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Rainfall Analysis for the Development of IDF relationships- A Case study of Vadodara city

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Abstract — *Rainfall Analysis is pre-requisite for designing efficient storm water management system. This paper includes the most accurate methodology for developing Rainfall Intensities-Duration-Frequancies (IDF) relationships. Vadodara city is taken as study area to design efficient River-lake interlinking system. For this, first necessary step is proper understanding of rainfall pattern and development of IDF curves. Daily Rainfall data (1970-2015) from gauge station in Vadodara city was analysed by Flood Frequency analysis by Gumbel's extreme value distribution to derive probabilities of daily maximum rainfall events using spread sheet., Rainfall intensities were derived for 60, 90, 120, 180, 240, 360, 480, 720, 1440 min of duration, this intensity duration relationship were plotted with log-log plot for 1 & 2 year return period. This particular return period was adopted for storm water management. Relationship of rainfall intensity with concentration time for a given frequency of occurrence for 10 min & 30 min intervals were plotted to generate IDF curves which will be considered as one of the important input parameter to design River-lake interlinking system.*

Keywords-Flood Frequency, Rainfall analysis, IDF relationship, Lake interlinking.

I. INTRODUCTION

Precipitation is parent phase of the hydrological cycle. Water from rainfall joins land surfaces & becomes Surface runoff and percolates. Then it joins ground water or sub surface runoff. As entire world faces the problem of change in hydrological cycle, variation in rainfall pattern and effect of climate differs variedly region to region. Many cities of the world are affected by sudden natural hazards like flood. A major reason for the flood is due to the problem of increased rainfall amount and increased intensity of shorter duration resulting in flash floods. Main objective of study is to understand and analyze rainfall pattern of urban area. Results of rainfall analysis will be considered as input for efficient design of River-Lake interlinking system which is one of the best plan for urban storm water management. Hydrological analysis of rainfall consists method of central simple moving average (Engineering Hydrology, K. Subramnya, 3rd edition, 2008) which shows 3 years and 5 years moving average for the daily rainfall data, Climate change analysis shows variations in climate at 5 years and 10 years interval. Analysis of the monthly rainfall covers evaluation of the numbers of rainy days and average rainfall for each month. Probability Analysis for one day Annual Maximum Rainfall (IS 5542-2003) covers Flood Frequency analysis to find out Probability and its Recurrence interval for subsequent one day rainfall, Development of the IDF curves covers Generation of shorter Duration Rainfall (IS 5542-2003) and Derivation rainfall intensities by Gumbel's Extreme value Distribution (CPHEEO,India). These IDF curves relationships for 1 in 1 year and 1 in 2 year Frequancy (CPHEEO,India), Rainfall intensities for 10 min 30 min intervals which is important input parameter for design of river-lake interlinking system.

II. STUDY AREA

Vadodara city (22.3072° N, 73.1812° E) has been taken for analysis of rainfall pattern for which efficient river-lake interlinking system will be designed. The city is situated in the fertile plane between the river Narmada and Mahi and on bank of Vishwamitri. The city limits under 162 sq km.of total area of Vadodara Mahanagar Seva-Sadan (VMSS). The city of Vadodara has south-west monsoon (June-September). The weather is generally cloudy with frequent spells of rainfall. Hydrological Analysis for Daily data of Rainfall can be carried out for creating Intensity-Duration-Frequancy (IDF) relationship for the city.

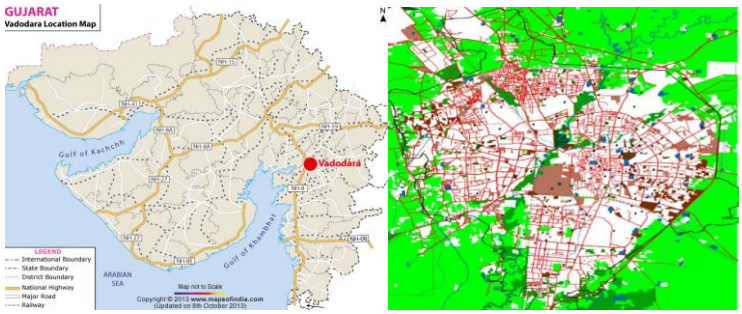

Figure 2.1 Vadodara city map

III. METHODOLOGY

Past years rainfall data (1970-2015) from SWDC center (Gandhinnagar) were collected for rain gauge station of SWDC situated at Vadodara city to analyze rainfall pattern and to develop IDF curves relationship.

