International Journal of Bio-resource and Stress Management 2017, 8(5):721-726

Full Research

Doi: HTTPS://DOI.ORG/10.23910/IJBSM/2017.8.5.1823

Construction of Intensity-Duration-Frequency Curves for Precipitation with Annual Maxima Data in Kumulur Region

Vanitha, S.* and V. Ravikumar

Dept. of Soil and Water Conservation Engineering and Agricultural Structures, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy (621 712), India

Corresponding Author

Vanitha, S.
e-mail: vanitha.subramani636@gmail.com

Article History

Article ID: AR1823
Received in 27th June, 2017
Received in revised form 16th September, 2017
Accepted in final form 4th October, 2017

Abstract

Intensity–duration–frequency (IDF) relationship of rainfall amounts is one of the most commonly used tools in water resources engineering for planning, design and operation of water resources projects. The Intensity-Duration-Frequency relationship is a mathematical relationship between the rainfall intensity, duration and return period. This relationship is determined through statistical analysis of recorded rainfall data. The objective of this study is to derive IDF relationship of rainfall at Kumulur region. A total durations ranging from 10 minutes to 24 hr (10 min, 20 min, 30 min, 60 min, 120 min, 180 min, 360 min, 720 min and 1440 min) for return periods of 2, 5, 10, 25, 50 and 100 years were analyzed. In this study, Yearly maximum rainfall data for Kumulur (1991–2014) was used. Empirical reduction formula of Indian Meteorological Department (IMD) has been used to estimate the short duration rainfall intensity from yearly maximum rainfall data. Gumbel and Log Pearson Type III (LPT III) Distribution method was used to construct IDF curves and equations. The results obtained using Gumbel method is somewhat higher than the outcomes obtained using the LPT III distribution method. The chi-square goodness of fit test was used to determine the best fit probability distribution. This study will be helpful in many design problems related to watershed management, such as runoff disposal and erosion control, it is necessary to know the rainfall intensities of different durations and different return periods.

Keywords: Rainfall, intensity, duration, frequency, gumbel, LPT III

1. Introduction

Rainfall intensity–duration–frequency curves are graphical representations of the amount of water that falls within a given period of time in catchment areas (Dupont and Allen, 2000).

Degradation of water quality, property damage and potential loss of life due to flooding is caused by extreme rainfall events. Historic rainfall event statistics (in terms of intensity, duration, and return period) are used to design flood protection structures and many other civil engineering structures involving hydrologic flows (McCuen, 1998; Prodanovic et al., 2007). Any change in climate produces modifications in extreme weather events, such as heavy rainfall, heat and cold waves, in addition to prolonged drought occurrences (Almazroui et al., 2012). Since rainfall characteristics are often used to design water structures, reviewing and updating rainfall characteristics (i.e., Intensity–Duration–Frequency (IDF) curves) for future climate scenarios is necessary (Mirhosseini et al., 2013).

Mathematical relation between the parameters-Return period T (which is also known as frequency referring to the annual frequency of exceedance f), Rainfall intensity I and Duration d can easily be found from the IDF curves (Elsebaie, 2012; Koutsoyiannis et al., 1998; Koutsoyiannis, 2003). The rainfall intensity can be found for a particular return period for varying durations of storm using the IDF curve or conversely, the IDF curve can be used for finding out the return period of a rainfall. (Matin et al., 1984) Developed the IDF curve for North-East region Bangladesh and also observed that the rainfall data in this region follow Extreme Value Type I or Gumbel distribution. (Chowdhury et al., 2007), develop the short duration rainfall IDF curve for Sylhet with return period of 2, 5, 10, 20, 50 and 100 years. But still there is the scope to identify a perfect from of IDF empirical formula for Sylhet out of widely used forms.

Three probability distribution analysis methods namely Log Pearson Type III, Gumbel and Log normal were used (AlHassoun, 2011) for developing a basic formula for approximating rainfall intensity in Riyadh (Saudi Arabia) and this formula could be used instead of developing an IDF curve. The main objectives of this study was to find the best probability distribution function for the annual maximum rainfall data by chi-square test as well as to develop short duration rainfall IDF curve with empirical equation for various return period in Kumulur Region.

