

# Establishment of Intensity-Duration-Frequency Formula for Precipitation in Puthimari Basin, Assam

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**ABSTRACT:** The rainfall Intensity-Duration-Frequency (IDF) relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resource projects, or for various engineering projects against design floods. The establishment of such relationships was reported as early as in 1932 (Bernard). Since then, many sets of relationships have been constructed for several parts of the globe. Different states of India have also developed this relationship. In this project an attempt has been made for the development of IDF relationship for Puthimari Basin, Assam. The classical approach for building IDF curves has three steps. In the first step, a probability distribution function is fitted to each duration sample. In the second step, the quantiles of several return periods  $T$  are calculated using the estimated distribution function from step one. Lastly, the IDF curves are determined by fitting a parametric equation for each return period, using regression techniques between the quantile estimates and the duration. In this project the calculation for return period is done according to Gumbel's distribution method and IDF curves were obtain by curve fitting method. The maximum intensity for return period of 2years, 5 years, 10 years, 25 years and 50years are calculated. This study has been conducted for the formulation and construction of IDF curves using data from the recording station.

**KEYWORDS:** Rainfall intensity, Design rainfall, Intensity-Duration-Frequency relationship (IDF), Puthimari Basin, Assam.

## NOTATIONS

$d$	= rainfall duration (hour)
$i$	= rainfall intensity (mm/hr)
$I_d^T$	= rainfall intensity for $d$ - hour duration and $T$ -year return period
$I_1^T$	= rainfall intensity for 1- hour duration and $T$ -year return period
$I_d^{50}$	= rainfall intensity for $d$ - hour duration and 50-year return period
$P$	= rainfall depth (mm)
$T$	= return period (years)
$K$	=frequency factor
$N$	=sample of size $N$
$S_n$	=reduced standard deviation, a function of sample size $N$
$X$	=intensity variate
$X_T$	=value of the variate $x$ with a return period $T$
$x_o$	=particular intensity
$\bar{x}$	= mean
$Y_T$	=reduced variate for a given time $T$
$\sigma_x$	= standard deviation of the variate $X$
$\sigma_{n-1}$	= standard deviation of the sample of size $N$
$y$	=dimensionless variable

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$\bar{y}_n$  = reduced mean, a function of sample size N

## I. INTRODUCTION

The rainfall intensity-duration-frequency (IDF) relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resources projects, or for various engineering projects against floods. The establishment of such relationships was done as early as in 1932 (Bernard, 1932). Since then, many sets of relationships have been constructed for several parts of the globe. There is a high need of IDF curves in the monsoon area like Assam, but the adequate long history data are not frequently available.

A rainfall intensity-duration-frequency (IDF) relationship is commonly required for designing of the water resource projects. There has been considerable attention and research on IDF relationship: Hershfield (1961) developed various rainfall contour 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 developed a generalized IDF formula for any location in the United States using three base rainfall depths:  $P_1^{10}$ ,  $P_{24}^{10}$ ,  $P_1^{100}$ , which describe the geographical variation of rainfall. Koutsoyiannis et al, (1998) cited that the IDF relationship is a mathematical relationship between the rainfall intensity  $i$ , the duration  $d$ , and the return period  $T$  (or, equivalently, the annual frequency of exceedance, typically referred to as “frequency” only).

## II. EMPIRICAL FORMULA

The IDF formulas are the empirical equations representing a relationship among maximum rainfall intensity (as dependant 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 of hydrology applications (Chow et al., 1988), four basic forms of equations used to describe the rainfall intensity duration relationship are summarized as follows:

*Talbot equation:*

$$i = \frac{a}{d+b} \quad (1)$$

*Bernard equation:*

$$i = \frac{a}{d^e} \quad (2)$$

*Kimijima equation:*

$$i = \frac{a}{d^e + b} \quad (3)$$

*Sherman equation:*

$$i = \frac{a}{(d+b)^e} \quad (4)$$

Where,  $i$  is the rainfall intensity (mm/hour);  $d$  is the duration (hours);  $a, b$  and  $e$  are the constant parameters related to the metrological conditions. These empirical equations show the rainfall intensity decreases with rainfall duration for a given return period. All functions have been widely used for hydrology practical applications.