3.1 Annual rainfall Analysis (1970-2015):

The statistical analysis of the collected daily rainfall data gives an average Annual rainfall Value. This analysis further shows moving average & climate change analysis.

3.1.2 Moving Average:

Moving Average is a technique for smoothing out the high frequency fluctuations of time series. Common method of moving average is central simple moving average, the basic principle is that for several data sets of time range n years starting from first stage of n years of data, the average of the data for n years is calculated and placed in the middle year of the range n. Usually the value of n is odd one.

3.1.3 Climate Change Analysis:

For this study, Average rainfall was determined at every 5 years and 10 years interval. The average value of rainfall was prepared by plots and trend lines which were added to examine the change in the rainfall pattern.

3.2 Monthly Rainfall Analysis (1970-2015):

The number of rainy days for each month and year were worked out for period of 1970-2015(46 years) and the change was observed by plotting them along with the average values for the period. The change in the maximum daily rainfall pattern over a large span can be determined by working out an average value for each decade and a plot prepared to observe the change. The analysis was also carried out for monthly rainfall pattern for the study period along with the number of rainy days in each month.

3.3 Daily rainfall Analysis (1970-2015):

Using Daily rainfall data, one day maximum annual rainfall values are worked out.

3.3.1 Probability Analysis for One Day Annual Maximum Rainfall:

The purpose behind frequency analysis of an annual series is to obtain a relation between the magnitude of the event and its probability of exceedance. It is a simple empirical technique to arrange the given annual extreme series in descending order of magnitude till the last event for which m equals the total number of record N and to assign an order number m (5542-2003). The probability P of an event equaled to or exceeded is given by the Weibull formula,

$$P = m/N+1 \quad (3.1)$$

The recurrence interval or return period,

$$T = 1/P \quad (3.2)$$

According to (IS: 5542-2003) 15 % increase shall be made in the daily maximum raw data and then after the data can be used for analysis.

3.4 Development of IDF curves:

All city data are analyzed to obtain extreme short rainfall intensity values.

3.4.1 IDF by using Daily Rainfall data(1970-2015):

The daily rainfall values after correction according to IS: 5542-2003 were converted into hourly rainfall data using following method.

3.4.1.1 Shorter Duration Rainfall Data generation using SWDC Daily Rainfall Data Series:

The extreme value series is used to generate shorter duration series (60, 90, 120, 180, 240, 360, 480, 720, 1440) by employing the IMD formula given as:

$$P_t = [P_{24} (t/24)^{(1/3)}] \quad (3.3)$$

P_t = rainfall of t mins duration in mm, P_{24} = daily rainfall value in mm, t = time duration in mins

3.4.1.2 Derivation of rainfall intensity:

Rainfall intensity for P_t for different duration of time is obtained using standard formula,

$$i = P_t / D \quad (3.4)$$

Where, D = Duration of event in hours

3.4.1.3 Derivation of IDF curve by Gumbel's Extreme Value Distribution:

Method refers following equation to evaluate Rainfall intensity (X_T) in mm/hr.

$$(X_T) = Xm + K_t s \quad (3.5)$$

Xm = Mean, s = standard deviation, K_t = Frequency factor for return period T.

$$\text{Where, } K_t = \sqrt{6}/\square \ [\ 0.5772 + \ln \{\ln(T/T\text{-}1)\}] \quad (3.6)$$

3.4.1.4 Determination of Constants:

The values of intensity and duration obtained from (3.5) were used to obtain the constants in the intensity equation suggested by CPHEEO manual, India by equation,

$$\text{Log(i)} = \log (a) - n \log (T) \quad (3.7)$$

Where, i = Rainfall intensity in mm/hr, T = Duration event of the storm in minutes, 'a' & 'n' are constants
The log-log plot can be obtained using intensity (i) and duration (t) values from table for 1 year and 2 year return period.

