Development of Intensity-Duration-Frequency Curves for precipitation in Western Watershed of Guwahati (Assam)

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Abstract- The 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 project, or for various engineering projects against design floods. The establishment of such relationships was reported as early as in 1932 (Bernard). The objective of this research is to derive IDF relationship of rainfall for western watershed of Guwahati, Assam. These relationships are useful in the design of urban drainage works, e.g. storm sewers, culverts and other hydraulic structures. In the study, rainfall depth for 10 years viz. 2001 to 2010 has been collected from the Regional Meteorological Centre Borjhar, Guwahati. Firstly, the data has been used to construct the mass curve for duration of more than 7 hours rainfall to calculate the maximum intensity and to form the intensity duration curves. Gumbel's frequency analysis technique has been used to calculate the probable maximum rainfall intensities for a period of 2 yr, 5 yr, 10 yr, 50 yr, 100 yr from the maximum intensity. Finally, regression analysis has been used to develop the intensity-duration-frequency (IDF) curve. Thus, from the analysis the values for the constants 'a','b' &'c' have been found out. The values of 'a' for which the sum of the squared deviation is minimum has been found out to be 40 and when the corresponding value of 'c' and 'b' for the minimum squared deviation of 'a' are 0.744 and 1981.527 respectively.

Keywords – Intensity-Duration-Frequency (IDF) relationship, design flood, watershed, Guwahati, maximum intensity, Gumbel's frequency analysis technique, mass curve, regression analysis.

I. INTRODUCTION

The Intensity-Duration-Frequency functions are a classical precipitation analysis tool, which relates the probability of occurrence of storms of given duration and intensity [1]. The establishment of such relationships was done as early as in 1932. Since then, many sets of relationships have been constructed for several parts of the globe [2].Therefore, there is a high need to construct the IDF curve for the various states of India where precipitation occurs mostly in the form of rain only. The magnitude of precipitation varies from place-to-place and from time-to-time. Differences in the magnitude of rainfall in various parts of a country at a given time and variations of rainfall at a place in various seasons of the year are responsible for many hydrological problems, such as floods and droughts. Hence, in order to counter-act these problems, precipitation data is necessary for carrying out different hydrological studies.

In this project, the Intensity-Duration-Frequency (IDF) curves have been studied which elaborates the relationship between the three important rainfall parameters like intensity, duration and frequency of a particular place which is very important in rainfall-runoff modeling with respect to water resources engineering, either for planning, designing and operating of water resources projects, or the protection of various engineering projects against floods. The conventional method to construct IDF curves has three main steps. The first step is to obtain annual maximum intensity series for each time interval length. Then, for each time interval a statistical analysis has to be done to compute the quantiles for different return periods. In the final step, the IDF curves are basically determined by fitting a specified parametric equation for each return period to the quantiles estimates by regression analysis.

II. OBJECTIVES OF THE STUDY

i) To collect the data of rainfall depth of 10 years from Guwahati basin.
ii) To draw the mass curves for a duration of more than 7 hours rainfall.
iii) To calculate the maximum intensity from the mass curves to construct the intensity duration curves.
iv) To calculate the maximum probable rainfall intensity for a period of 2 yr, 5 yr, 10 yr, 50 yr, 100 yr from the maximum intensity using Gumbel's distribution.
v) To construct the intensity-duration-frequency curve by regression analysis.

III. LITERATURE REVIEW

Hafiz Zubair Khan (2007) [1], has made a study on the total hourly-recorded available precipitation data for different parts of NWFP collected from different departments and the analysis has been made. Making use of the data, functions of intensity-duration-frequency for precipitation was developed for the Bannu region, representing the lower hilly and plane areas in NWFP. The IDF curves are plotted for 2, 5, 10, 25, 50 and 100-year return periods. The theoretical intensities of precipitation calculated by the developed functions are in close agreement with those recorded at the stations through automatic gages. The correctness of the developed function was ascertained through its comparison with existing equations for depth duration developed for the world's largest rainfall events. The function developed was found to be more realistic results for regions in NWFP.

Le Minh Nhat, Yasuto Tachikawa and Kaoru Takara (2006)[2], motivated by the fact that though many sets of relationships between rainfall intensity-duration-frequency had been established in several parts around the globe, such map with rainfall intensity contours had not been established in many developing countries, including Vietnam. Besides, there was a high need of IDF curves in the monsoon region of Vietnam. This research is to construct IDF curves for seven stations in the monsoon area of Vietnam and to propose a generalized IDF formula using base rainfall depth, and base return period for Red River Delta (RRD) of Vietnam.

Umesh C Kothyari and Ramchandra J. Garde(1992)[3] developed a rainfall Intensity-Duration-Frequency Formula for India. This study includes the analyzing of data from 80 rain-gauge stations in India. A relationship for rainfall intensity, duration and frequency was developed by assuming that general properties of the convective cells that are associated with short period (i.e. less than 24hours) rainfalls are similar in different hydraulic regions. The correctness of the developed relationship was ascertained through its comparison with existing equations and the use of data from different hydrological regions. The proposed relationships may be used in India for design practices.

