.659	5
23	Kao	Nawadih	176.12	247.21	113.24	.458	-.442	5
24	Kudra	Bahura	445.48	199.35	116.34	.584	.642	6
25	Torai	Surajera	77.70	134.83	93.68	.695	.695	8
26	Suru	Hurungda	62.16	51.99	31.51	.606	.210	5
27	Gopalraidih	Gopalraidih	11.66	29.15	14.97	.514	.457	6
28	Sindar	Dhanabindi	90.65	285.91	165.03	.577	1.200	8
28	Tripta	Kharauni	104.43	279.67	175.40	.627	.746	7
30	Dhibri	Sugathan	56.57	94.42	67.57	.716	1.151	6
31	Orhri	Belchar	150.89	172.13	59.36	.345	1.795	5
32	Bunbuni	Kasoia	64.00	153.34	37.87	.247	.858	5

A = Catchment Area in sq. km.; $\overline{Q}$ = Mean Annual Flood in cumec; SD = Standard Deviation; CV = Coefficient of Variation; CS = Coefficient of Skewness; SS = Sample Size

Estimation of regional parameters for GEV distribution based on L-moment approach

The regional parameters of the GEV distribution have also been estimated using the L-moments approach following the procedure described in the Technical Report (NIH, 1997-98). The values of these parameters are mentioned below.

$$K = -0.083, \quad u = 0.692 \text{ and } \alpha = 0.463$$

The regional parameters of the GEV distribution have also been computed based on the PWM approach. Fig.1 shows comparison of the growth factors obtained using L-moment and PWM approaches for GEV distribution.

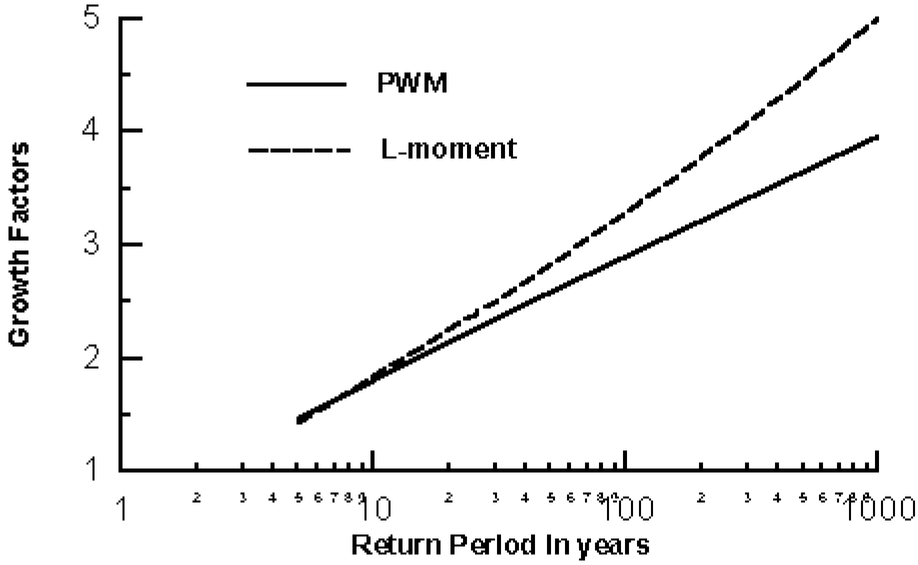

Figure 1. Comparison of Growth Factors for L-moment and approaches with return period for GEV.

Development of Relationship Between Mean Annual Peak Flood and Catchment Area

The following regional relationship has been developed between mean annual peak flood ($\overline{Q}$) and catchment area (A) for the region.

$$\overline{Q} = 13.74\, A^{0.52} \tag{1}$$

for this relationship correlation coefficient is, r = 0.74.

Regional flood frequency relationship for gauged catchments of South Bihar

The form of the regional frequency relationship for the GEV distribution is expressed as:

$$Q_T / \overline{Q} = u + \alpha Y_T \tag{2}$$

Here, Q_T is T-year return period flood estimate, $\overline{Q}$ is the mean annual peak flood and Y_T is GEV reduced variate corresponding to T-year return period i.e.

$$y_T = \left[1 - \left\{ -\ln\left(1 - \frac{1}{T} \right) \right\}^k \right] \Big/ k \tag{3}$$

Substituting the values of regional parameters based on L-moment approach the above regional flood frequency relationship is expressed as:

$$Q_T = \left[0.692 - 5.58 \left\{ 1 - \left(-\ln\left(1 - \frac{1}{T}\right) \right)^{-0.083} \right\} \right] * \overline{Q} \quad (4)$$

For estimation of flood of desired return period for a small to moderate size gauged catchment of South Bihar, the above regional flood frequency relationship may be used.

Alternatively, flood frequency estimates may be obtained by multiplying the mean annual peak flood of the catchment ($\overline{Q}$) by corresponding value of growth factors given in Table 2.

