SUMMER INTERNSHIP REPORT ON

DEVELOPMENT OF IDF CURVES USING DAILY RAINFALL DATA FOR DIFFERENT RETURN PERIODS FOR TAWI RIVER BASIN

By

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Certificate

I hereby certify that the project work entitled "Development of IDF curves using daily rainfall data for different return periods for Tawi river basin" carried out by Ms. Gargi Bindal, B-tech (CE), Graphic Era University, Dehradun is an authentic record of work carried out by her during June 11, 2016 to August 10, 2016 under my guidance.

I appreciate the sincerity and hard work put by Ms. Gargi for completing the task in two months period. I wish her success in her future endeavor.

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Gargi

(Gargi Bindal)

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ABSTRACT

Estimation of rainfall Intensity-Duration-Frequency (IDF) is commonly required for the design of hydraulic control structures and for water resources management, planning and development. The use of IDFcurves become more cumbersome, hence a generalized empirical relationship was also developed for the study area. The relationships between rainfall intensity, duration and the return period of a certain rainfall amount were determined through statistical analysis of rainfall data. Daily rainfall data for the year 1977 to 2007 was collected from IndianMeteorological Department (IMD) for Jammu, Batote and Bhaderwah stations and the IMD empirical reduction formula was used to estimate the short durationrainfall using Gumbel's probability distribution method. Rainfall data were then used to develop the rainfall intensity duration frequency curves with return periods of 2, 5, 25, 50, 100, 200, 500 and 1000 years for durations of5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 80, 100, 120 and 180 minutes. The results of the study can be used to develop IDF curves which are useful for hydraulic designing of culverts, pipes and small bridges.

Keywords: Intensity-Duration-Frequency (IDF) curve, Rainfall intensity, return period, maximum daily rainfall, Gumbel's probability distribution.

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Chapter 1

1.0 INTRODUCTION

Knowledge on intense rainfall characteristics ishighly valued in Engineering and Agronomy for the dams dimensioning and hydraulic projects for irrigation, drainage and the control of water erosion, as well as facilitating the understanding of hydrological processes of river basins. (Celio et al,2012). Lack of inadequate and under design drainage system cause water logging problem. For proper designing of drainage system, culverts, small bridges etc. short duration rainfall intensity is most important (Rashid et al ,2012). Hence, it is desirable to know the magnitude and frequency of intense rainfall characterized by its duration, intensity and return period. Hence, the concept of rainfall Intensity Duration Frequency curves was mooted which could serve as one of the most important tools in water resource engineering to assess the risk and vulnerability of water resource structure as well as for planning, design and operation. (Celio et al,2012)

The rainfall IDF curves are graphical representation of rainfall intensity within a given time period. In other words, IDF curve is a graph with duration plotted as abscissa, intensity as ordinate and a series of curves, one for each return period. The development of IDF curves for a location or a region is very important for engineering applications because: 1) it helps to predict when a location or a region will be flooded.2) it helps to pinpoint when a certain rainfall rate or a specific volume of flow will recur in a location or region in the future.3) it helps in estimation of design discharge for flood control structure. The information derived from IDF curves is then used in hydraulic design to size culverts and pipes. (Logah et al,2013)

The establishment of IDF relationships goes back to the 1930's (Chow, 1988). Since then, different forms of relationships have been constructed for several regions of the world. Al-Shaikh (1985) derived rainfall intensity-duration-frequency relationships for Saudi Arabia through the analysis of available rainfall intensity data. Al-Khalaf (1997) conducted a study for predicting short-duration, high intensity rainfall in Saudi Arabia. Further studies by Al-Sobayel (1983) and Al-Salem (1985) performed Rainfall Frequency Distribution analysis for Riyadh, Shaqra and Al-Zilfi areas in KSA. Koutsoyiannis (1998) proposed construction of the intensity-duration-frequency curves using data from both recording and non-recording stations.

Mohymont *et al.*, (2004) assessed IDF-curves for precipitation for three stations in Central Africa and proposed more physically based models for the IDF-651 curves. Precipitation frequency values for Kinshasa-Yangambi have been produced by Mohymont *et al.* (2004). With the recent technology of remote sensing and satellite data, Awadallah *et al.* (2011) conducted a study for developing IDF curves in scarce data regions using regional analysis and satellite data. Awadallah *et al.* (2011) presented a methodology to overcome the lack of ground stations rainfall by the joint use of available ground data with TRMM satellite data to develop IDF curves and he used a method to develop ratios between 24 hr rainfall depth and shorter duration depths. Al-Hassoun (2011) developed an empirical formula to estimate rainfall intensity in Riyadh region.

The present study is an attempt to develop an intensity-duration-frequency empirical formula which will further guide in creation of IDF curves to estimate rainfall intensity for any duration and any return period with minimum effort. Daily rainfall data for the period of 1977 to 2007 was collected from India Meteorological Department (IMD), Government of India and the IMD empirical reduction formula was used to estimate the short duration rainfall using Gumbel's Extreme Value Distribution. The IDF curves were then plotted for short duration rainfall of 5,10,15,20,25,30,35,40,45,50,60,80,100, 120 and 180 minutes for a return period of 2,5,25,50,100,200, 500 and 1000 years. Then a generalized empirical relationship was developed. This study had been undertaken under the two months summer internship at National Institute of Hydrology(NIH) Roorkee with following objectives:

1) To estimate the short duration rainfall from daily rainfall data.

2) To develop IDF curves for Tawi river basin for different return periods.

2.0 LITERATURE REVIEW

The development of IDF curves for a location or a region is very important as it serves as one of the most important tools in water resource engineering to assess the risk and vulnerability of water resource structure as well as for planning, design and operation. So a literature review has been done to set the background on what has been explored on our topic so far and to identify new ways to interpret prior research.

Study Conducted by Henrick et al (2002) presented the modelling of extreme rainfall characteristics. This modelling was based on PDS method which helped in the analysis of all events above threshold level and for regional modelling of the PDS (Partial duration series) parameters, GLS (Generalized least squares) regression model is used.The resulting model was used for estimation of Rainfall Intensity-Duration-Frequency curves.