Trevor M.Daniell and Guillermo Q. Tabios III (2008)[4] carried out a rainfall Intensity Duration Frequency (IDF) analysis for the Asia Pacific Region. In this study it was discussed that different participating countries employed different methods of analysis for their rainfall intensity-duration-frequency (IRDF) curves. During the APFRIEND meeting in Kuala Lumpur in June 2005 attended by different country representatives from Australia, China, Indonesia, Japan, Korea, Malaysia, New Zealand, Philippines and Vietnam, it was decided that a worthwhile undertaking of the group would be to learn from the various participating countries how their RIDF analysis are conducted. At the end of the workshop the different country representatives were asked to supply extreme rainfall data from their own countries to be sent to everyone so that a comparison of the various methods used in RIDF analysis and subsequently estimating design rainfalls could be made by individuals from participating countries.

IV. EXPERIMENT AND RESULT

The data of twenty four hours rainfall for ten years (2001-2010) have been collected from Indian Meteorological Department, Borjhar (Guwahati) using non recording rain gauges for Guwahati city, Assam. The following steps are hence followed:

1) *Construction of mass curve* : The rainfall data for ten years is collected. The rainfalls are recorded at an interval of one hour. The cumulative values of these rainfall readings are computed and a graph is plotted between the

cumulative values in mm and the time in hours. The cumulative values are plotted along Y-axis and the time along X-axis. After plotting, a curve is then obtained which is a non uniform curve. From the curves a maximum intensity of one hour duration is computed for every year.

2) *Construction of Intensity-Duration curves:* It is observed that the most intense storms last for very short durations. As the duration of storm increases, the maximum average intensity of storm decreases. In this step, an intensity-duration graph is plotted for every year. The maximum intensities of a particular year are plotted along Y-axis against the corresponding time along X-axis. The curve obtained is exponentially decreasing in nature.

3) *Calculation of the probable maximum rainfall intensities for some assumed return periods:* This is done by Gumbel's probability distribution method. The hourly maximum intensity for each hour is found out for the 10 years i.e. say for 1 hr, the maximum 1 hour intensity for the 10 years is found out. The maximum probable rainfall intensity for 2, 5, 10, 50 and 100 years are calculated. The Gumbel's Equation for practical use is given by [5&6]

$$x_T = \bar{x} + K\,\sigma_{n-1}$$

Where x_T = value of the variate X of a random hydrologic series with return period

σ_{n-1} = standard deviation of the sample of size N = $\sqrt{\frac{\Sigma(x-\bar{x})}{N-1}}$

K = frequency factor expressed as $\frac{y_T - \bar{y}_n}{S_n}$

y_T = reduced variate, a function of T and is given by

$$y_T = -[\ln.\ \ln\frac{T}{T-1}]$$

Or $y_T = -[0.834 + 2.303 \log \log \frac{T}{T-1}]$

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

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

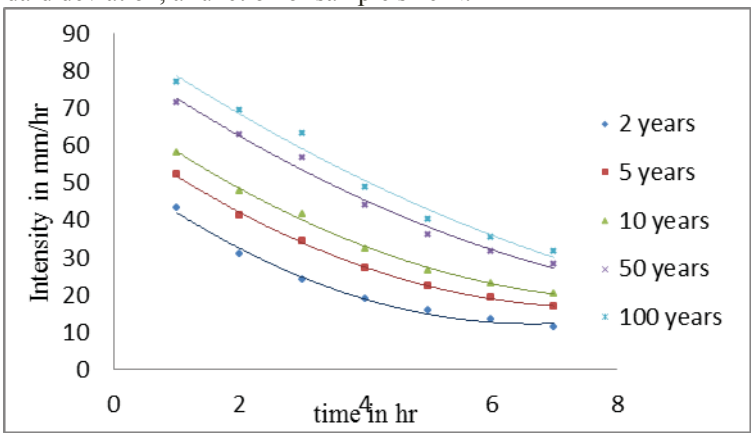

Fig. 1: Intensity-Duration-Frequency curve

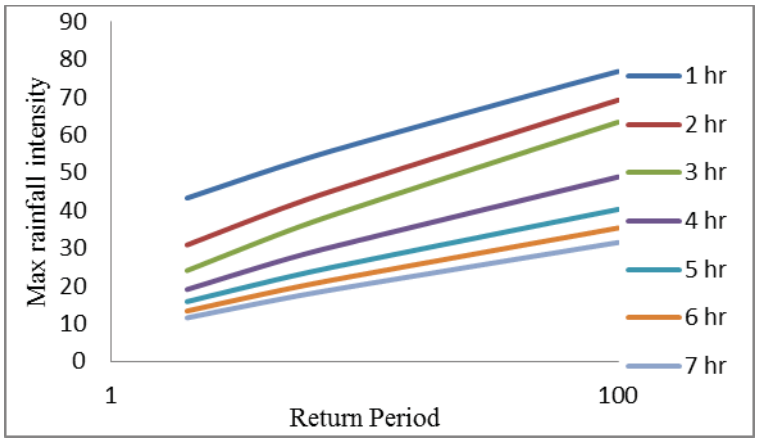

Fig.2: Intensity-Frequency curve

4) *Regression analysis:* Regression analysis tries to find out the average relationship between the variables. It refers to the methods by which estimates are made of the values of one variable from the knowledge of the values of one or more other variables. In regression analysis, however one variable is taken as the dependent variable and the other taken as the independent variables thus making it possible to study the cause and effect relationship. However, the maximum intensity varies inversely with the duration and generally an equation of the form

