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Development of Intensity Duration Frequency Relationship for Short Duration Rainfall

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Abstract: The rainfall Intensity Duration Frequency (IDF) relationship is one of the most commonly used tools in water resources engineering for planning, designing and operation of water resources projects. In the present paper rainfall data of 14 raingauge stations of Punpun basin located in Bihar was used for regional rainfall frequency analysis based on L-moment approach facilitated to find the robust distribution for these daily raingauge stations having data availability of 9-17 years. The robust distribution was used to find the IDF relationship and curves for short duration rainfall for Punpun basin. From the IDF curves parameters of empirical equations for the gauged locations were determined and contour maps were generated. IDF curves for ungauged locations were developed form the generated contour maps using GIS and finally a generalized IDF curve incorporating return period and the duration of rainfall for particular a station was developed.

Key words: *L-moment, rainfall, contour, intensity, duration, frequency, parameter, gauged, ungauged*

INTRODUCTION

The intensity duration frequency (IDF) relationship is one of the most important hydrologic tools utilized by water resource engineers for planning, designing and operation of water resources projects. Local IDF equations are estimated on the basis of rainfall intensities abstracted from the rainfall depths of different durations observed at rainfall gauging stations. In some regions, there may exist a number of raingauges operating sufficiently for long time to yield a reliable estimation of IDF relationships. But in most of the regions, self recording rain gauge (SRRG) data are either non-existent or their sample sizes are too small. Daily precipitation data is the most accessible and available source of rainfall information. Thus for regions where data at short time interval are not available, it is necessary to derive IDF characteristics of short duration events from the daily rainfall statistics. The establishment of such relationships was done as early as in 1932 (Bernard, 1932). Since then, many sets of relationships have been developed for several parts of the globe. But, such maps with rainfall intensity contours had not developed in many developing countries.

Hershfield (1961) developed various rainfall contours maps to provide the design rain depths for various return periods and durations. Bell (1969) proposed a generalized IDF formula using the one hour, 10 years rainfall depths (P_1^{10}) as an index. Chen (1983) further generalized the formulae for any location in the United States using three base indices of rain depths P_1^{10}, P_{24}^{10}, P_1^{100} which describe the geographical variation of rainfall. Koutsoyiannis *et al*. (1998) developed a mathematical relationship between the rainfall intensity *i,* the duration *d*, and the return period *T* for IDF curves. For Indian basin generalized formula based on the catchment constants, duration and return period have been used (Subramanya, 1984).

This paper proposes the approach of development of IDF curves using rainfall records of Punpun basin using empirical equations best suited for the basin. Normally IDF relationship is derived from the network of daily rainfall records. Also the parameters of the regional IDF formulas are generated for ungauged areas to estimate the rainfall intensity for various return periods and duration using L-moment approach. The method proposed in this study has been applied to ungauged rainfall locations and verified on dummy station (arbitrarily proposed). Also an effort has been made to develop generalized IDF formula with daily rainfall depths and return period.

The following three steps have been followed (i) Identification of the best robust distribution for the Punpun basin using L-moment approach, (ii) Development of IDF curves for 14 stations using empirical functions, and (iii) Development of generalized IDF equation at a particular location of the study area.

L-MOMENTS

L-moments are defined as liner combinations of Probability Weighted Moments (PWMs). They are robust to outliers and virtually unbiased for small samples, making them suitable for rainfall frequency analysis, including identification of distribution and parameter estimation. Greenwood *et al*., (1979) defined PWMs of a random variable X with cumulative distribution function F(X) by equation (1).

$$M_{p,r,s} = E\left[X^p \left\{F(X)^r\right\}\left\{1 - F\left(X^s\right)\right\}\right] \tag{1}$$

Particularly useful special cases are the probability weighted moments $\alpha_r = M_{1,0,r}$ and $\beta_r = M_{1,r,o}$.for a distribution that has a quantile function *x(u),*

for *p=1* and *s = 0*, Eq.(1) gives

$$\beta_r = E\left[X\left\{F(X)^r\right\}\right] = \int_0^1 X(u) u^r du \tag{2}$$

The first four L-moments, expressed as liner combination of PWMs, are:

$$\lambda_1 = \beta_0 \quad (3)$$

$$\lambda_2 = 2\beta_1 - \beta_0 \quad (4)$$

$$\lambda_3 = 6\beta_2 - 6\beta_1 + 6\beta_0 \quad (5)$$

$$\lambda_4 = 20\,\beta_3 - 30\,\beta_2 + 12\,\beta_1 - \beta_0 \quad (6)$$

Where λ_1 (L-mean) is a measure of central tendency, λ_2 (L-standard deviation) is a measure of dispersion. Their ratio λ_2/λ_1 is termed as L-CV (L-coefficient of variation) or τ_2, whereas the ratio, λ_3/λ_2 is referred to as τ_3 (L-skewness), and the ratio λ_4/λ_2 is referred to as τ_4 (L-kurtosis).