Study conducted by Nhat and Takara (2006) was used to construct Intensity-Duration-Frequency (IDF) curves for seven stations in monsoon area of Vietnam and proposed a generalized IDF formula using base rainfall depth, and base return period for Red river Delta of Vietnam. Two main procedures were presented. The first produced the set of IDF curves at 7 stations by using empirical functions. The second produced a generalized IDF equations for location area. Formulation and construction of IDF curves was done using data from recording station by using empirical equation and parameters were generated for ungauged areas for estimating estimate rainfall intensity.

A comprehensive attempt was made by Singh.V and Zhang.L(2007) to derive Intensity-Duration-Frequency (IDF) curves from bivariate rainfall frequency analysis using Copula method, which did not assume rainfall variables to be independent or normal or have same type of marginal distributions. The bivariate distributions were then employed to determine conditional return period and IDF curves needed for urban drainage design.

A comprehensive attempt was made by Langousis and Venziano (2007) to develop methods to estimate the intensity-duration-frequency curves for three rainfall models with local multifractalbehaviour and varying complexity. Three approaches used were: Model1 used physical notion ofrainstorm events and was capable of producing curved IDF plots in log- log scale. Model2 represented rainfall process as a sequence of intervals of fixed duration D,each with random average intensity. Model3 represented rainfall as a series of multifractal cascades with no additional variability.

Study conducted by Awadallah et al (2011) explored the joint use of limited data from ground rainfall stations and Tropical Rainfall Measuring Mission (TRMM) data for developing Intensity-Duration-Frequency (IDF) curves where very limited ground station rainfall records were available. An index flood procedure was adopted for generating the theoretical regional distribution equation. Rainfall depths at various return period were calculated for all stations and plotted spatially. TRMM data were used to develop ratios between 24-hrs rainfall depth and shorter duration depths. Homogeneity and variances were first checked for both types of data. Regional patterns along with developed ratios were used to develop regional IDF curves.

An attempt was made by Angela et al (2012) towards working on the change in intensity-duration-frequency curves under climatic conditions. A non-parametric K-nearest neighbor weather generator(WG) algorithm was used for synthetically creating long time series of weather data. Daily maximum rainfall datasets were collected and used as input into WG. WG used shuffling mechanism and perturbation mechanism. Two climate scenarios were selected for analysis, climate change lower bound (CCLB) which used observed rainfall as WG input and climate change upper bound (CCUB) which modified observe record and then used it as input. Outputs were used to generate IDF curves.

Study was undertaken by Mirrhosseini et al (2013) to assess expected changes inIntensity-Duration-Frequency (IDF) curves from current climate to projected future climate. For providing future IDF curves,3 hourly-precipitation data stimulated by six combinations of global and regional climate models were temporarily downscaled using astochastic method. Performance of downscaling method was evaluated and IDF curves were developed for state of Alabama.The results of all six climate models suggest that future precipitation patterns for Alabama were expected to veer towards less intense rainfall for short duration events. However, for long duration events(>4hrs.)results were not consistent across the models. This uncertainty was diminished by developing ensemble model as a result of incorporating all six climate models,performing an uncertainty analysis and creating a probability based IDF curve

A comprehensive attempt was made by Dupont and Allen to revise and update the existing rainfall Intensity-Duration-Frequency (IDF) curves for the commonwealth of Kentucky. The nine curves that currently govern Kentucky were based on data from first order weather conditions in and around Kentucky. However, the new curves only utilize data from within the state. The data was gathered from both first order and co-operative weather conditions. In accordance with Bulletin71, the new curves reflect the climatological zones located within the state thus producing only 4 IDF curves.

Extreme climatic events were growing more severe and frequent, calling into question how prepared our infrastructure for dealing with these changes. Current infrastructure design was based on Intensity-Duration-Frequency (IDF) curves prepared with stationary assumption i.e., extremes will not vary significantly over time. A stationary climate assumption may lead to underestimation of extreme precipitation by as much as 60% which increased flood risk and failure risk. Hence, a study conducted by Cheng and Aghakouchak (2014) presented a generalized framework for estimating non-stationary IDF curves and their uncertainties using Bayesian interference. The fundamental concept was based on generalized extreme value distribution (GEV) combined with Bayesian interference for uncertaintyassessment.

Study conducted by Desramaut(2008) proposed a statistical downscaling approach, based on the scale invariance concept, to incorporate Global Climate Model(GCM) outputs in the derivation of Intensity-Duration-Frequency (IDF) curves and estimation of urban design storms for current and future climates under different climate change scenarios. The estimated design storms were then used in estimation of runoff peaks and volumes for urban watershed using popular Storm Water Management Model(SWMM).

Rainfall records for 30 yrs. were used to establish an empirical model that correlate rainfall Intensity-Duration-Frequency for Makurdi area. They were analyzed by sorting out the maximum monthly rainfall depths with their corresponding durations and ranked in descending order of mag. and their return periods were computed. All rainfall depths were converted to rainfall intensities. The Sherman's mathematical method was employed to develop station constant and IDF curves for Makurdi.It was observed that for a given return period, IDF curves decreased with increasing time interval. IDF curves were then used for construction of hydrologic structures such as dams, and other drainage systems in Makurdi metropolis.

A study conducted by Al-Awadi(2016) to assess the rainfall IDF relationships and to derive a relationship between intensities and duration for a no. of recurrence intervals through regression of generated Intensity-Duration-Frequency (IDF) curves for Baghdad city. Maximum daily rainfall data for Baghdad city was used during last 11 yrs. (2004-2014) and Indian Meteorological Department (IMD) empirical reduction formula was used to estimate the short duration rainfall intensity with respect to six frequency periods(2,5,10,25,50,100yrs.). Techniques like Gumbel, Log Normal and Log Pearson Type 3 Distribution had been used to develop relationship between rainfall intensity, storm duration and return period. All of them were located at acceptable significance level with small priority to Log Pearson Type3 Distribution.