$$I = \frac{C}{(t+a)^b} \quad \ldots(4.1)$$

is assumed between I and t. The values between *c*, *a* and *b* are obtained through regression analysis. In equation (4.1) while t is generally expressed in minutes, *I* may be expressed in mm/hr or cm/hr. The regression constants are different for different locations. Taking logarithms on both sides transforms equation (4.1) into a linear form

$$\log I = \log C - b\log(t+a) \quad \ldots(4.2)$$

The best values of *a*, *c* and *b* are those for which the sum of the squared deviations is minimum, i.e.

$$S = \sum[\log I - \{\log C - b\log(t+a)\}]^2 \quad \ldots(4.3)$$

are considered. Partial differentiation of *S* with respect to *c* and *b* yields

$$\sum \log I = n\log C - b\sum \log(t+a) \quad \ldots.. (4.4)$$

$$\sum[\log I \log(t+a)] = \log C \sum \log(t+a) - b\sum[\log(t+a)]^2 \quad \ldots.. (4.5)$$

where *n* is the number of observations and all the summations are over all the observed values. After obtaining the required summation, equation (4.2) and (4.3) may be solved to provide the best values of *C* and *b* for any assumed value of a is found only by trial and error method. The value of *a* for which the sum of the squared deviation is minimum is found out. When corresponding value of *C* and *b* for the minimum squared deviation of *a* is put in equation (4.1) and is calculated we must get back the intensity for that particular time.

Thus, taking different values of a, we calculated the corresponding values of b and c. We obtained the minimum squared deviation of rainfall intensity at a=40, b=0.744 and c=1981.527. Thus the desired regression equation comes out to be

$$I = \frac{1981.527}{(t+40)^{0.744}}$$

V. CONCLUSION

This study presents some insight into the way in which the rainfall is estimated in Western part of Guwahati. Since the city is growing horizontally and at a swift pace, the rainfall intensity is found to be non-uniform throughout the city. A relation for the region has to be obtained to estimate the maximum intensity of rainfall for any duration and return period. In this study an attempt has been made to obtain the IDF relationship for Guwahati Basin, Assam using different existing equations (4.1, 4.4 and 4.5). Using this method, the same can be found out for other cities as well by collecting the rainfall data for the respective city. The following conclusions can be made from this analysis:

(i) The gradual exponential decrease of IDF curves for different return periods reveal that our mass curve construction and the conclusion of maximum intensity for all the years are satisfactory.

(ii)The values of '*a*' for which the sum of the squared deviation is minimum is found out and when the corresponding value of '*c*' and '*b*' for the minimum squared deviation of '*a*' is put in the equation 4.1 and is back calculated, the values of intensity for the corresponding time interval is found out to be approximately same.

(iii) The values of '*a*', '*b*' and '*c*' are found out to be 40, 0.755 and 1981.527 respectively.

(iv) The IDF relationship obtained for this basin may not be applicable for other river basins.

There are various scopes for future development. Firstly, the values of the constants evaluated in this particular concerned area of study directly relates to the rainfall data of this area, i.e. the western watershed of Guwahati and hence, will be different in different localities since the rainfall data will vary. Secondly, as the city of Guwahati is enlarging day-by-day, it has been seen that the rainfall intensity is not uniform throughout the city, therefore, a factor of safety is necessary to be considered while evaluating the Intensity-Duration-Frequency curves by using the rainfall data for different parts of the city.

REFERENCES

[1] Hafiz Zubair Khan(2007*),* "Precipitation intensity-duration-frequency functions for the Bannu region NWFP Pakistan,IJE Transactions, B: Applications, 60 - Vol. 20, No. 1, April 2007

[2] Le Minh Nhat, Yasuto Tachikawa and Kaoru Takara (2006)," Establishment of Intensity-Duration-Frequency Curves for precipitation in the monsoon area of Vietnam", Proceeding of the ASCE, HY5, pp 99-116

[3] Umesh C Kothyari and Ramchandra J. Garde(1992), "Rainfall Intensity-Duration-Frequency Formula for India", Journal of Hydraulic Engineering,Vol. 118, Vol. 118, No.2, pp 323-336.

[4] Trevor M. Daniell and Guillermo Q. Tabios III(2008), " Rainfall Intensity Duration Frequency (IDF) Analysis for the Asia Pacific Region, Technical documents in Hydrology, No.2. International hydrological Programme.

[5] Dr. P. Jaya Rami Reddy (2008), A Textbook of Hydrology, University Science Press

[6] K. Subramanya (2006) Engineering Hydrology, Tata McGraw-Hill Education Private Limited, New Delhi.