Table 2. Growth factors for various return periods for South Bihar.

Return Period (Years)	5	10	25	50	100	200	500	1000
Growth Factor	1.43	1.84	2.39	2.82	3.28	3.77	4.45	5.00

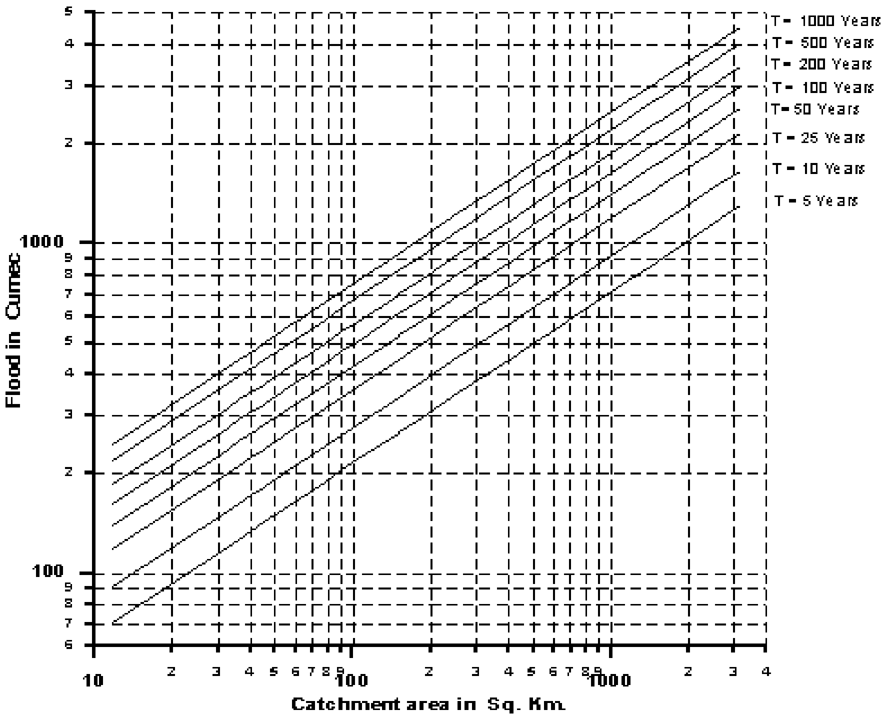

Figure 2. Variation of flood frequency estimates with catchment area for south Bihar.

Regional flood formula for ungauged catchments of South Bihar

The L-moment based regional flood frequency curves derived for the GEV distribution have been coupled with the relationship between mean annual peak flood and the catchment area and the regional flood formula mentioned below has been developed for estimation of floods of desired return periods for ungauged catchments of South Bihar.

$$Q_T = \left[-67.1 + 76.6 \left\{ -\ln\left(1 - \frac{1}{T}\right) \right\}^{-0.083} \right] A^{0.52} \tag{5}$$

Here, Q_T is flood estimate for T year return period in cumec, and A is catchment area in square kilometers.

The graphical representation of this regional flood formula is given in Fig. 2. This graphical representation may also be used for estimation of floods for various return periods for the ungauged catchments of South Bihar.

Comparison of Flood Estimates for Different Return Periods for the Gauged and Ungauged Cases of the Test Catchments

With the objective of comparing the flood estimates computed for different return periods for the gauged and ungauged cases, the above described procedure was repeated using the annual maximum peak flood data and catchment area of 29 sites out of the 32 sites of the study area. The regional values of the L-moment based parameters of the GEV distribution using the data of 29 sites is given below. While considering the test catchments as gauged catchments, their mean annual maximum peak flood and the regional flood frequency relationship developed using the data of 29 catchments were used for computing the floods of various return periods.

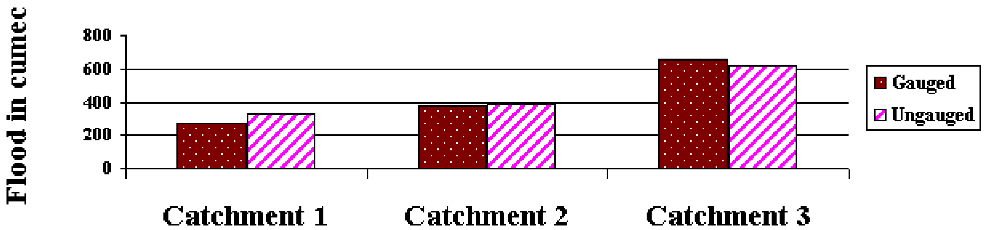

Figure 3. Comparison of floods for gauged and ungauged cases of three test catchments for 50 year return period.