Once frequency is known, the maximum rainfall intensity of the basin is determined chosing the best robust distribution among. Generalized Extreme Value (GEV), Generalized Logistic (GLO), Generalized Normal (GNO), Pearson type-II (PE3) using the L-moments approach. The rainfall intensities for each duration and a set of selected return periods 2, 3, 5, 10, 20, 50, 100 years are calculated. The empirical formulas are used to construct the rainfall IDF curves. The least-square method is applied to determine the parameters of the empirical IDF equation.

EMPIRICAL IDF FORMULAS

The IDF formulas are the empirical equations representing a relationship among maximum rainfall intensity (as dependent variable) and other parameters of interest such as rainfall duration and frequency (as independent variables). There are several commonly used functions found in the literature (Chow *et al.*, 1988). Four basic forms of equations used to describe the rainfall intensity duration relationship are summarized as follows:

Talbot equation: $$i = \frac{a}{d + b} \quad (7)$$

Bernard equation: $$i = \frac{a}{d^e} \quad (8)$$

Kimijima equation: $$i = \frac{a}{d^e + b} \quad (9)$$

Sherman equation: $$i = \frac{a}{(d + b)^e} \quad (10)$$

where i is the rainfall intensity (mm/hr); d is the duration (minutes); a*, b,* and e are the constant parameters related to the meteorological conditions.

These empirical equations show rainfall duration for a given return period. All these functions are widely used in hydrological applications. The least-square method is applied to determine the parameters of empirical IDF equations that are used in this study. The value of parameters have been chosen on the basis of minimum Root Mean Square Error (RMSE) between the IDF relationships produced by the frequency analysis and simulated by the IDF equations.

REGIONALIZATION OF RAINFALL PARAMETERS

The rainfall IDF curves are derived from the point rain gauges. A set of IDF curves were developed. SRRG data is required for the IDF curves. But the network of Ordinary Rain Gauge (ORG) stations for daily records is available in higher density than SRRG records in the basin. Thus the regional IDF formula parameters are generated for ungauged areas to estimate rainfall intensity for various return periods and durations. The method proposed in this study was verified and found reasonable and with good agreement to ungauged rainfall locations. After determining the parameters of IDF formula a, *b,* and *e* for the same return period using Arc View/ GIS was used to interpolate the values for generation of contour maps of each parameter. The generated map of the parameter was then used for ungauged rainfall station.

GENERALIZED IDF FORMULA

A set of IDF curves constitute a relation between rainfall intensity, duration of the rainfall and the return period of an event and is defined by the inverse of the annual exceedence probability which is expressed as:

$$i = f(T, d) \tag{11}$$

Where i is the rainfall intensity (mm/hr), d is the duration of the rainfall (min) and T is return period (years).

According to Koutsoyannis *et al.* (1998) the IDF curve is a mathematical relationship between the rainfall intensity i, the duration d, and return period T. The typical IDF relationship for a specific return period is a special case of the generalized formula given by Koutsoyannis *et al.* (Eq. 12).

$$i = \frac{a}{\left(d^{v} + b\right)^{e}} \tag{12}$$

where a, b, e and v are non negative coefficients. Thus, the generalized equation: with v=1 and e=1 forms Talbot equation; v=1 and $b=0$ is Bernard equation; e=1 is Kimijima equation and v=1 is Sherman equation. This empirical expression is the outcome of the experiences gathered from several studies. The corresponding errors associated with the equation (12) assuming v=1 has been studied numerically and simplified by equation (13).

$$i = \frac{a}{(d+b)^e} \tag{13}$$

Bell (1969) proposed a generalized IDF formula using P_1^{10} , P_{24}^{10} and P_1^{100}. Bell developed the following two generalized IDF relationships for high intensity short duration rainfall which also takes care of geographical variation of rainfall.

$$\frac{P_d^T}{P_{60}^T} = 0.54d^{0.25} - 0.50 \quad (5<d<120\text{min}) \tag{14}$$

$$\frac{P_d^T}{P_d^{10}} = 0.21\ln T + 0.52 \quad (2?T?100 \text{ years}) \tag{15}$$

Bell (1969) and Chen (1983) further simplified and generalized the above expression (Eq. 14 & 15) and the modified form is given below.

$$\frac{I_d^T}{I_{d^I}^{T^I}} = f_1(T) f_2(d) \tag{16}$$

where T is the return period, d is the rainfall duration; T^I is a constant return period as the base value; d^I a constant rainfall duration. I^T_d is the rainfall intensity with a return period (T) and rainfall duration d (min). $I_{d^I}^{T^I}$ is the rainfall intensity T^I return period and a base d^I minute rainfall duration. f_1 *(T)* is a function of only return period and assumed to be the ratio of I_d^T to $I_d^{T^I}$. Here the function does not depend on the duration d. f_2 *(d)* is a function of only duration d and assumed to be the ratio of I_d^T to $I_{d^I}^T$. Here the function does not depend on the return period T.