3.4.1.5 IDF curves for 1 in 1 year and 1 in 2 year Frequency:

Using the constants of the rainfall intensity equation obtained from log log plot, the IDF curves were developed for 1 year return period as well as 2 year return period.

IV. RESULTS OF ANALYSIS:

4.1 Results of Annual Rainfall Analysis: (Figure 4.1)

Annual Rainfall analysis gives following results:
Average annual rainfall - 947.37 mm, Maximum rainfall period – July and September
Minimum Rainfall – 303.60 mm, Maximum Rainfall – 2160.60 mm

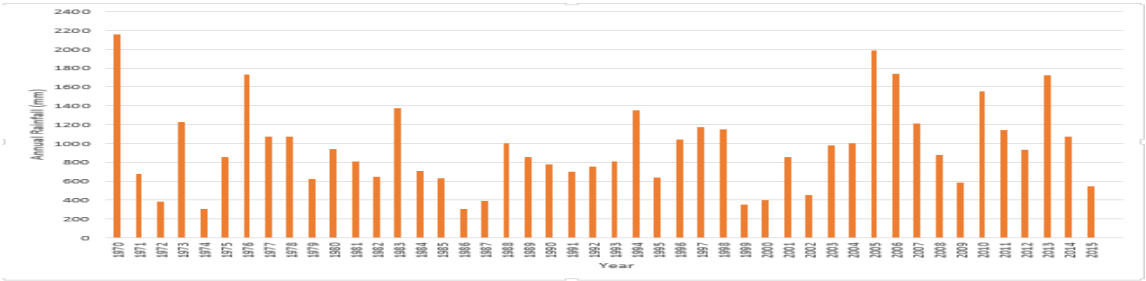

Figure 4.1 Annual Rainfall of Vadodara city (1970-2015)

4.1.1 Results of Moving Average: (Figure 4.2)

Central Simple Moving Average method was applied to get 3 year and 5 year moving average for city.

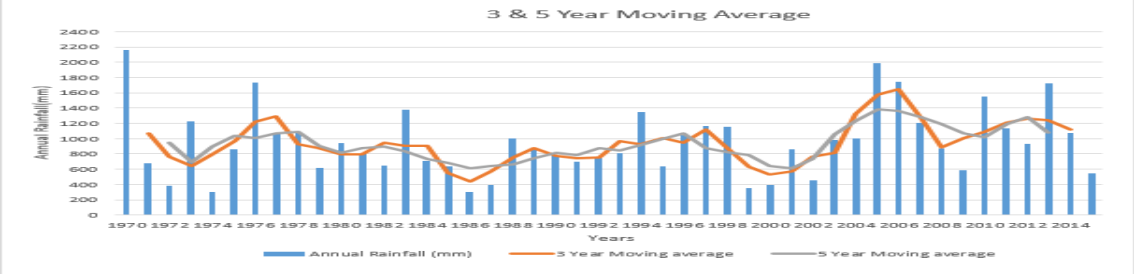

Figure 4.2 Three and Five Year Moving Mean (1970-2015)

4.1.2 Results of Climate Change Analysis: (Figure 4.3)
Plots for 5 year and 10 year average rainfall values and its trend lines were prepared for Vadodara city.

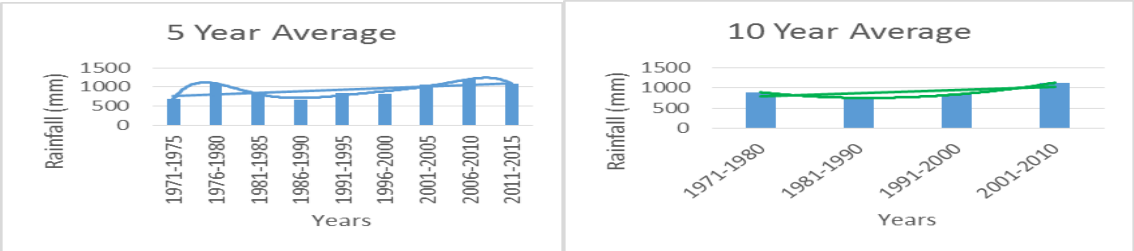

Figure 4.3 Five and Ten Year Average Rainfall

4.2 Results of Monthly Rainfall Analysis (1970-2015): (Figure 4.4-4.8)

The Change was observed by plotting monthly rainfall values and Rainy days with monsoon period (months). Average number of rainy days for the study period 9.8 days per month and the average monthly rainfall is 194.07 mm.