## III. CALCULATION OF RETURN PERIOD BY GUMBEL'S METHOD

The extreme value distribution was introduced by Gumbel and is commonly known as Gumbel's distribution. The estimate of rainfall intensity of given duration for different return periods is obtained by this method. It is one of the most widely used probability-distribution function for extreme values in hydrologic and meteorological studies for prediction of flood peaks, maximum rainfalls, maximum wind speed etc. It was confirmed that the Gumbel's distribution well describes the variation of annual series of maximum rainfall intensity.

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According to this theory of extreme events, the probability of occurrence of an event equal to or larger than a value  $x_0$  is:

$$P(X \geq x_0) = 1 - e^{-y} \tag{5}$$

In which  $y$  is a dimensionless variable given by

$$\begin{aligned} y &= \alpha(x - a) \\ a &= \bar{x} - 0.45005\sigma_x \\ \alpha &= 1.2825/\sigma_x \end{aligned}$$

Thus,

$$y = \frac{1.2825(x-\bar{x})}{\sigma_x} + 0.577 \tag{6}$$

Where  $\bar{x}$  = mean and  $\sigma_x$  = standard deviation of the variate  $X$ . In practice it is the value of  $X$  for a given  $P$  that is required and as such eq. (5) is transposed as

$$y_p = -\ln[-\ln(1 - P)] \tag{7}$$

Noting that the return period  $T = 1/P$  and designating  $Y_T$  = the value of  $y$ , commonly called the reduced variate, for a given  $T$

$$Y_T = -\left[\ln \ln \frac{T}{T-1}\right] \tag{8}$$

Or

$$Y_T = -\left[0.834 + 2.303 \log \log \frac{T}{T-1}\right] \tag{9}$$

Now rearranging eq. (6), the value of the variate  $X$  with a return period  $T$  is

$$X_T = \bar{x} + K\sigma_x \tag{10}$$

where

$$K = \frac{Y_T - 0.577}{1.2825} \tag{11}$$

### IV. GUMBEL'S EQUATION FOR PRACTICAL USE

Equation (10) giving the value of the variate  $X$  with a recurrence interval  $T$  is used as

$$X_T = \bar{x} + K\sigma_{n-1} \tag{12}$$

Where  $\sigma_{n-1}$  = standard deviation of the sample of size  $N$

$$= \sqrt{\frac{\sum(x-\bar{x})^2}{N-1}}$$

$K$  = frequency factor expressed as

$$K = \frac{Y_T - \bar{Y}_n}{S_n} \tag{13}$$

In which  $X_T$  = reduced variate, a function of  $T$  and is given by

$$Y_T = -\left[\ln \ln \frac{T}{T-1}\right] \tag{14}$$

Or

$$Y_T = -\left[0.834 + 2.303 \log \log \frac{T}{T-1}\right]$$

$\bar{Y}_n$  = reduced mean, a function of sample size  $N$

$S_n$  = reduced standard deviation, a function of sample size  $N$

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## V. GENERALIZED INTENSITY - DURATION - FREQUENCY FORMULA

A set of Intensity-Duration-Frequency (IDF) curves constitutes a relation between the intensity (more precisely, the mean intensity) of precipitation (measured in  $mm/h$ ), the duration or the aggregation time of the rainfall (in  $hour$ ) and the return period of the event. The return period of an event (here the rainfall intensity or depth) indicates how frequent this event is and is defined by the inverse of the annual exceedance probability. Denote by  $i$  the rainfall intensity ( $mm/h$ ),  $d$  the duration of the rainfall ( $hour$ ) and  $T$  the return period (years). The IDF relation is mathematically as follows:

$$i = f(T, d) \quad (15)$$

The rainfall intensity is a function of the variables  $T$  and  $d$ . Koutsoyiannis *et al.* (1998) cited that the IDF relationship is a mathematical relationship between the rainfall intensity  $i$ , the duration  $d$ , and the return period  $T$  (or, equivalently, the annual frequency of exceedance, typically referred to as 'frequency' only). The typical IDF relationship for a specific return period is a special case of the generalized formula as given in equation:

$$i = \frac{a}{(d^{v+b})^e} \quad (16)$$

where  $a, b, e$  and  $v$  are non-negative coefficients.