Chapter 3

3.0 STUDY AREA

3.1 GENERAL TOPOGRAPHY: -

The Tawi River basin is a small part of western Himalayan and is contained in between 32^0-35' to 33^0-35' North Latitude & 75^{0-}45' to 75^{0-}45' East Longitude. At its upper part the basin is narrow and elongated while it broadens down along lower part. The upper portion of the basin is characterized by rugged mountainous topography, whereas lower basin consists of low hills and a gradational plain. The average height of basin is about 2200 meter above mean sea level. The basin ground elevation varies from 4000 meter to 400 meter above mean sea level. The slope of basin is from east to west in the upper part, while North-East to south –West in the lower part. The river, at its upper reaches is fed by melting of snow and ice of Kali- Kundi Glaciers at its origin and by rain. In the lower catchment it is predominantly rain fed. A small area of about 200 square meter. is snow bound.

The Tawi river basin falls mostly within the districts of Jammu, Udhampur, and small portion of Doda districts. In the present Study, the area of about 1885 sq.mt. Up to Jammu has been considered.

3.2 CLIMATE

In the Tawi Basin July and August are generally the wettest months with about 55% rainfall and November is the least rainy month with about 2-3% of total rainfall. Tawi experience heavy flood in July & August. Monsoon starts from first July with heavy thunder showers and up to mid-September. Normal annual rainfall varies is characterized with three distinct features: -

The north eastern catchment area comprising of Bhaderwah and adjoining area where climate is extra tropical mountain type. The mountain type climate has wide variation in temperature and rainfall depending upon the location and direction of the land features. In this area winter is very severe and influence of south-west monsoon is negligible.

Central territory consisting of Udhampur districts where also climate is of mountain type but having sufficient influence of monsoon.

The South – western zone consisting of Jammu district where climate is warm with strong monsoon influence, can be described as similar to tropical wet & dry climate during certain part of the year. The river Tawi is snow fed at its origin firm the Kali Kundi glacier. The Kali-Kundi and Seoj-Dhar start experiencing snowfall in November. Snow is very deep and in some years continuous till May.

3.3 WATER RESOURCES

The River Tawi is endowed with vast water resources potential for irrigation, domestic water supply and power Generation. The river is of about 141 km. length up to the point it enters Pakistan, from its origin at Himalayan Kali-Kundi glacier. It has nine major tributaries carrying discharge of Tawi was 4.3 lakh cusec in September, 1988 at Jammu and minimum discharge was about 300-400 cusecs. Low water flow is experienced during the month of October, November and December. But there are occasional rises of water level during winter due to rains and on the early summer due to snow melt from the seasonal snow cover in the upper catchment.

3.4 SOIL

Comprehensive soil survey for Tawi basin has not yet been done. However, the soil classification of Tawi basin exhibits zonal properties as follows: -

In Doda districts, of which a very small portion is lying with in the basin, the soils are mainly alluvial in nature. Whereas in the midlands or foots hills, the process of colluviation seems predominant. Generally, the silt or other material, brought down by the action of water gets deposited at the foot hill and give rise to soil formation. The texture, in general varies from sandy loam, sandy, to silty clay loam.

In Udhmapur part, the soils are moderately deep to deep on the mid hills and plateaus whereas deep to very deep at the foothills. The texture in general is coarse to medium.

Soils of district Jammu are alluvial subtropical having a texture varying between sandy loams to silty clay loam. The lower part is recent alluvium whereas the outer plains are Pleistocene. The foothills of Siwaliks are moderately deep to deep soils with coarse texture having stony face in general and due to lack of irrigation; these are left as uncultivated fallows.

3.5 GEOLOGY

Western Himalaya is geologically described as lying within moving belt of earth's crest. Like other parts Tawi basin mainly consists of Siwaliks, Murree and granite intrusion. Tawi basin has three Meso geomorphic regions: -

Kaplas Granite zone from Kaplas range to Panjal Thrust. Kaplas granite associated with Bhaderwah slate, Sewa para gneiss etc. are the main features of the area. Maximum elevation of Kaplas range is 400 m.

Thrust Zone from Panjal thrust to Udhampur thrust having same tectonic structures like Panjal thrust. The height of this region is from 700 m to 1900 m.

Siwalik zone: - Lying between Udhampur thrust and Jammu. Most of the Region consists of hilly as well as plain areas.

3.6 RIVER PROFILE

Form origin to outfall the long section of Tawi River exhibits wide degree of variations. The variation in Slopes along different river reaches are as follows: -

R.L. 4000m	-	1600m	= Steep gradient of 1:10:42
R.L. 1600m	-	900m	= Slight changes in slopes
Below		800m	= Slope is decreasing

However,Variation is not linear. The gradient changes from very steep at upper part to concave and flat in the lower courses. The reason may be there is degradation process in upper stage and aggradation process in lower stages. Based on field investigations it has been reported that flood plains, meander, meander core and other depositional landforms are formed at the lower course of the river. There are all indicative of non-regime nature of the river.

3.7THE TRIBUTARIES OF THE RIVER TAWI

Nine predominant tributaries of the river Tawi have been identified asfollows: -

Kali Kundi: - About 4 km long this tributary has a long profile, concave Its level varies from 4000m to 3200 m.

Pich: - It is 2.0 km long and predominantly degrading in nature. Its level varies from 3600 m to 3200 m.

Magri: - The stream profileindicates two breaks; first at 3200 m and second on 2600 m elevation. It is 9.5 km long and elevation varies from 3600 m to 2000 m.

Chenani: -This left bank tributary flows between altitude of 1100 m to 1700 m and is 7.5 km long.

Dhak Nalla: - The profile of this river also shows steepness varying from 900 m to 800 m. R.L. Its length is about 2.5 Km.

Naddal Khud: - The profile represents small breaks due to the tectonic structure of the area. Its R.L. varies from 1200 m to 700 m and is about 5.8 km long.

Calari: -The profile of this Sewalik stream shows astraight linewithout any break. The aggradation process is predominant in the basin of Calari because of the absence of high slope. It is about 15 km long and R.L. is from 900 m to 700 m.

Pharos: - Its profile presents a steep gradient with high degradation processes. The 5.25 km long river course is between elevations 3600 m to 2400 m.

Gamhi: -The course of river is generally straight with small breaks at places. Its length is about 19 km while elevation varies from 700 m to 400 m.