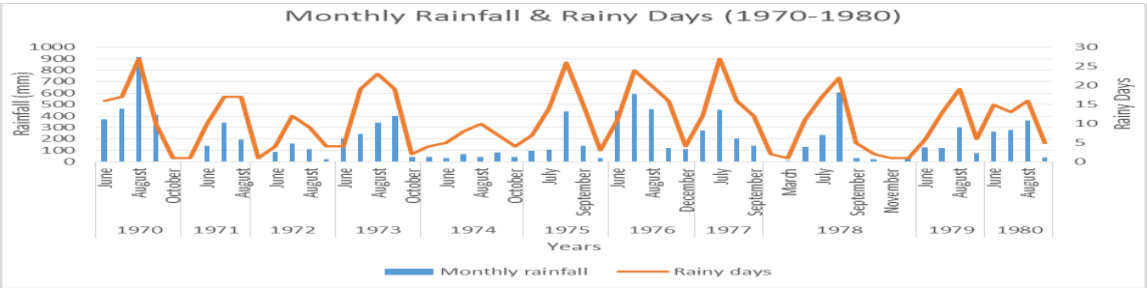

Figure 4.4 Monthly Rainfall Analysis (1970-1980)

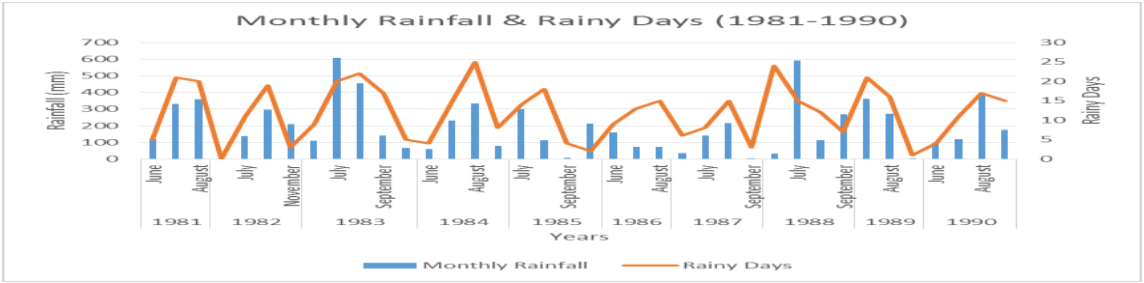

Figure 4.5 Monthly Rainfall Analysis (1981-1990)

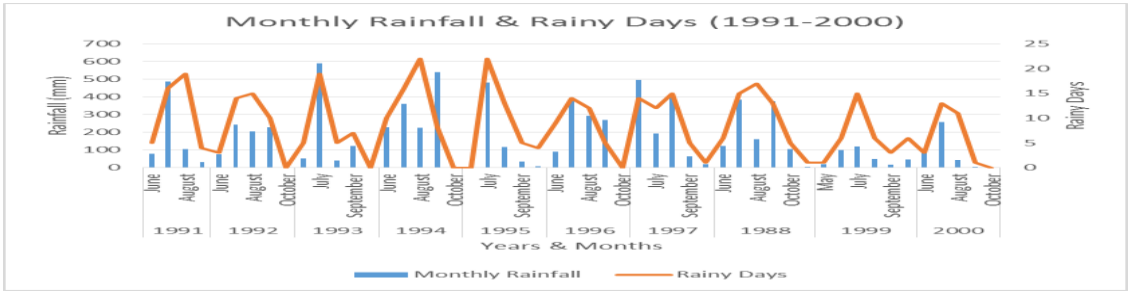

Figure 4.6 Monthly Rainfall Analysis (1991-2000)