Thus, the equation that is more general: with  $v = 1$  and  $e = 1$  it will be Talbot equation;  $v = 1$  and  $b = 0$  is Sherman;  $e = 1$  is Kimijima equation and  $v = 1$  is Sherman. This expression is an empirical formula that encapsulates the experience from several studies. A numerical study shows if it is assumed that  $v = 1$ , the corresponding error is much less than the typical estimation errors which results in the equation:

$$i = \frac{a}{(d+b)^e} \quad (17)$$

Bell (1969) proposed a generalized IDF formula using the one hour, 10 years rainfall depths;  $P_1^{10}$ , as an index. Cheng-lung Chen (1983) further developed a generalized IDF formula for any location in the United States using three base rainfall depths: 1-hour rainfall depth, 10-year returns  $P_1^{10}$ ; 24-hours rainfall depth, 10-years returns  $P_{24}^{10}$ , and 24-hours rainfall depth, 100-years returns  $P_1^{100}$ , which describe the geographical variation of rainfall. Bell developed generalized IDF relationships for high intensity short duration rainfall. Bell established two general relationships:

$$\frac{P_d^T}{P_{60}^T} = 0.54d^{0.25} - 0.50 \quad (5 < d < 120 \text{ min}) \quad (18)$$

$$\frac{P_d^T}{P_{10}^T} = 0.21 \ln T + 0.52 \quad (2 \leq T \leq 100 \text{ years}) \quad (19)$$

The IDF relationship produced by frequency analysis at each recording rain gauge was fitted to the following equation suggested by Bell (1969) and Chen (1983) may consider expressions of the type:

$$\frac{I_d^T}{I_d^T} = f_1(T) f_2(d) \quad (20)$$

where  $T$  is the return period (year),  $d$  the rainfall duration;  $T'$  is a constant return period (year) as the base value;  $d'$  a constant rainfall duration as the base value.  $I_d^T$  is the rainfall intensity with a  $T$  year return period and  $d$  hour rainfall duration.  $I_{d'}^{T'}$  is the rainfall intensity with a base  $T'$  year return period and a base  $d'$  hour rainfall duration.  $f_1(T)$  is a function of only return period  $T$  and assumed to be the ratio of  $I_d^T$  to  $I_{d'}^{T'}$ . 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  $I_{d'}^{T'}$ . 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,  $f_1(T)$  is the ratio of  $I_d^T$  to  $I_{d'}^{T'}$  given by:

$$f_1(T) = \frac{I_d^T}{I_{d'}^{T'}} = \frac{I_d^T}{I_{d'}^{T'}} = c + \lambda \ln T \quad (21)$$

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And  $f_2(d)$  is the ratio of  $I_d^T$  to  $I_d^T$  and is a function of the rainfall duration

$$f_2(d) = \frac{I_d^T}{I_d^T} = \frac{I_d^T}{I_d^T} = \frac{a}{(a)^e} \tag{22}$$

After combining Equation (20), (21) and (22), the generalized formula of rainfall intensity frequency can be written as

$$I_d^T = I_d^T (c + \lambda \ln T) \frac{a}{(a)^e} \tag{23}$$

The equation (23) is generalized formula of rainfall intensity frequency formula using base on rainfall intensity with  $d'$  – hour rainfall duration, and  $T'$  – year return period.