Bell (1969), Chen (1983) and Koutsoyiannis *et al.* (1998) proposed the function of the return period $f_1(T)$ as the ratio of I_d^T and $I_d^{T^I}$ to proposed the following

$$f_1(T) = \frac{I_d^T}{I_d^{T^I}} = \frac{I_d^T}{I_{d^I}^{T^I}} = c + \lambda \ln(T) \tag{17}$$

And f_2 *(d)* is the ratio of I_d^T and $I_{d^I}^T$ which is the function of rainfall duration

$$f_2(d) = \frac{I_d^T}{I_{d^I}^T} = \frac{I_d^T}{I_{d^I}^{T^I}} = \frac{a}{(d+b)^e} \tag{18}$$

After combining equation (16), (17) and (18), the generalized formula of rainfall intensity and frequency can be written as

$$I_d^T = I_{d^1}^{T^1}(c + \lambda \ln(T))\frac{a}{(d+b)^e} \tag{19}$$

STUDY AREA

The Punpun basin lies between latitude 24°11′ to 25°00′ N and longitude 84°10′ to 85°20′ E. It is located on the right bank of the river Ganga and bounded by the Sone river system on its west and Kiul-Harohar-Falgu river system in the east. On its northern side, it is the river Ganga and on its southern side, bounded by Chotonagpur hills. The drainage map of Punpun river basin with the locations of rain gauge stations is shown in Fig. 1.

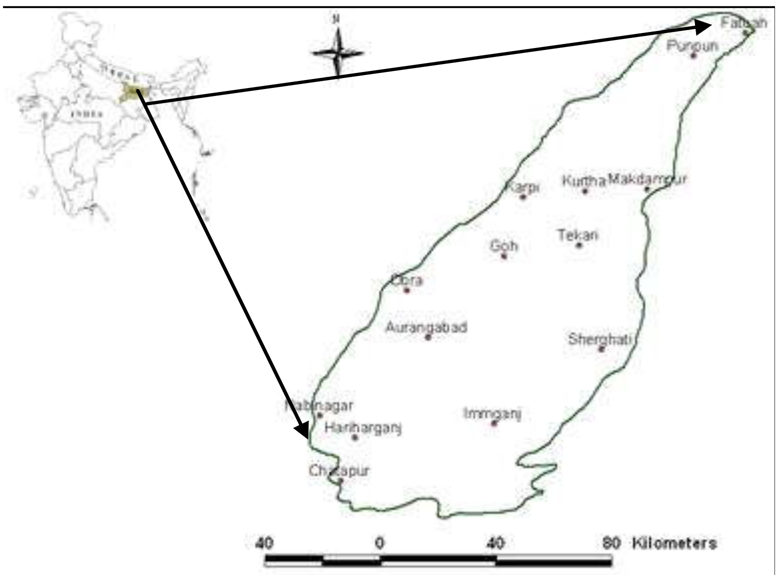

Figure 1. Location of the rain gauge stations in the Punpun basin

ANALYSIS OF L-MOMENTS

Data screening: It is a preliminary screening test of the data set by discordance measures (D_i). Hosking and Wallis (1997) defined the discordance measure (D_i) for N sites in the group, where $u_i = \left[t_2^{(i)} t_3^{(i)} t_4^{(i)}\right]^T$ is a vector containing the sample L-moment ratios t_2, t_3 and t_4 values (of each site) for *i* sites, analogous to their regional values termed as τ_2, τ_3 and τ_4. T denotes transpose of a vector of matrix.

$$D_i = \frac{1}{3} N (u_i - \bar{u}) A_m^{-1} (u_i - \bar{u}) \tag{20}$$

$$\text{where, } \quad \bar{u} = N^{-1} \sum_{i=1}^{N} u_i \quad \text{and} \quad A_m = \sum_{i=1}^{N} \left(u_i - \bar{u} \right) \left(u_i - \bar{u} \right)^T \tag{21}$$

The site '*i*' is declared to be discordant, if D_i is greater than the critical value of the discordance statistics D_i, given in a tabular form by Hosking and Wallis (1997).