Chapter 4

4.0 METHODOLOGY

In order to achieve the study objectives,the data used and methodologies adopted in the current study have been described in subsequent sections:

4.1 DATA

The daily 24-hour rainfall data for the years 1977 to 2007 was collected from India Meteorological Department (IMD), Pune for three stations viz. Jammu, Batote and Bhaderwah. The annual maximum 24-hour rainfall data for each of the years had been extracted from the daily time series. This data was used for the estimation of short duration rainfall intensity duration frequency.

4.2 ESTIMATION OF SHORT DURATION RAINFALL

Indian Meteorological Department (IMD) used an empirical reduction formula (Eqn. 1) forestimation of various duration like 5,10,15,20,25,30,35,40,45,50.60,80,100,120,180 minutes rainfall values fromannual maximum values. Chowdhury et al. (2007), used Indian Meteorological Department (IMD) empirical reduction formula to estimate the short duration rainfall from daily rainfall data.

$$P_t = P_{24}\left(\frac{t}{24}\right)^{\frac{1}{3}} \qquad \ldots (1)$$

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 hour.

4.3 GUMBLE'S EXTREMRE VALUE TYPE-1 DISTRIBUTION

The maximum rainfall intensities for various return periods wereestimated using probability distribution function. Gumbel's Extreme Value Type-1 Distribution (Chow et al,1988) is one of the most widely used probabilistic distribution functions for extreme values inhydrologic and meteorologic studies for prediction of flood peaks, maximum rainfalls,maximum wind speed etc.

In this study gumbel's extreme value distribution has been used for probability distribution of the daily rainfall data. (Eqn. 2)

$X_T = \bar{X} + K * \sigma_{n-1}$ ......

(2)

$K = -\frac{\sqrt{6}}{\pi}[0.5772+\ln\left[\ln\left[\frac{T}{T-1}\right]\right]]$ ....

(3)

Where, X_T= value of the variate X of a random hydrologic series with a return period T,

$\bar{X}$= Mean of variate,

σ_{n-1} = standard deviation of the variate,

K = frequency factor which depends upon the return period, T and the assumed frequency distribution.

T= return period

4.4 INTENSITY DURATION FREQUENCY CURVES

The following steps were involved in developing the IDF curves for the stations. Thirty-one yearsof annual maximum rainfall depths were abstracted each for 5,10,15,20,25,30,35,40,45, 50, 60,80,100, 120 and 180 minutes' durations. The mean andstandard deviation of the annual maximum rainfall values were estimated for the given rainfall durations by using the functions:"average $(x_1, x_2, x_3, \dots\dots\dots x_n)$"and "stdev $(x_1, x_2, x_3, \dots\dots\dots x_n)$", respectively in Microsoft Excel program.

The rainfall intensity was computed by dividing the designed rainfall depth for a given return period in mm by the given rainfall duration in hours as defined in Eqn. (4).

$i=\frac{X_T}{d} \dots (4)$

where i is the rainfall intensity (mm/hr.), $X_T$is the designed rainfall depth (mm) for a given return period (T) and d is the duration of the rainfall (hours). The designed rainfall depth,X_T for a given return period (T) was estimated using Eq. (5).

$X_T = \bar{X} + K * \sigma_{n-1} \dots. (5)$

where X andσ_{n-1} are the mean and standard deviation, respectively, of the maximum rainfall depths (mm) of a specified duration and Kis the rainfall frequency factor for a given return period. The frequency factor for 2-, 5-,25-, 50-,100-,200-,500-and 1000-year return periods were computed using the Gumbel's distribution as given by the expression in Eq. (3).

4.5 IDF EMPIRICAL EQUATION

IDF empirical equations are the equation that estimates the maximum rainfall intensity for different duration and return period. Different procedures and formulas have been proposed in various literatures (Chow, 1964; Bell, 1969; Chen, 1983; Aron et al. 1987; Kouthyari and Garde, 1992.IDF is a mathematical relationship between the rainfall intensity i, the duration td, and the return period T. Equation (6) IS the form of IDF empirical equation which is used in this study.

$i = x * (t_d)^{-y} \dots. (6)$

where, i is the rainfall intensity in mm/hr.,

td is the rainfall duration in minutes.

x and y are the fitting parameter.

Chapter 5

5.0 RESULTS AND DISCUSSIONS

5.1 ESTIMATION OF DAILY MAXIMUM SHORT DURATION RAINFALL:

In the present study, various short duration rainfalls like 5,10,15,20,25,30,35,40,45, 50, 60,80,100,120 and 180 minutes were estimated from annual maximum 24 hours rainfall data using Indian meteorological empirical reduction formula for the three rainfall stations.

Table 1 gives the daily maximum rainfall data for Jammu station which have been estimated from annual maximum rainfall data followed by Table 2 and Table 3 which gives daily maximum rainfall data for Batote and Bhaderwah stations respectively.

Table 1: Daily maximum short duration rainfall for Jammu station

year	Annual maximum rainfall	Maximum rainfall for following duration (mm)			
		5min	15min	30min	60min
1977	192	29.07	41.93	52.83	66.56
1978	143.3	21.70	31.30	39.44	49.68
1979	53	8.03	11.58	14.58	18.37
1980	79	11.96	17.26	21.74	27.39
1981	131	19.84	28.61	36.05	45.42
1982	53.5	8.10	11.69	14.72	18.55
1983	61.9	9.38	13.52	17.03	21.46
1984	113.6	17.21	24.81	31.26	39.39
1985	100.7	15.25	22.00	27.71	34.91
1986	172.6	26.19	37.75	47.55	59.90
1987	79.4	12.05	17.37	21.88	27.56
1988	270.4	41.02	59.14	74.50	93.84
1989	167.8	25.46	36.70	46.23	58.23
1990	93.8	14.21	20.49	25.81	32.52
1991	123.6	18.75	27.03	34.05	42.90
1992	100.2	15.20	21.92	27.61	34.77
1993	94.8	14.38	20.74	26.12	32.90
1994	109.4	16.60	23.93	30.14	37.97
1995	119.6	18.14	26.16	32.95	41.51
1996	218.4	33.13	47.77	60.17	75.80