2. Materials and Methods

2.1. Data collection

For this study 24 hr daily rainfall data for Kumulur (1991–2014) was collected from Agro climate Research Centre (ACRC), Tamilnadu Agricultural University (TNAU). From the daily data, maximum yearly rainfall data was used in the analysis (Table 1).

Table 1: Maximum daily rainfall recorded in Kumulur during 1991–2014

Year	ODMR	Year	ODMR	Year	ODMR
1991	151.0	1999	206.0	2007	158.0
1992	85.1	2000	90.5	2008	149.0
1993	106.0	2001	84.0	2009	176.0
1994	71.8	2002	157.0	2010	137.0
1995	100.0	2003	57.6	2011	78.5
1996	123.0	2004	116.0	2012	94.4
1997	69.7	2005	115.0	2013	80.0
1998	120.0	2006	69.9	2014	67.0

ODMR: One day maximum rainfall (mm)

2.2. Constructing of IDF curves

IDF curves are developed through a three step procedure Chow (1988); Singh (1992). Firstly, the records are fit into any of the probability distribution functions for a specific time period, for instance 10 minutes, 20 minutes, 30 minutes, 1 hour, … 24 hour. After it is completed, the probability distribution function selected for determining rainfall intensities for a specific time period and return period like 2, 5, 10, 50, 100 years, etc. Lastly, two approaches can be used: (a) an equation or mathematical relation is developed relating rainfall intensities, return periods and time durations, (b) a graphical illustration of the rainfall intensities determined for specific time durations and return periods.

2.3. Estimation of short duration rainfall

Indian Meteorological Department (IMD) use an empirical reduction formula (Eq. 1) for estimation of various duration like 1-hr, 2-hr, 3-hr, 5-hr, 6-hr and 12-hr rainfall values from annual maximum values. IMD empirical reduction formula was used to estimate the short duration rainfall from daily rainfall data in Sylhet city and found that this formula give the best estimation of short duration rainfall (Chowdhury et al., 2007). In this study this empirical formula (Eq. 1) was used to estimate short duration rainfall in Kumulur region.

$P_t = P_{24}$ → (1)

Where,

P_t is the required rainfall depth in mm at t-hr duration

P_{24} is the daily rainfall in mm

t is the duration of rainfall for which the rainfall depth is required in hr

2.4. Gumbel theory of distribution

Gumbel distribution methodology was selected to perform the flood probability analysis. The Gumbel theory of distribution is the most widely used distribution for IDF analysis owing to its suitability for modelling maxima. It is relatively simple and uses only extreme events (maximum values or peak rainfalls). The Gumbel method calculates the 2, 5, 10, 25, 50 and 100 year return intervals for each duration period and requires several calculations. Frequency precipitation P_T (in mm) for ach duration with a specified return period T (in year) is given by the following equation:

$P_T=P_{ave} + KS$ → (2)

Where , K is Gumbel frequency factor given by:

$K= - [0.5772+ \ln[\ln[T/(T-1)]]]$ → (3)

Where

P_{ave} is the average of the maximum precipitation corresponding to a specific duration.

In utilizing Gumbel distribution, the arithmetic average in Eq. (2) is used:

$P_{ave}= 1/n$ → (4)

Where

P_i is the individual extreme value of rainfall

n is the number of events or years of record

The standard deviation is calculated by Eq. (5) computed using the following relation:

$S= [1/(n-1)$ → (5)

Where, S is the standard deviation of P data. The frequency factor (K), which is a function of the return period and sample size, when multiplied by the standard deviation gives the departure of a desired return period rainfall from the average. Then the rainfall intensity, I_T (mm/h) for return period T is obtained from:

$I_T = P_t / T_d$ → (6)

Where, T_d is duration in hours.

The frequency of rainfall is usually defined with reference to the annual maximum series, which consists of the largest values observed in each year. An alternative data format for rainfall frequency studies is based on the peak-over threshold concept, which consists of all precipitation amounts above certain thresholds selected for different durations. Due to its simpler structure, the annual-maximum-series method is more popular in practice (Borgaet et al., 2005).