## V. METHODOLOGY AND RESULT

The data of twenty four hours rainfall for ten years have been collected from Indian Meteorological Department, Borjhar (Guwahati) using non recording rain gauges for Puthimari Basin, Assam. Every storm in a year, from 1991 to 2000, was analyzed to determine the maximum intensities for durations of 1, 2, 3, 4, 5, 6 and 7 hour. Thus each storm gave one value of maximum intensity for a given duration. The largest of all such values was taken to be the maximum intensity in that year for that duration. The graph shows the variation of maximum intensity and duration of rainfall for the year 2000. Clearly it can be observed that with the increasing of rainfall duration, maximum intensity of rainfall decreases.

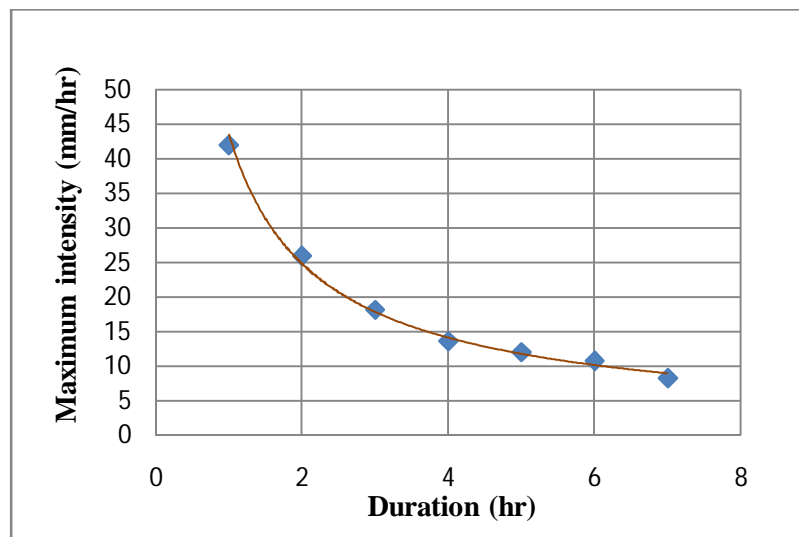


Fig.1 Intensity-Duration Curve for 2000

The calculation of design intensity for a particular return period is found out according to Gumbel’s distribution method. The maximum intensity for return period of 2 years, 5 years, 10 years, 25 years and 50 years with the duration of 1 hour, 2 hour, 3 hour, 4 hour, 5 hour, 6 hour and 7 hour are calculated. The maximum intensity is shown in Table 1 as follows:

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Table 1. The design intensity of rainfall with duration and return period at Puthimari Basin, Assam.

Return Period (years)	Design intensity for 1 hour duration	Design intensity for 2 hour duration	Design intensity for 3 hour duration	Design intensity for 4 hour duration	Design intensity for 5 hour duration	Design intensity for 6 hour duration	Design intensity for 7 hour duration
2	47.0547130	29.1303582	23.4920218	18.6796605	15.1823329	12.8852616	11.5979711
5	70.0404576	43.0229985	35.5445615	29.0317182	23.4198261	19.6561636	17.5699081
10	85.2623870	52.2231699	43.5261567	35.8871972	28.8749698	24.1400815	21.5290954
25	104.495319	63.8476015	53.6109152	44.5491062	35.7675528	29.8055192	26.5315351
50	118.763398	72.4712634	61.0923605	50.9750010	40.8808614	34.0084618	30.2426282

## VI. GENERALIZED RAINFALL INTENSITY DURATION FREQUENCY FORMULA AT PUTHIMARI BASIN, ASSAM

### A. INTENSITY-FREQUENCY RATIOS

The function  $f_1(T)$  is the ratio of  $I_d^T$  to  $I_d^{T'}$  and is a function of the return period (equation 21). The ratio of  $I_d^T / I_d^{T'=50years}$  for various return period are given in Table (2). Here, T=50 years is considered as the base return period.

Table 2. Ratio of  $I_d^T / I_d^{T'=50years}$  at for Puthimari Basin, Assam.