1997	139.5	21.16	30.51	38.43	48.41
1998	74	11.23	16.19	20.39	25.68
1999	146.4	22.21	32.02	40.34	50.81
2000	112.2	17.02	24.54	30.91	38.94
2001	94.8	14.38	20.74	26.12	32.90
2002	97.1	14.73	21.24	26.75	33.70
2003	115	17.45	25.15	31.68	39.91
2004	77.8	11.80	17.02	21.44	27.00
2005	67.2	10.20	14.70	18.51	23.32
2006	137	20.78	29.97	37.75	47.55
2007	145.2	22.03	31.76	40.00	50.39
AVERAGE RF	118.8	18.02	25.98	32.73	41.23

Table 2: Daily maximum short duration rainfall for Batote station

Year	Annual maximum rainfall	Maximum rainfall for following duration(mm)			
		5min	15min	30min	60min
1977	60.40	9.16	13.21	16.64	20.96
1978	95.7	14.52	20.93	26.37	33.21
1979	138.1	20.95	30.21	38.05	47.93
1980	89.6	13.59	19.60	24.69	31.10
1981	88.2	13.38	19.29	24.30	30.61
1982	83.8	12.71	18.33	23.09	29.08
1983	94.2	14.27	20.58	25.92	32.66
1984	300	45.51	65.62	82.65	104.11
1985	106.20	16.08	23.19	29.22	36.82
1986	77.4	11.74	16.93	21.32	26.86
1987	95.8	14.51	20.93	26.36	33.22
1988	316.2	47.97	69.16	87.12	109.74
1989	86.1	13.04	18.81	23.69	29.85
1990	125	18.96	27.34	34.44	43.38
1991	86.6	13.14	18.94	23.86	30.05
1992	170	25.79	37.18	46.84	59.00
1993	159.8	24.20	34.90	43.98	55.41
1994	100.8	15.27	22.02	27.74	34.95
1995	99	15.02	21.65	27.28	34.36
1996	255.4	38.75	55.86	70.37	88.64
1997	124	18.81	27.12	34.16	43.03
1998	114.4	17.36	25.02	31.52	39.70
1999	63	9.56	13.78	17.36	21.86

2000	47.4	7.19	10.37	13.06	16.45
2001	60	9.10	13.12	16.53	20.82
2002	91.8	13.93	20.08	25.29	31.86
2003	161.6	24.48	35.30	44.47	56.03
2004	74.6	11.32	16.32	20.55	25.89
2005	158.2	24.00	34.60	43.59	54.90
2006	166.4	25.20	36.35	45.79	57.69
2007	108.8	16.51	23.80	29.98	37.76
AVERAGE RF	122.53	18.58	26.79	33.75	42.51

Table 3: Daily maximum short duration rainfall for Bhaderwah station

Year	Annual maximum rainfall	Maximum rainfall for following duration (mm)			
		5min	10min	30min	60min
1977	41	6.21	8.96	11.28	14.22
1978	84.5	12.80	18.46	23.25	29.30
1979	95.2	14.44	20.82	26.23	33.04
1980	84.4	12.80	18.46	23.25	29.29
1981	79	11.99	17.28	21.77	27.42
1982	66.6	10.10	14.57	18.35	23.11
1983	90	13.63	19.66	24.76	31.20
1984	300	45.44	65.53	82.56	104.02
1985	73.4	11.14	16.05	20.22	25.47
1986	82	12.44	17.94	22.59	28.46
1987	84.6	12.83	18.50	23.31	29.36
1988	200	30.34	43.75	55.10	69.41
1989	51.2	7.77	11.20	14.11	17.77
1990	80.20	12.15	17.52	22.07	27.81
1991	63	9.56	13.78	17.36	21.86
1992	75	11.36	16.38	20.64	26.00
1993	129	19.54	28.18	35.50	44.73
1994	90	13.63	19.66	24.77	31.20
1995	89.20	13.51	19.48	24.55	30.93
1996	95.2	14.42	20.79	26.20	33.01
1997	124.6	18.87	27.22	34.29	43.20
1998	106	16.05	23.15	29.17	36.75
1999	58.2	8.83	12.73	16.04	20.20
2000	78.5	11.89	17.15	21.60	27.22
2001	50.2	7.62	10.98	13.83	17.42

2002	84.8	12.87	18.55	23.36	29.43
2003	118.2	17.93	25.85	32.57	41.02
2004	67.4	10.23	14.74	18.57	23.39
2005	135.4	20.54	29.62	37.30	46.99
2006	130.2	19.75	28.48	35.87	45.19
2007	60	9.10	13.12	16.53	20.82
AVERAGE RF	95.71	14.51	20.92	26.36	33.20

5.2 ESTIMATION OF RAINFALLINTENSITIES FOR VARIOUS RETURN PERIODS

Above estimated short duration rainfall data were thenused in Gumbel's Extreme Value Type-1 Distribution (Chow et al,1988)methodin order todetermine the rainfall and their corresponding returnperiods as shown in the tables below, which further guided us in developing rainfall IDF curves.

Table 4 shows the rainfall intensities (mm/hr) atdifferent rainfall durations and return periods for Jammu station followed by Table 5 and Table 6 which represents the rainfall intensities for Batote and Bhaderwah station respectively.

Table 4: Rainfall Intensity for various return periods for the Jammu station

Duration (min)	Rainfall Intensity (mm/hr)							
	Return Period (year)							
	2	5	25	50	100	200	500	1000
5	201.71	279.96	397.22	445.77	493.97	542.00	605.36	653.24
10	127.05	176.33	250.18	280.76	311.12	341.37	381.27	411.43
15	96.94	134.55	190.90	214.24	237.40	260.48	290.93	313.94
20	80.02	111.06	157.57	176.83	195.95	215.00	240.13	259.13
25	68.95	95.70	135.78	152.38	168.85	185.27	206.93	223.29
30	61.06	84.74	120.23	134.93	149.52	164.06	183.23	197.73
35	55.09	76.46	108.49	121.75	134.91	148.03	165.33	178.41
40	50.40	69.95	99.24	111.37	123.42	135.41	151.24	163.20
45	46.59	64.66	91.74	102.96	114.09	125.18	139.82	150.87
50	43.43	60.27	85.52	95.97	106.35	116.69	130.33	140.64
60	38.46	53.37	75.73	84.98	94.17	103.33	115.40	124.53
80	31.74	44.05	62.50	70.15	77.73	85.29	95.26	102.79
100	27.35	37.96	53.86	60.44	66.98	73.49	82.08	88.57
120	24.22	33.61	47.69	53.52	59.31	65.08	72.68	78.43
180	18.48	25.65	36.39	40.84	45.26	49.66	55.46	59.85