From the raw data, the maximum precipitation (P) and the statistical variables (average and standard deviation) for each duration (10, 20, 30, 60, 120, 180, 360, 720 and 1440 min) were computed. Table 2 shows the computed frequency precipitation (P_T) values and intensities (I_T) for different durations and six return periods following the methodology previously described

2.5. Log pearson type (LPT) III

The LPT III probability model is used to calculate the rainfall intensity at different rainfall durations and return periods

Table 2: Computed frequency precipitation values and intensities for different durations and return periods using Gumbel Method for Kumulur

Pavg		10 min		20 min		30 min		60 min	
		21.214		26.695		30.56		38.5	
S		7.516		9.459		10.830		13.641	
T (year)	K	P_T mm	I_T mm hr^{-1}	P_T mm	I_T mm hr^{-1}	P_T mm	I_T mm hr^{-1}	P_T mm	I_T mm hr^{-1}
2	-0.164	19.979	119.872	25.140	75.421	28.785	57.570	36.258	36.258
5	0.719	26.624	159.745	33.503	100.509	38.360	76.720	48.319	48.319
10	1.305	31.024	186.145	39.040	117.120	44.699	89.398	56.304	56.304
25	2.044	36.583	219.501	46.036	138.107	52.709	105.418	66.393	66.393
50	2.592	40.708	244.246	51.225	153.676	58.651	117.302	73.878	73.878
100	3.137	44.801	268.809	56.377	169.130	64.549	129.098	81.307	81.307

Table 2: Continue...

Pavg		120 min		180 min		360 min		720 min		1440	
		48.496		55.507		69.918;		88.071		110.937	
S		17.183		19.667		24.774		31.206		39.308	
T (year)	K	P_T mm	I_T mm hr^{-1}	P_T mm	I_T mm hr^{-1}	P_T mm	I_T mm hr^{-1}	P_T mm	I_T mm hr^{-1}	P_T mm	I_T mm hr^{-1}
2	-0.164	45.672	22.836	52.275	17.425	65.847	10.974	82.943	6.912	104.477	4.353
5	0.719	60.864	30.432	69.663	23.221	87.749	14.625	110.531	9.211	139.229	5.801
10	1.305	70.922	35.461	81.175	27.058	102.250	17.042	128.798	10.733	162.238	6.760
25	2.044	83.631	41.815	95.721	31.907	120.573	20.095	151.877	12.656	191.309	7.971
50	2.592	93.059	46.529	106.512	35.504	134.165	22.361	168.999	14.083	212.876	8.870
100	3.137	102.417	51.209	117.223	39.074	147.657	24.610	185.994	15.499	234.284	9.762

to form the historical IDF curves for each station. LPT III distribution involves logarithms of the measured values. The mean and the standard deviation are determined using the logarithmically transformed data. In the same manner as with Gumbel method, the frequency precipitation is obtained using LPT III method. The simplified expression for this distribution is given as follows:

$P^* = \log (P_i)$ → (7)

$P_T^* = P_{ave}^* + K_T S^*$ → (8)

$P_{ave}^* = 1/n \sum_{i=1}^{n} P^*$ → (9)

$S^* = [1/(n-1) \sum_{i=1}^{n} (P^*-P_{avg}^*)2]1/2$ → (10)

Where P_T^*, Pave*, S* are as defined previously but based on the logarithmically transformed P_i values; i.e. P* of Eq. (7). K_T is the Pearson frequency factor which depends on return period (T) and skewness coefficient (Cs). The skewness coefficient, Cs, is required to compute the frequency factor for this distribution. The skewness coefficient is computed by Eq. (11) (see Chow, 1988 ; Burke and Burke, 2008).

$$Cs = \frac{n\sum_{i=1}^{n} (P_i^*-P_{avg}^*)3}{(N-1)\ (N-2)\ (S^*)3} \quad \rightarrow (11)$$

K_T values can be obtained from tables in many hydrology references; for example reference (Chow, 1988). By knowing the skewness coefficient and the recurrence interval, the frequency factor, KT for the LPT III distribution can be extracted. The antilog of the solution in Eq. (7) will provide the estimated extreme value for the given return period. Table 3 show the computed frequency precipitation P_T values and intensities I_T for six different durations and six return periods using LPT III methodology.