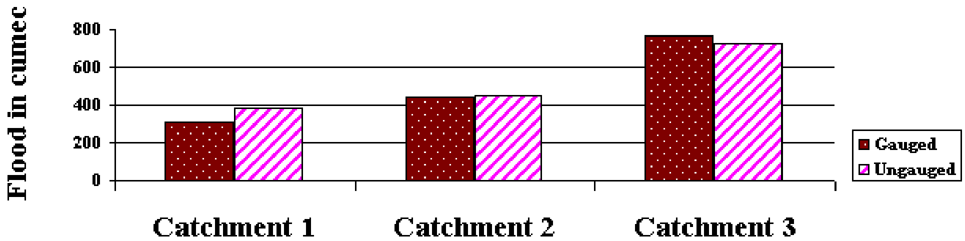

Figure 4. Comparison of floods for gauged and ungauged cases of three test catchments for 100 year return period.

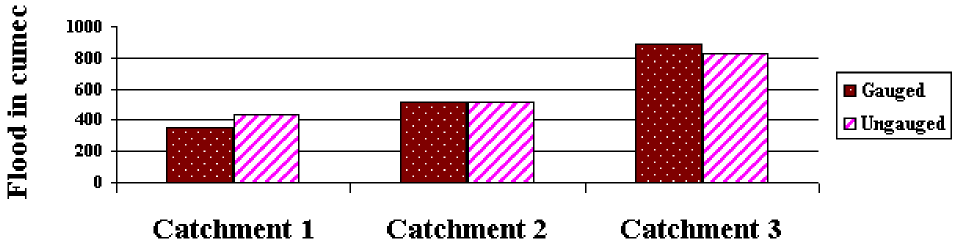

Figure 5. Comparison of floods for gauged and ungauged cases of three test catchments for 200 year return period.

When these test catchments are considered as ungauged catchments, the developed regional flood formula based on the data of 29 catchments has been used for estimation of floods of various return periods. In the regional flood formula, the catchment area of these three test catchment has been utilized. Figs. 3, 4 and 5 show the comparison of floods for gauged and ungauged cases of three test catchments for 50, 100 and 200 year return periods respectively.

CONCLUSIONS

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

In this study, regional flood frequency relationship has been developed using the L–moment based GEV distribution utilizing the annual maximum peak flood data of the 32 small to moderate size catchments of South Bihar. For estimation of floods of different return periods for the small to moderate size gauged catchments of South Bihar, the developed regional flood frequency relationship may be used. This requires an estimate of the mean annual peak flood of the catchment. Alternatively, the mean annual peak flood of the catchment may be multiplied by the corresponding growth factors.

The L-moment based regional flood frequency curves derived for the GEV distribution have been coupled with the relationship between mean annual peak flood and the catchment area and the regional flood formula has been developed for estimation of floods of desired return periods for ungauged catchments of South Bihar. The developed regional flood formula or its graphical representation may be used for estimation of floods of desired return periods for small to moderate size ungauged catchments of South Bihar. The conventional empirical flood formulae do not provide floods of various return periods. However, the regional flood formula developed in this study is capable of providing flood estimates for desired return periods.

As the flood formula has been developed using the data of small to moderate size catchments ranging from 11.7 to 3171.0 km^2; therefore this formula may be used for estimation of reliable flood frequency estimates for catchments of about 10 to 3500 km^2 in areal extent for South Bihar.

Based on the analysis carried out using the data of 29 sites for testing the regional flood formula for the three test catchments, it is observed that the percentage deviation between the ungauged and gauged cases of the test catchment No. 1 is about 22%; while for the test catchment No. 2 and 3, the percentage deviation is about 2% and 6% respectively.

Form of the developed regional flood formula is very simple, as for estimation of floods of desired return periods for an ungauged catchment; it requires only catchment area, which is readily available. Hence, this formula may be used by the field engineers for estimation of floods of desired return periods for ungauged catchments of South Bihar.

The relationship between mean annual peak flood and catchment area developed on the basis of available data is able to explain 74% of initial variance(correlation coefficient r = 0.74). However, if physiographic and climatic characteristic other than catchment area are used, then it may further improve the regional flood formula.

For most of the gauging sites, annual maximum peak flood data used in this study have been obtained from the three-hourly observed data. However, for some of the sites, the annual maximum peak floods have also been obtained from one-hourly and six-hourly data. Further, out of 32 gauging sites, data are available only for a record length of 8 years or less than 8 years for 26 gauging sites. In all, total 291 values of annual maximum peak flood are available for the entire South Bihar region. Thus, the average record length per gauging site is only about 9 years. As all the annual maximum peak flood values have not been obtained from the short interval observations like one-hourly observations and also the record length is short, hence, the results of the study are subject to these limitations. However, the developed regional flood frequency relationship and the regional formula may be revised for obtaining more accurate flood frequency estimates, when the annual maximum peak flood data based on one-hourly observations, for a longer period, become available.

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