Table 5: Rainfall Intensity for various return periods for the Batote station

Duration (min)	Rainfall Intensity(mm/hr) Return Period(year)							
	2	5	25	50	100	200	500	1000
5	203.47	308.42	465.70	530.83	595.48	659.89	744.88	809.11
10	128.16	194.26	293.31	334.33	375.05	415.62	469.15	509.60
15	97.79	148.23	223.81	255.11	286.18	317.14	357.98	388.85
20	80.72	122.35	184.74	210.58	236.22	261.77	295.48	320.96
25	69.56	105.43	159.19	181.46	203.56	225.57	254.62	276.58
30	61.59	93.36	140.97	160.68	180.25	199.75	225.47	244.91
35	55.58	84.24	127.19	144.98	162.64	180.23	203.44	220.98
40	50.84	77.06	116.36	132.63	148.78	164.87	186.10	202.15
45	47.00	71.24	107.56	122.61	137.54	152.42	172.04	186.88
50	43.81	66.41	100.27	114.29	128.21	142.07	160.37	174.20
60	38.80	58.80	88.79	101.20	113.53	125.81	142.01	154.25
80	32.02	48.54	73.28	83.53	93.71	103.84	117.21	127.32
100	27.59	41.82	63.15	71.98	80.75	89.48	101.00	109.71
120	24.44	37.04	55.92	63.74	71.50	79.24	89.44	97.15
180	18.65	28.26	42.67	48.64	54.56	60.46	68.25	74.13

Table 6: Rainfall Intensity for various return periods for the Bhaderwah station

Duration (min)	Rainfall Intensity (mm/hr) Return Period(year)							
	2	5	25	50	100	200	500	1000
5	159.38	238.59	357.28	406.44	455.23	503.84	567.97	616.44
10	100.39	150.28	225.05	256.02	286.75	317.37	357.77	388.31
15	76.61	114.68	171.74	195.37	218.82	242.19	273.02	296.32
20	63.23	94.66	141.76	161.27	180.63	199.92	225.36	244.60
25	54.49	81.57	122.16	138.97	155.65	172.28	194.21	210.78
30	48.25	72.24	108.18	123.06	137.84	152.56	171.98	186.65
35	43.54	65.18	97.61	111.04	124.37	137.65	155.18	168.42
40	39.83	59.63	89.30	101.58	113.78	125.93	141.96	154.07
45	36.82	55.12	82.55	93.91	105.18	116.42	131.24	142.44
50	34.32	51.38	76.95	87.54	98.05	108.52	122.33	132.77
60	30.39	45.50	68.14	77.52	86.82	96.10	108.33	117.58
80	25.09	37.56	56.25	63.99	71.67	79.32	89.42	97.05
100	21.62	32.37	48.47	55.14	61.76	68.36	77.06	83.64
120	19.14	28.66	42.92	48.83	54.69	60.53	68.24	74.06
180	14.61	21.87	32.75	37.26	41.73	46.19	52.07	56.52

The estimated Rainfall intensities for a return period of 100 years for short duration of 5,15,30 and 60 minutes for Jammu, Batote and Bhaderwah stations were compared and putted together in a tabular form. From the table below it was concluded that Batote has maximum rainfall intensity for all the durations.

Table 7: comparison of rainfall intensities for 100 years return period for different stations

Duration(min)	Jammu	Batote	Bhaderwah
5	493.98	595.48	455.23
15	237.40	286.18	218.82
30	149.52	180.25	137.84
60	94.18	113.53	86.82

Table 8 represents the estimation of frequency factor (K) for different return periods.

Table 8: Estimated frequency factors for respective return period

Return Period (T year)	Frequency Factor (K)
2	-0.16
3	0.25
5	0.72
10	1.30
25	2.04
50	2.59
100	3.14
200	3.68
500	4.39
1000	4.94

5.3 DEVELOPMENT OF IDF CURVES

Rainfall IDF curves i.e., rainfall intensity-duration-frequency curves were developed for short durations of 5,10,15,20,25,30,35,40,45,50.60,80,100,120,180 minutes' and return periods of 2,5,25,50, 100,200 and 1000 years. The developed IDF curves are shown in Figures below. These were obtained by plotting the rainfall intensity valuesagainst their durations for the different return periods It is noted that the rainfall intensity decreases as duration increases. For particular duration as return period increases rainfall intensity tends toincreases.

Figure 1,2 and 3represents the rainfall IDF curves for Jammu, Batote and Bhaderwah station respectively.