2.6. Goodness of fit test

The aim of the test is to decide how good is a fit between the observed frequency of occurrence in a sample and the expected frequencies obtained from the hypothesized distributions. A goodness-of-fit test between observed and expected frequencies is based on the chi-square quantity, which is expressed as,

$$\lambda 2 = \sum_{i}^{k}=1 \frac{(Oi-Ei)2}{Ei} \ (Oi-Ei)2 \quad \rightarrow (13)$$

Where

λ^2 is a random variable whose sampling distribution is approximated very closely by the chi-square distribution. The symbols Oi and Ei represent the observed and expected

Table 3: Computed frequency precipitation values and intensities for different durations and return periods using LPT III Method for Kumulur

T (year)	K	10 min			20 min			30 min		
		P*T mm	PT mm	IT mm hr^{-1}	P*T mm	PT mm	IT mm hr^{-1}	P*T mm	PT mm	IT mm hr^{-1}
2	-0.017	1.299	19.907	119.442	1.399	25.061	75.183	1.457	28.642	57.284
5	0.836	1.427	26.73	160.38	1.527	33.651	100.953	1.586	38.548	77.096
10	1.292	1.496	31.333	187.998	1.596	39.446	118.338	1.655	45.186	90.372
25	1.785	1.570	37.154	222.924	1.670	46.774	140.322	1.729	53.58	107.16
50	2.107	1.619	41.591	249.546	1.718	52.24	156.72	1.777	59.841	119.682
100	2.4	1.663	46.026	276.156	1.763	57.943	173.829	1.821	66.222	132.444

Table 3: Continue...

T (year)	K	60 min			120 min			180 min		
		P*T mm	PT mm	IT mm hr^{-1}	P*T mm	PT mm	IT mm hr^{-1}	P*T mm	PT mm	IT mm hr^{-1}
2	-0.017	1.558	36.141	36.141	1.658	45.499	22.749	1.717	52.119	17.373
5	0.836	1.686	48.529	48.529	1.786	61.094	30.547	1.845	69.984	23.328
10	1.292	1.755	56.885	56.885	1.855	71.614	35.807	1.914	82.035	27.345
25	1.785	1.829	67.453	67.453	1.929	84.918	42.459	1.988	97.275	32.425
50	2.107	1.877	75.336	75.336	1.978	95.06	47.53	2.036	108.643	36.214
100	2.4	1.922	83.368	83.368	2.022	105.196	52.598	2.080	120.226	40.075

Table 3: Continue...

T (year)	K	360 min			720 min			1440 min		
		P*T mm	PT mm	IT mm hr^{-1}	P*T mm	PT mm	IT mm hr^{-1}	P*T mm	PT mm	IT mm hr^{-1}
2	-0.017	1.817	65.615	10.935	1.917	82.604	6.883	2.017	103.992	4.333
5	0.836	1.945	88.105	14.684	2.045	110.917	9.243	2.146	139.959	5.831
10	1.292	2.014	103.276	17.212	2.114	130.017	10.834	2.214	163.682	6.820
25	1.785	2.088	122.462	20.410	2.188	154.17	12.847	2.289	194.536	8.105
50	2.107	2.137	137.088	22.848	2.237	172.584	14.382	2.337	217.27	9.052
100	2.4	2.181	151.705	25.284	2.281	190.985	15.915	2.381	240.436	10.018

frequencies, respectively, for the i-th class interval in the histogram. The symbol k represents the number of class intervals. If the observed frequencies are close to the corresponding expected frequencies, the λ^2 value will be small, indicating a good fit; otherwise, it is a poor fit. A good fit leads to the acceptance of null hypothesis, whereas a poor fit leads to its rejection. The critical region will, therefore, fall in the right tail of the chi-square distribution. For a level of significance equal to a, the critical value is found from readily available chi-square tables and λ^2> constitutes the critical region (Oyebande, 1982).