Test of regional homogeneity: If the variability of the cloud of points on a plot of L-CV versus L-skewness and/or L-skewness versus L-kurtosis is large, the possibility that they do not belong to a single population. This can be tested by means of the L-moment heterogeneity tests. The L-moment test for heterogeneity fits a four-parameter Kappa distribution to the regional data set, which generates a series of 500 equivalent regions data by numerical simulation and compares the variability of the L-statistics of the actual region to those of the simulated series. Three heterogeneity statistics can be employed to test variability of three different L-statistics: H_1 for L-CV, H_2 for the combination of L-CV and L-skewness and H_3 for the combination of L-skewness and L-kurtosis. The H_1 statistics has much better discrimination power than H_2 and H_3 statistics (Hosking and Wallis1997). The general form of H-statistics is given by equation (22).

$$H = \left(V_{obs} - \mu_V \right) / \sigma_V \tag{22}$$

where μ_V and σ_V are mean and standard deviation of the simulated values of *V*. V_{obs} is the observed dispersion, calculated from the regional data and is based on a corresponding *V*-statistics in terms of L-moment ratio *t*, defined by equations (23 and 24).

$$V = \left\{ \sum_{i=1}^{N} n_i \left(t^i - t^R \right)^2 / \sum_{i=1}^{N} n_i \right\}^{1/2} \tag{23}$$

$$t^R = \sum_{i=1}^{N} n_i t^{(i)} / \sum_{i=1}^{N} n_i \tag{24}$$

The H-statistics indicate that the region under consideration is homogeneous when H<1; possibly homogeneous when 1≤ H< 2; and definitely heterogeneous when H ≥ 2. The details of L-statistics including the value of discordance measure are given in Table 1. It was found that the D_i values for 14 sites vary from 0.09 to 1.88, all of which are less than the critical D_i values of 2.971 (Hosking and Wallis, 1997). The heterogeneity measures (H), computed using the data of 14 rain gauge sites

Table 1. Rainfall data and statistical parameters for 14 rain gauge station of the Punpun basin.

Sl.	Name of the rain gauge locations	Mean annual maximum rainfall (mm)	L-CV (τ_2)	L-CS (τ_3)	L-CK (τ_4)	Sample size (Years)	Discordance measures (D_i)
1	Chatapur	98.790	0.2671	0.0489	0.0902	13	0.80
2	Tekari	74.160	0.3381	0.2656	0.2802	13	1.88
3	Punpun	89.100	0.2423	0.0158	0.1602	12	0.99
4	Aurangabad	114.490	0.1966	0.1735	0.1817	17	0.73
5	Fatuah	101.360	0.2183	0.2850	0.3546	09	1.30
6	Hariharganj	104.240	0.2227	0.2995	0.1902	16	0.76
7	Karpi	87.730	0.3166	0.0477	0.0240	13	1.56
8	Nabinagar	82.830	0.2707	0.3815	0.2436	13	0.75
9	Immganj	107.030	0.2990	0.3031	0.2228	12	0.38
10	Kurtha	79.970	0.3675	0.2842	0.1128	12	1.40
11	Sherghati	117.350	0.2626	0.3499	0.0984	15	1.77
12	Obra	88.920	0.1991	0.1121	0.2937	13	1.22
13	Goh	100.880	0.2892	0.2284	0.1620	13	0.09
14	Makdampur	113.320	0.2152	0.1496	0.1920	14	0.36

of Punpun basin was found less than 1.0 (Table 2). Since H<1, the region has been treated as homogeneous.

***Selection of best-fit distribution*:** Generally goodness of fit measure is used to evaluate the suitability of data of a particular site to be consistent with the fitted probability distribution. Hosking and Wallis (1997) found that L-moment ratio diagram and Z-statistic are the two criteria which can identify the best-fit distribution suitable for a region. L-moment ratio diagram compare sample estimates of the dimensionless L-moment ratios. The Z-statistic is defined by equation (26).

$$Z^{DIST} = \left(\tau_4^{DIST} - \bar{\tau}_4 + \beta_4\right) \Big/ \sigma_4 \qquad (25)$$

where the superscript 'DIST' refer to a particular distribution, β_4 and σ_4 are the bias and standard deviation of τ_4 (L-kurtosis) respectively, which is defined by equations (27, 28).

$$\beta_4 = \frac{1}{N_{sim}} \sum_{m=1}^{N_{sim}} \left(\bar{\tau}_{4m} - \bar{\tau}_4 \right) \tag{26}$$

$$\sigma_4 = \sqrt{\frac{1}{N_{sim}-1} \sum_{m-1}^{N_{sim}} \left(\bar{\tau}_{4m} - \bar{\tau}_4 \right)^2 - N_{sim}\beta_4^2} \tag{27}$$

where N_{sim} is the number of simulated regional data sets generated using Kappa distribution in a similar way as for the heterogeneity statistics, the subscript m denotes the m^{th} simulated region. The distribution for which Z^{DIST} value is very close to zero will be declared the best fit distribution. However, a reasonable criterion is $|Z^{DIST}| \leq 1.64$.