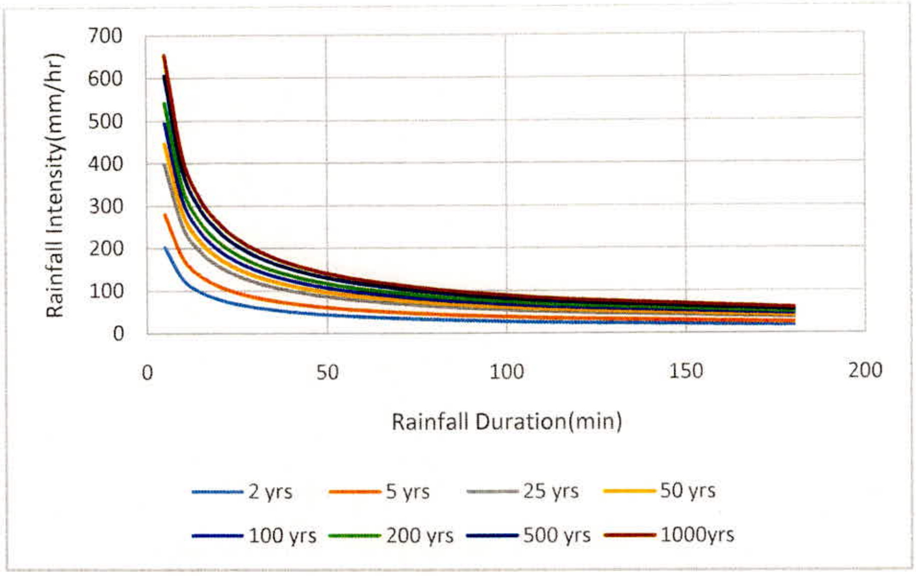

Fig.1:Intensity duration frequency curve for Jammu station

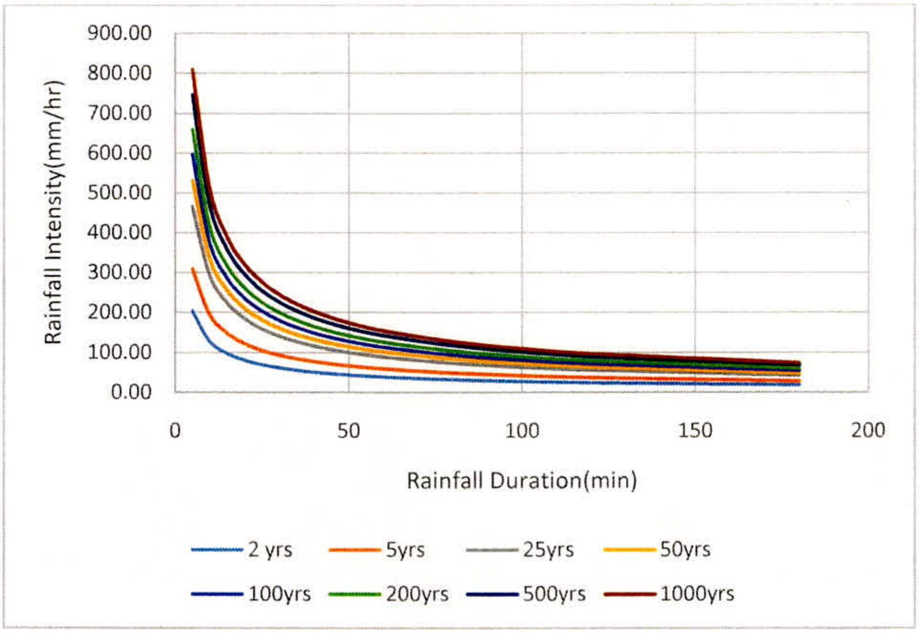

Fig.2:Intensity duration frequency curve for batote station

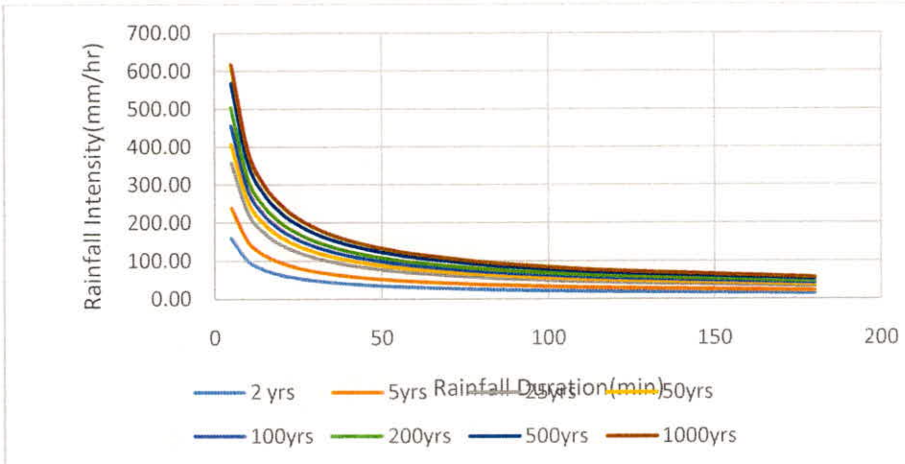

Fig.3: Intensity duration frequency curve for Baderwah station

5.4 DERIVATION OF IDF EMPIRICAL EQUATION

The use of thesecurves becomes more cumbersome and hence ageneralized empirical relationship was developed. Rainfall IDF empirical equation constant x and y were calculated for different return period. IDF empirical equation wasformed by putting the value of x and y in the mentioned equation format for each return period separately as shown in Tables below.the parameter y remains aconstant of 0.6667.

Table 9 represents the empirical equation developed for all the three stations.

Table 9: Rainfall IDF empirical equation for respective return period

Return Period (year)	Jammu	Batote	Bhaderwah
2	$i = 590.05 * (t_d)^{-0.667}$	$i = 595.19 * (t_d)^{-0.667}$	$i = 466.19 * (t_d)^{-0.667}$
5	$i = 818.96 * (t_d)^{-0.667}$	$i = 902.22 * (t_d)^{-0.667}$	$i = 697.81 * (t_d)^{-0.667}$
25	$i = 1162 * (t_d)^{-0.667}$	$i = 1362.3 * (t_d)^{-0.667}$	$i = 1044.9 * (t_d)^{-0.667}$
50	$i = 1304.1 * (t_d)^{-0.667}$	$i = 1552.9 * (t_d)^{-0.667}$	$i = 1188.7 * (t_d)^{-0.667}$
100	$i = 1445.1 * (t_d)^{-0.667}$	$i = 1742 * (t_d)^{-0.667}$	$i = 1331.4 * (t_d)^{-0.667}$
200	$i = 1585.6 * (t_d)^{-0.667}$	$i = 1930.5 * (t_d)^{-0.667}$	$i = 1473.5 * (t_d)^{-0.667}$
500	$i = 1770.9 * (t_d)^{-0.667}$	$i = 2179.1 * (t_d)^{-0.667}$	$i = 1661.1 * (t_d)^{-0.667}$
1000	$i = 1911 * (t_d)^{-0.667}$	$i = 2367 * (t_d)^{-0.667}$	$i = 1802.8 * (t_d)^{-0.667}$

Chapter 6

6.0 CONCLUSION

In this study, the maximum short duration rainfall for different time steps was abstracted from the daily rainfall data for three IMD rainfall stations namely Jammu, Batote and Bhaderwah. Then extreme rainfall for various return period were estimated using Gumbel's Extreme Value distribution and these values were further used to develop the IDF curves for the stations. The empirical equations for IDF also has been derived. Data derived from the rainfall intensity-duration-frequency curves are needed by hydrologist and engineers involved in planning and design of water resources projects. The maximum rainfall intensity of any storm over any return period can be obtained from the IDF curve.The IDF curves are therefore recommended for predicting, when a location or region will get flooded.