3. Results and Discussion

The purpose of this study was to develop IDF curves and derive an empirical formula to estimate the rainfall intensity at Kumulur. The IDF curves are used as an aid when designing drainage structures for any engineering project. The curves allow the engineer to design safe and economical flood control measures. Rainfall estimates in mm and their intensities in mm hr^{-1} for various return periods and different durations were analysed using the two techniques: (Gumbel and LPT III). The results are listed in Tables 2–3 for the kumulur regions. According to the IDF curves, rainfall estimates are increasing with increase in the return period and the rainfall intensities decrease with rainfall duration in all return periods. Rainfall intensities rise in parallel with the rainfall return periods. The results obtained from the two methods have good consistency.

From the raw data, the maximum rainfall (P) and the statistical variables (average and standard deviation) for each duration (10, 20, 30, 60, 120, 180, 360, 720, 1440 min) were calculated. Various duration of rainfalls like 10, 20, 30, 60, 120, 180, 360, 720 and 1440 min were estimated from annual maximum 24 hours rainfall data using Indian Meteorological empirical reduction formula. These estimated various duration data were used in Gumbel Extreme Probability Method and Log Pearson Type III to determine rainfall (P_T) values and intensities (I_T) for Kumulur. After finding out the rainfall (P_T) values and intensities (I_T) in Figure 1 and 2 Rainfall IDF curves are shown using Gumbel and LPT III method for Kumulur.

It was shown that there were small differences between the results obtained from the two methods, where Gumbel method gives slightly higher results than the results obtained by Log Pearson III.

The goodness-of-fit tests were used to choose the best statistical distribution among those techniques. Results of the chi-square goodness of fit test on annual series of rainfall are shown in Table 4. As it is seen all of the data fit the distributions at the level of significance of α=0.95, which yields $ƛ^2$ cal <1.145. Therefore $ƛ^2_{cal}$ <$ƛ^2_{tab}$, we accept the null hypothesis. There is good correspondence between theory and experiment.