Years Return	2	5	10	25	50
Ratios $f_1(T)$	0.3960	0.5897	0.7179	0.8798	1

The parameter  $\lambda$  is slope value of linear regression relationship between the log-transformed values of return periods (T) and the ratios of rainfall intensity:

$$f_1(T) = \frac{I_d^T}{I_d^{50}} = 0.279 + 0.428 \log T \tag{24}$$

The parameter  $\lambda=0.428$  and  $c=0.279$  with correlation coefficient value  $r=0.998$ .

### B. INTENSITY-DURATION RATIOS

The function  $f_2(T)$  is the ratio of  $I_d^T$  to  $I_{d'}^T$  and is a function of the duration (equation 22). The ratio of  $I_d^T / I_{d'=1}^T$  for various durations are given in Table (3). Here,  $d'=1$  hour is considered as the base duration.

Table 3. Ratio of  $I_d^T / I_{d'=1}^T$  at for Puthimari Basin, Assam.

Duration (hour)	1	2	3	4	5	6	7
Ratios $f_2(d)$	1	0.6102	0.5144	0.4292	0.3442	0.2863	0.2546

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The ratio  $f_2(d)$  was fitted by Bernard equation:

$$f_2(d) = \frac{I_d^T}{I_1^T} = \frac{1.025}{d^{0.68}} \quad (25)$$

The parameter  $a=1.025$  and  $e=0.68$  with correlation value  $r=0.986$ .

Combining equation (24), (25) the generalized Intensity Duration Frequency formula at Puthimari Basin, Assam, with rainfall intensity in 1 hour and 50 years return period is 118.763398 mm/hr, gives:

$$I_d^T = 118.763398(0.279 + 0.428 \log T) \frac{1.025}{d^{0.68}} \quad (26)$$

Generalized rainfall intensity duration frequency formula at Puthimari Basin as:

$$I_d^T = \frac{33.9633 + 52.1015 \log T}{d^{0.68}} \quad (27)$$

The rainfall intensity can calculate from equation (27) for any duration ( $d$ ) and return period ( $T$ ) at Puthimari Basin, Assam.

The graph shown in fig 2, shows the relationship between maximum intensity and return period for a particular duration of rainfall as per Table 1(which is the actual curve as per available data) as well as the curve obtained between maximum intensity and return period from the equation 27 (which is the predicted curve after the analysis).