The Z^{DIST} statistic for the various distributions is given Table 3. It is observed that the $|Z^{DIST}|$ statistic value are lower than 1.64 for the four distributions namely GLO, GEV, GNO, and PE-III. Further, for GLO distribution $|Z^{DIST}|$ value (0.29) is found to be very close to zero. Thus, based on the L-moment ratio diagram (Fig. 2) as well as $|Z^{DIST}|$ statistic criteria, the GLO distribution has been identified as the robust distribution for Punpun basin. The values of the regional parameters for the distributions, which have $|Z^{DIST}|$ statistic value less than 1.64 are given in Table 4.

RAV = Regional Average.

The GLO distribution was identified as the robust distribution for Punpun basin. The regional quantile function of the GLO distribution is expressed as equation (28).

$$f(x) = \xi + \alpha\left[1 - \{1/(T-1)\}^k\right]/k \tag{28}$$

The values of regional parameters of the GLO distribution for Punpun basin were found to be ξ=0.911, α =0.243, and κ=-0.210 and substituting these values in the equation (Eq. 28), we get (Eq. 29)

Table 2. Heterogeneity measures for Punpun basin

Sl.	Heterogeneity measures		Values
1.	*Heterogeneity measure (H1)*		
	(a)	Observed standard deviation of group L-CV	0.0507
	(b)	Simulated mean of standard deviation of group L-CV	0.0533
	(c)	Simulated standard deviation of standard deviation of group L-CV	0.0109
	(d)	Standardized test value H (1)	-0.24
2.	*Heterogeneity measure H (2)*		
	(a)	Observed average of L-CV / L-Skewness distance	0.1163
	(b)	Simulated mean of average L-CV / L-Skewness distance	0.1372
	(c)	Simulated standard deviation of average L-CV / L-Skewness distance	0.0245
	(d)	Standardized test value H (2)	-0.85
3.	*Heterogeneity measure (H3)*		
	(a)	Observed average of L-Skewness/L-Kurtosis distance	0.1253
	(b)	Simulated mean of average L-Skewness/L-Kurtosis distance	0.1760
	(c)	Simulated standard deviation of average L-Skewness/ L-Kurtosis distance	0.0296
	(d)	Standardized test value H (3)	-1.71

Table 3. Z^{DIST} statistic values for various distributions

Sl..	Distribution	Z^{DIST} statistic
1	GLO	0.29
2	GEV	-0.70
3	GNO	-0.97
4	PE III	-1.51

Table 4. Regional Parameters for various distributions

ξ =0.911	α =0.243	κ =-0.210
ξ =0.772	α =0.356	κ =-0.061
ξ =0.902	α =0.429	κ =-0.434
μ =1.000	σ =0.488	γ = 1.269

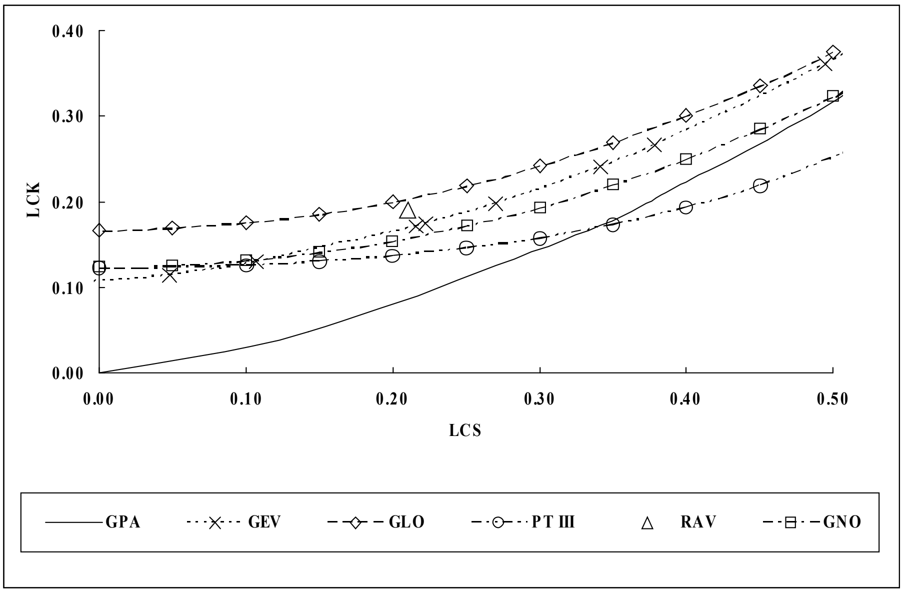

Figure 2. L-moments ratio diagram for Punpun basin

$$f(x) = -0.246 + 1.157\left(\frac{1}{T-1}\right)^{-0.210} \tag{29}$$

The GLO distribution is used to calculate the rainfall intensity at different durations and return periods to forms the historical IDF curves for each station. Using the GLO distribution function, maximum rainfall intensity of considered durations for 2, 5, 10, 20, 50, 100 years return periods, have been determined (Fig. 3). The relationship between the maximum rainfall intensities and the duration for various return periods are determined by fitting empirical functions.