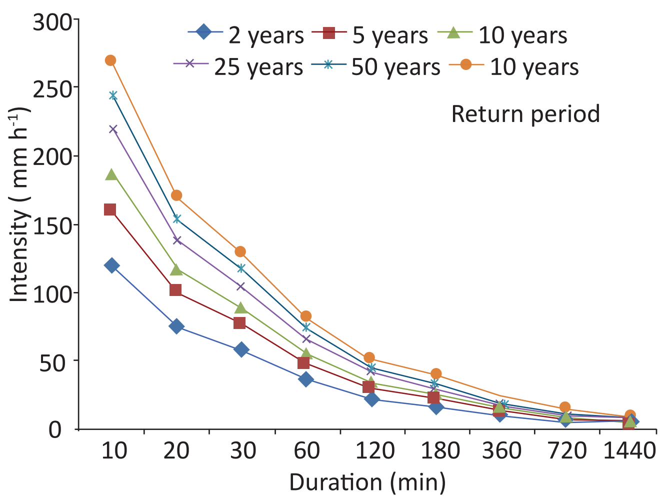

Figure 1: IDF Curves by Gumbel method for Kumulur

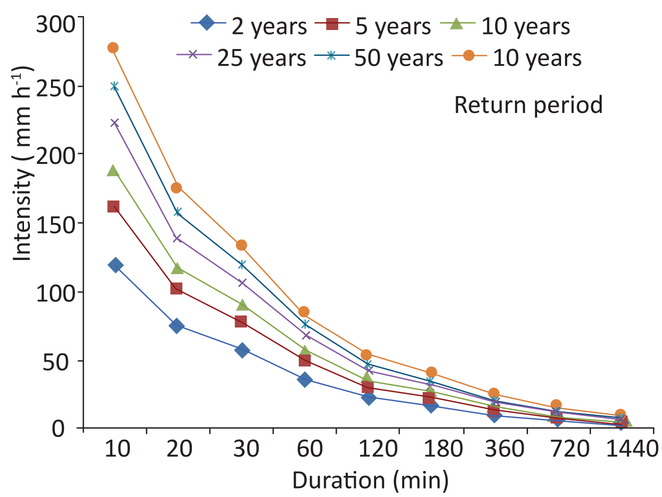

Figure 2: IDF Curves by LPT III method for Kumulur

Table 4: Results of chi-square goodness of fit test on annual maximum rainfall

Region	Distribution	Duration in minutes								
		10	20	30	60	120	180	360	720	1440
Kumulur	Gumbel	0.703	0.743	0.752	0.730	0.746	0.715	0.710	0.747	0.741
	Log pearson type III	0.752	0.726	0.737	0.748	0.730	0.728	0.740	0.730	0.728

4. Conclusion

Gumbel method gave some larger rainfall intensity estimates compared to LPT III distribution. The chi-square test was used to examine the combinations or contingency of the observed and theoretical frequencies and also to decide about the type of distribution which the available data set follows. The results of the chi-square test showed that in all the durations, the null hypothesis of extreme rainfall series has Gumbel and LPT III distribution which is acceptable at 95% level of significance.

5. References

AlHassoun, S.A., 2011. Developing an empirical formulae to estimate rainfall intensity in Riyadh region. Journal of King Saud University-Engineering Sciences 23, 81–88.

Almazroui, M., Islam, M.N., Athar, H., Jones, P.D., Rahman, M.A., 2012. Recent climate change in the Arabian Peninsula: annual rainfall and temperature analysis of Saudi Arabia for 1978–2009. International Journal of Climatology 32, 953–966.

Borga, M., Vezzani, C., Fontana, G.D., 2005. "A Regional Rainfall Depth–duration–frequency equations for an alpine region" department of land and agro forest environments, university of padova, legnaro 35020, Italy, Natural Hazards 36, 221–235.

Burke, C.B., Burke, T.T., 2008. Storm Drainage Manual. Indiana LTAP.

Chow, W.T., 1988. Handbook of applied hydrology. McGraw-Hill.

Chowdhury, R., Alam, J.B., Das, P., Alam, M.A., 2007. "Short duration rainfall estimation of sylhet: imd and uswb method" Journal of Indian Water Works Association, 285–292.

Dupont, B.S., Allen, D.L., 2000. Revision of the rainfall intensity duration curves for the commonwealth of

Kentucky. Kentucky Transportation Center, College of Engineering, University of Kentucky, USA.

Elsebaie, I.H., 2012. Developing rainfall intensity–duration–frequency relationship for two regions in Saudi Arabia, Journal of King Saud University–Engineering Sciences 24(2), 131–140.

Koutsoyiannis, D., Kozonis, D., Manetas, A., 1998. A mathematical framework for studying rainfall intensity–duration–frequency relationships. Journal of Hydrology 206, 118–135.

Koutsoyiannis, D., 2003. "On the appropriateness of the Gumbel distribution in modelling extreme rainfall," in Proceedings of the ESF LESC Exploratory Workshop, Hydrological Risk: recent advances in peak river flow modelling, prediction and real-time forecasting, Assessment of the impacts of land-use and climate changes, European Science Foundation, National Resea. 303–319.

Matin, M.A., Ahmed, S.M.U., 1984. "Rainfall Intensity Duration Frequency Relationship for the N-E Region of Bangladesh" Journal of Water Resource Research.

McCuen, R., 1998. Hydrologic analysis and design. Prentice-Hall, Englewood Cliffs, N.J., Mirhosseini, G., Srivastava, P., Stefanova, L., 2013. The impact of climate change on rainfall Intensity–duration–frequency (IDF) curves in Alabama. Reg Environ Change 13(1), 25–33.

Oyebande, L., 1982. Deriving rainfall intensity–duration–frequency relationships and estimates for regions with inadequate data. Hydrological Science Journal 27(3), 353–367.

Prodanovic, P., Simonovic, S.P., 2007. Development of rainfall intensity duration frequency curves for the city of london under the changing climate. Water Resour Res Report, London.

Singh, V.P., 1992. Elementary hydrology. New Jersey: Prentice Hall.