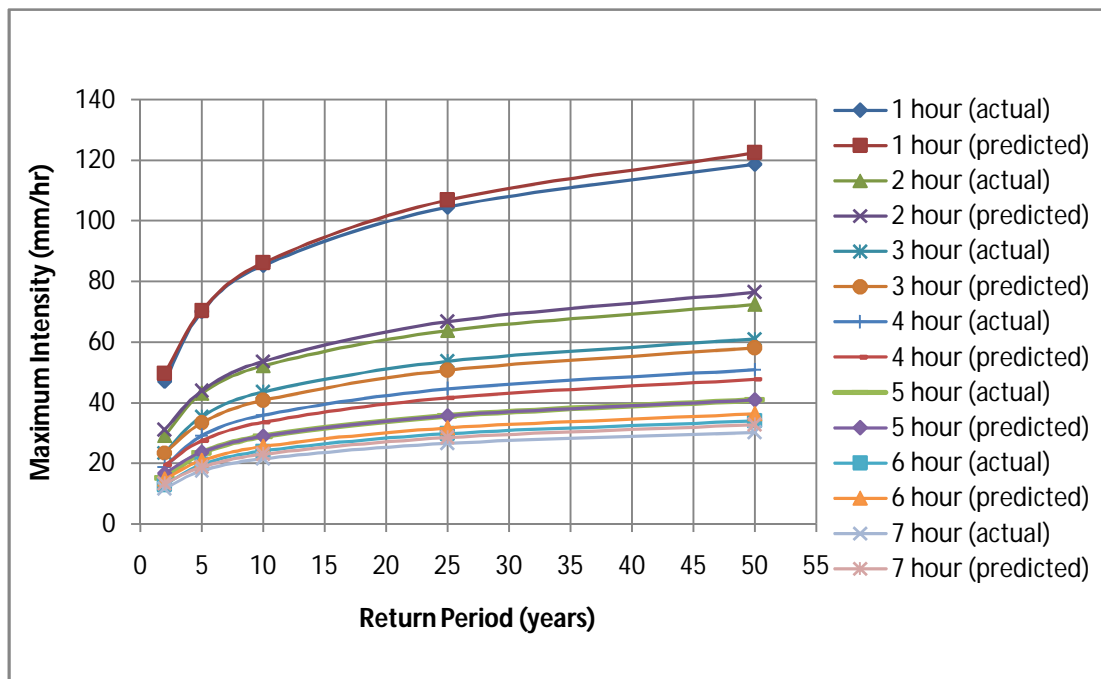


Fig 2. Variation of Intensity and Return period as per Table 1 and as per predicted equation 27.



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The graph shown in fig 3, shows the relationship between maximum intensity and the duration for a particular return period as per Table 1(which is the actual curve as per available data) as well as the curve obtained between maximum intensity and return period from the equation 27 (which is the predicted curve after the analysis).

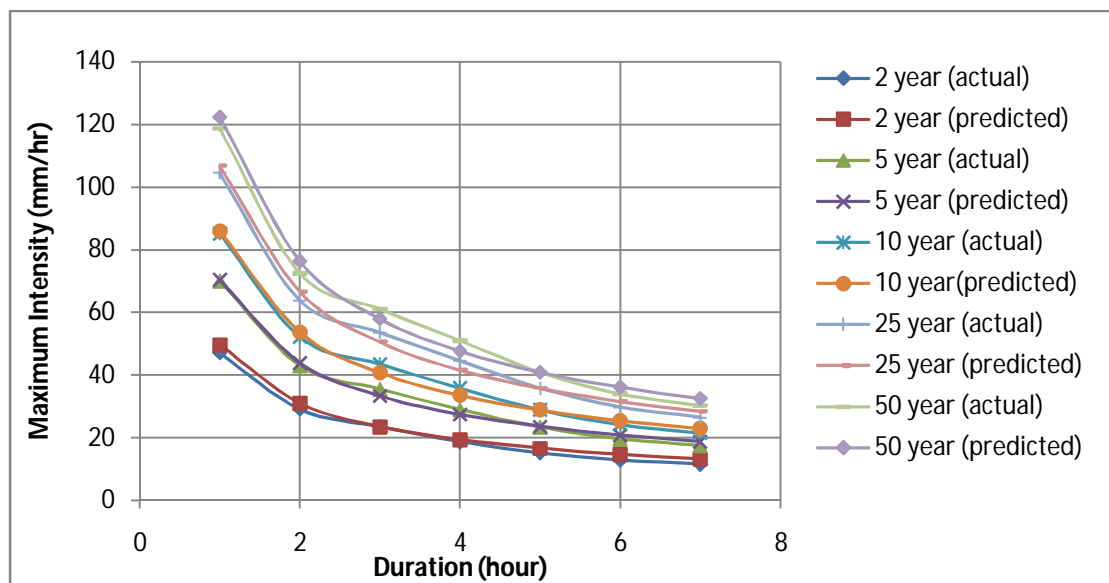


Fig 3. Variation of Intensity and Duration as per Table 1 and as per predicted equation 27.

### VII. CONCLUSIONS

The IDF formula parameters have been generated to estimate rainfall intensity for various return periods and rainfall durations. Its main objective is to estimate the maximum intensity of rainfall for any duration and return period. In this study an attempt has been made to obtain this relationship for Puthimari Basin, Assam by using Gumbel's distribution method for determining Return period and best fit curve method to establish Intensity-Duration and Frequency curve. In this work 1 hour duration and 50 years return period is taken as base rainfall duration and base return period for the analysis. Hence from the equation (27) one can estimate intensity of rainfall for any duration and for any return period.

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