The IDF curves for 14 stations were constructed by using empirical equations of Talbot, Bernard, Kimijima and Sherman (Eqs.7-10). Least-square method was applied to determine the parameters of the empirical IDF equations used to develop intensity-duration relationships. The values of parameters in the IDF equations were chosen based on minimum Root Mean Square Error (RMSE) between the IDF relationships produced by the frequency analysis and simulated by the IDF equations. The RMSE is defined as

$$RMSE = \sqrt{\frac{\sum_{j=1}^{m}\sum_{k-1}^{n}\left(I_{ij}^{k} - I_{ij}^{k}*\right)^2}{mn}} \tag{30}$$

where *m* is the number of various rainfall durations, *n* is the number of various return periods, I_{ij}^{k} is the rainfall intensity derived by GLO distribution for *j* hour duration for *k* year return period at *i* station, and I_{ij}^{k} *is the rainfall intensity estimated by equation (7 to 10) for *j* hour duration and *k* year return period at *i* station.

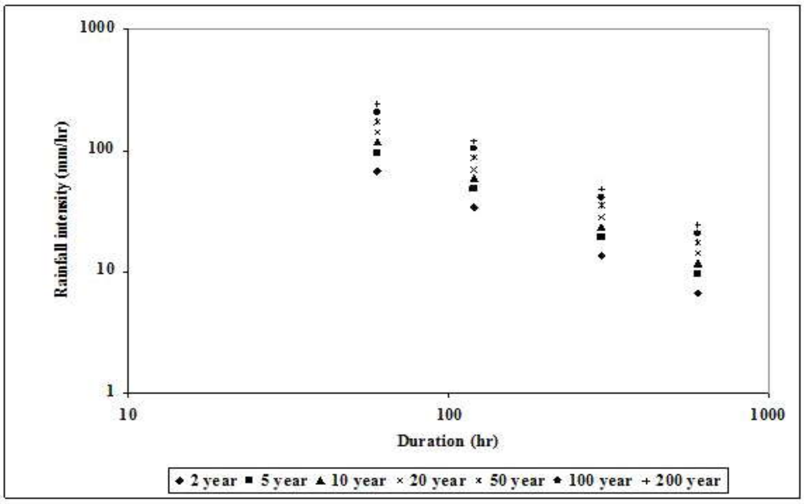

Figure 3. Maximum rainfall intensity for different time intervals and return periods obtained from the GLO distribution at Tekari station

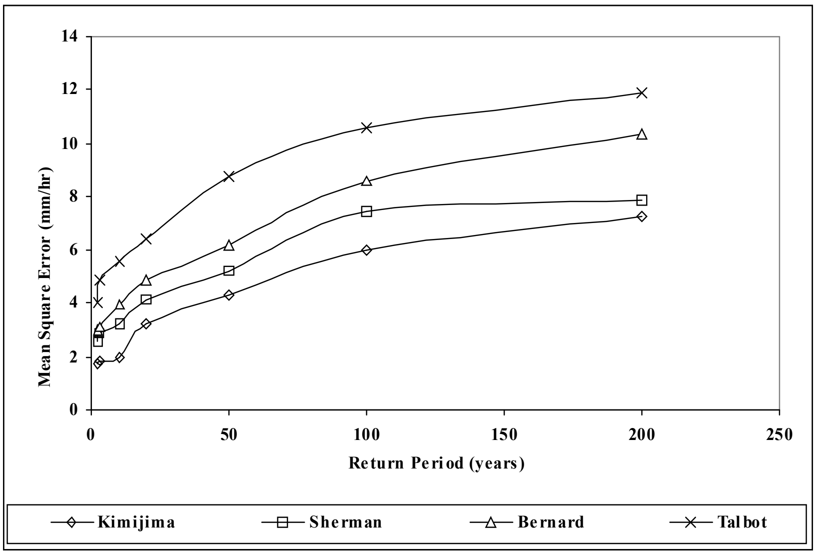

Figure 4. Comparison of the Root mean square error (RMSE)

Table 5. The parameters of the Kimijima equation as IDF curves for 100 years return period