REFERENCES-

Al-Awadi A.T. (2016). Assessment of Intensity-Duration-Frequency models for Baghdad city, Iraq. Vol.12(12):7-11, February.

Al Hassoun, S.A. (2011). Developing an empirical formula to estimate rainfall intensity in Riyadh region. Journal of King Saud University-Engineering Sciences.

Al-Khalaf, H.A. (1997). Predicting short-duration, high-intensity rainfall in Saudi Arabia. M.S. Thesis, Faculty of the College of Graduate Studies; King Fahad University of Petroleum and Minerals, Dhahran (K.S.A).

Al-Salem, H.S. (1985). Rainfall Frequency Distribution in Shaqra and Al-Zilfi Areas, B.S. Project, Civil Engineering Department, King Saud University, Riyadh, KSA, Jan. 1985.

Al-Shaikh, A. A. (1985). Rainfall frequency studies for Saudi Arabia. M.S.Thesis, Civil Engineering Department, King Saud University ,Riyadh (K.S.A).

Al-Sobaye, A.E. (1983). Rainfall Frequency Distribution for Riyadh, B.S. Project, Civil Engineering Department, King Saud University, Riyadh (K.S.A), Jan. 1983.

Angela Peck, Predrag Prodanovic and Slobodan P.P. Simonovic. (2012) Rainfall Intensity-Duration-Frequency curves under climate change: city of London, Ontario, Canada. Canadian Water Resources Journal, Vol.37:177-189.

Aron G., Wall D. J., White E. L. and Dunn C. N. (1987). "Regional rainfall intensity-duration frequency curves for Pennsylvania." Water Resources Bulletin. 23(3): 479-485.

Awadallah A.G., M.ElGamal, A.El Mostafa and H.E.Badry (2011) Developing Intensity-Duration-Frequency (IDF) curves in scarce data region: an approach using regional analysis and satellite data. Scientific Research Publishing, Engineering, Vol.3(3): 215–226.

Bell F. C., (1969). "Generalized rainfall-duration frequency relationship", ASCE J. Hydraulic Eng., 95, 311–327.

Célio Orli Cardoso, Idelgardis Bertol, Olívio José Soccol Carlos, Augusto de Paiva Sampaio (2012) .Generation of Intensity Duration Frequency Curves and Intensity Temporal Variability Pattern of Intense Rainfall for Lages/SC . Brazilian Archives of Biology and Technology, December.

Chen C. I. (1983). "Rainfall intensity-duration frequency formulas. Journal of Hydraulic Engineering." 109(12): 1603-1621.

Cheng L. and Aghakouchak A. (2014) Non stationary precipitation Intensity-Duration-Frequency (IDF) curves for infrastructure design in a changing climate. Scientific Reports.

Chow V.T. (1964). Handbook of Applied Hydrology. McGraw- Hill, New York. 9-49, 9-62.

Chow V.T., D.R.Maidmet and L.W.Mays (1988). "Applied Hydrology", McGraw- Hill, New York. Probability, Risk and Uncertainty Analysis for Hydrologic and Hydraulic Design,10: 361 – 398.

Desramaut N. (2008) Estimation of Intensity-Duration-Frequency (IDF) curves for current and future climates. McGill University Montreal, Quebec, Canada.

Dupont B.S. and Allen D.L. Revision of rainfall Intensity-Duration-Frequency (IDF) curves for the commonwealth of Kentucky. Kentucky Transportation Centre Research Report.

Frequency Curves for Accra in Ghana. International Journal of Latest Research in Engineering and Computing (IJLREC)Vol.1:67-73, September-October.

Henrick Madsen, Peter Steen Mikkelsen, Dan Rosbjerg and Poul Harremoes. (2002) Regional estimation of rainfall intensity-duration-frequency curves by using generalized least squares regression of partial duration series statistics. Water Resources Research, Vol. 38:1-11, November.

Kothyari, U.C. and Grade, R.J. (1992). "Rainfall intensity duration frequency formula for India." Journal of Hydraulic Engineering. ASCE, 118(2), 323-336.

Koutsoyiannis, D., Kozonis, D., & Manetas, A. (1998). A mathematical framework for studying rainfall intensity-duration-frequency relationships. Journal of Hydrology, 206(1), 118-135.

Langousis Andreas and VenzianoDaniele (2007) Intensity-Duration-Frequency curves from scaling representation of rainfall. Water Resources Research, Vol.43(2), feburary.

Logah F.Y., K. Kankam-Yeboah and E. O. Bekoe (2013) Developing Short Duration Rainfall Intensity.

M.O.Isikwue, S.B.Onoja and K.J.Laudan(2012). Establishment of an empirical model that correlates rainfall Intensity-Duration-Frequency (IDF) curves for Makurdi area, Nigeria. International Journal of Advances in Engg. and Tech., November.

Mirrhosseini G., P.Srivastva and L.Stefanova. (2013) The impact of climate change on rainfall Intensity-Duration-Frequency (IDF) curves in Alabama. Regional Environmental Change Vol13:25-33, August.

Mohymont, B., Demar'ee1, G.R., Fakadu, D.N. (2004). Establishment of IDF-curves for precipitation in the tropical area of Central Africa – comparison of techniques and results, Department of Meteorological Research and Development, Royal Meteorological Institute of Belgium, Ringlaan 3, B-1180 Brussels, Belgium.

Nhat L.M. and TakaraY.T.K. (2006) Establishment of Intensity-Duration-Frequency (IDF) curves for precipitation in monsoon area of Vietnam.

Rashid M.M., S.B.Faruque and J.B.Alam (2012) Modeling of Short Duration Rainfall Intensity Duration Frequency (SDR-IDF) Equation for Sylhet City in Bangladesh .ARPN Journal of Science and Technology, vol. (2), March.

Singh.V and Zhang.L (2007). Intensity-Duration-Frequency (IDF) curves using the Frank Archimedean Copula. Journal of Hydrologic EngineeringVol.12:651-662, November.