Sl.	Name of the rain gauge locations	*a*	*b*	*e*	Coefficient *R*	RMSE
1	Chatapur	20796.68	20	0.989	0.992	6.224
2	Tekari	15881.21	26	0.959	0.981	6.024
3	Punpun	17082.00	20	0.949	0.986	6.399
4	Aurangabad	24719.30	20	0.989	0.992	6.224
5	Fatuah	19433.00	20	0.949	0.988	6.960
6	Hariharganj	19403.00	18	0.949	0.986	7.279
7	Karpi	16868.00	20	0.950	0.986	6.261
8	Nabinagar	16851.25	24	0.950	0.981	6.706
9	Immganj	22401.00	23	0.965	0.986	7.674
10	Kurtha	15466.30	20	0.952	0.986	5.636
11	Sherghati	26458.59	22	0.996	0.991	6.588
12	Obra	17182.00	24	0.988	0.977	8.000
13	Goh	19809.62	20	0.956	0.986	6.930
14	Makdampur	24804.25	22	0.994	0.989	6.856

Comparison among the four empirical methods (Eqs. 7 to 10) for IDF formula were made and found that Kimijima equation (Eq. 9) was showing minimum RMSE (Fig. 4) and fitted well. Thus for all the rain gauge stations of Punpun basin, the parameters of the Kimijima equation were determined for 100 year return period (Table 5) that has RMSE ranging 5.636 to 8.0 mm/hr with correlation coefficient R = 0.98. The RMSE with Kimijima equation are less than 8.0 mm/hr. Thus the Kimijima equation was accepted and used for development of the IDF relationship of Punpun basin.

REGIONALIZATION OF RAINFALL PARAMETER

After determining the parameters *a, b* and *e* of IDF formula for the same return period interpolation technique was applied to generate contour maps in GIS environment using Arc-View.

The parameter contour maps and the IDF relation were generalized for further use to estimate IDF curves of an ungauged location with various return periods.

The results were applied to an ungauged location (Rafigunj), verified and found satisfactory. The parameter contour maps of *a, b* & *e* for Kimijima equation are shown in Fig. 5.

From the parameter contour maps of the entire basin, ungauged rainfall station of Rafiganj the values of *a*, *b* & *e* have been determined as a= 20000.00, b= 21.55, c= 0.963. Accordingly the IDF curve of Rafiganj was developed for 100 year return period (Eq. 31).

$$i = \frac{a}{d^e + b} = \frac{20000.000}{d^{0.963} + 21.550} \tag{31}$$

GENERALIZED IDF FORMULA AT TEKARI STATION

(1) Intensity-Frequency Ratios

The function f_1 *(T)* is the ratio of I_d^T and $I_d^{T^I}$ is the function of the return period (Eq. 17). The Tekari station was used to illustrate how to define the generalized IDF formula. For this example: T^I=100 year as the base return period. The ratio is of $I_d^T / I_d^{T^I=100}$ for various durations and return periods are given in Table 6. The ratio show little variation with duration, thus it is a function of return period only.

Table 6. Average relationship between rainfall intensity and duration at Tekari

Return period	2	5	10	20	50	100	200
f_1 *(T)*	0.326	0.466	0.569	0681	0.851	1.000	1.172

The linear regression relationship between the log-tranformed values of return periods (T) and the ratios of rainfall intensity is given by Eq. (32) whereλ is slope value.

$$f_1(T) = \frac{I_d^T}{I_d^{T^I}} = \frac{I_d^T}{I_{d^I}^{T^I}} = c + \lambda \ln(T) = 0.1697 + 0.1811 \ln(T) \tag{32}$$

we have developed the relation for Tekari in which the parameter c=0.1697 and λ = 0.1811 with correlation coefficient value *r* = 0.995.

The intensity-duration ratios are calculated for every available data. The calculations are made in order to obtain the average value of the ratios consider in each duration. The ratios 60-minute rainfall intensity and duration ($I_d^T / I_{d^I=60}^T$) for same return period *T*. the ratio *f2* was fitted by Sherman equation:

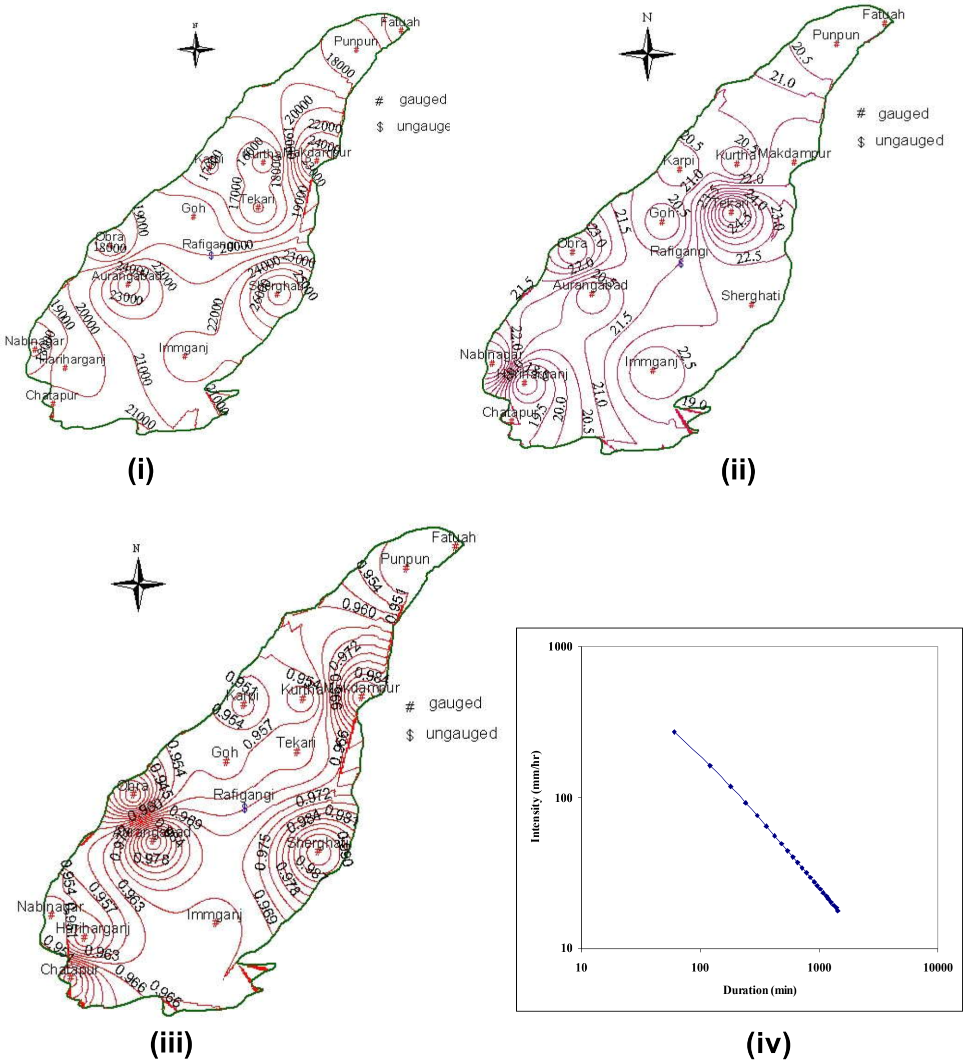

Figure 5. Parameter contours of Kimijima equation with 100 years return period and IDF curves at ungauged point i) contour map of a ii) contour map of b iii) contour map of e and iv) rainfall IDF curves at Rafiganj (ungauged location)

$$f_2(d) = \frac{I_d^T}{I_{d^1}^T} = \frac{I_d^T}{I_{d^1}^{T^1}} = \frac{62.810}{(d+16.00)^{0.956}} \quad (33)$$

The parameter a=62.81, b=16 and e=0.956 with correlation coefficient value r=0.992. Combing equations (32) and (33) the generalized IDF formula at Tekari station, with rainfall intensity in 60 minute with 100 years return period is 206.981 mm/hr, accordingly the formula has been developed for Tekari station (Eq. 34).

$$I_d^T = 206.981(0.1697 + 0.1811 \ln T)\frac{62.810}{(d+16.00)^{0.956}} \quad (34)$$

Generalized rainfall IDF formula for Tekari station is as under

$$I_d^T = \frac{2206.180 + 2354.386 \ln T}{(d+16.00)^{0.956}} \quad (35)$$

The rainfall intensity can be calculated from (35) equation for any duration (d) and return periods (T).

CONCLUSIONS

The study has been carried out for development of IDF curves using data of 14 rainguage stations employing empirical equations. Based on the L-moments approach the GLO distribution has been identified as the robust distribution for the study area. Four empirical functions have been used to represent IDF relationship for Punpun basin and 3 parameters function (Kimijima) has been used to estimate rainfall intensity quartiles.

After regionalization of rainfall parameters, development of IDF equation was carried out for ungauged area to estimate rainfall intensity for various return period and rainfall durations. The parameter contour maps have been prepared to estimate rainfall intensity of an ungauged location namely Rafiganj for 100 year return period.

More specifically, this research is to generalize IDF formula using some base rainfall duration and return period of Tekari station. In fact, IDF curves give the rainfall intensity at a point but information about storm characteristics are also required for larger catchments. Hence for large basin development of Intensity-Duration-Area-Frequency curve (IDAF) is recommended for evaluation of design storms using a scaling approach.

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