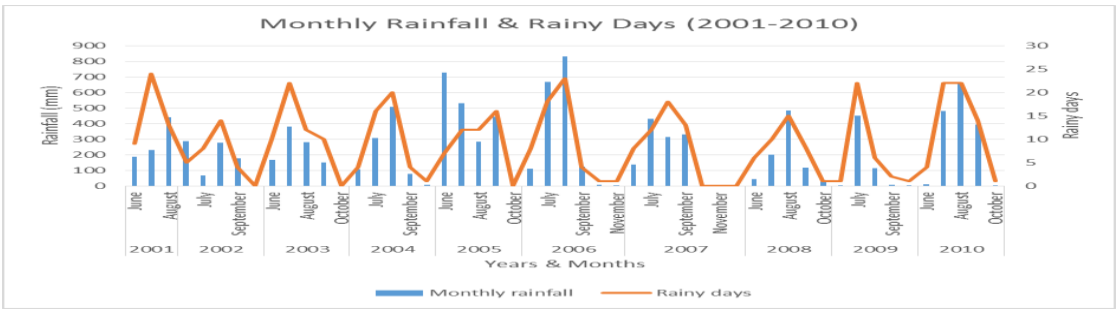

Figure 4.7 Monthly Rainfall Analysis (2001-2010)

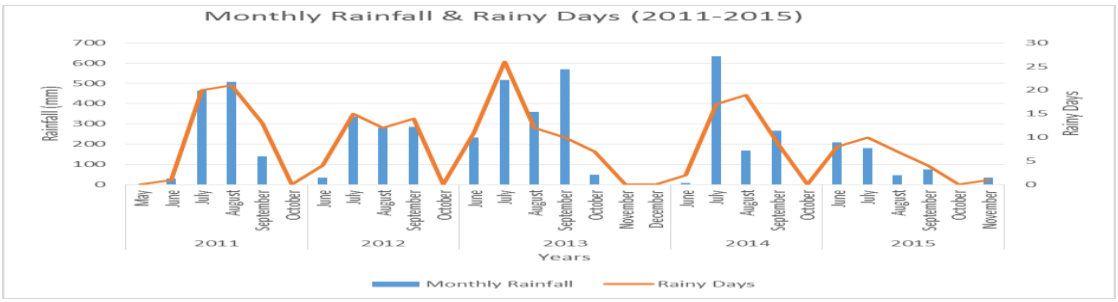

Figure 4.8 Monthly Rainfall Analysis (2011-2015)

4.3 Results for Daily Rainfall Analysis and Probability Analysis for One Day Annual Maximum Rainfall (1970-2015): (Figure 4.9, 4.10)

Probability (P) for maximum One Day Maximum Rainfall of 362.25 mm is 0.0213 and Return period (T) is 47 years . Probability (P) for minimum One Day Maximum Rainfall of 36.34 mm is 0.9787 and Return period (T) is 1 year.

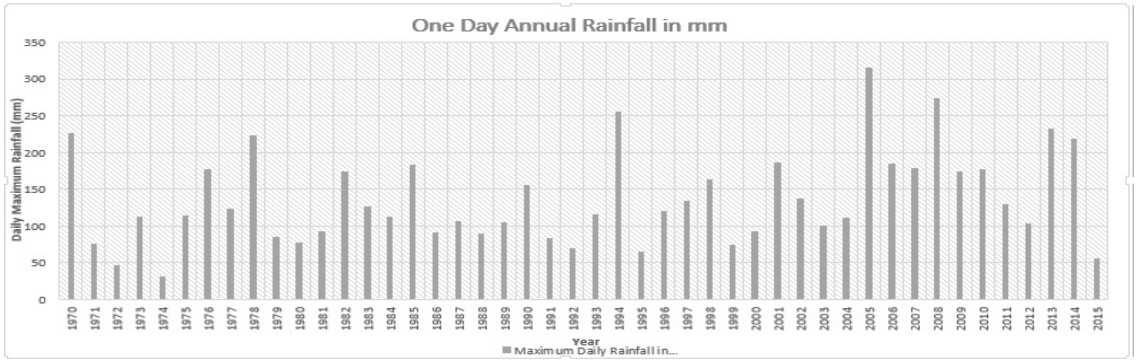

Figure 4.9 One Day Annual Rainfall

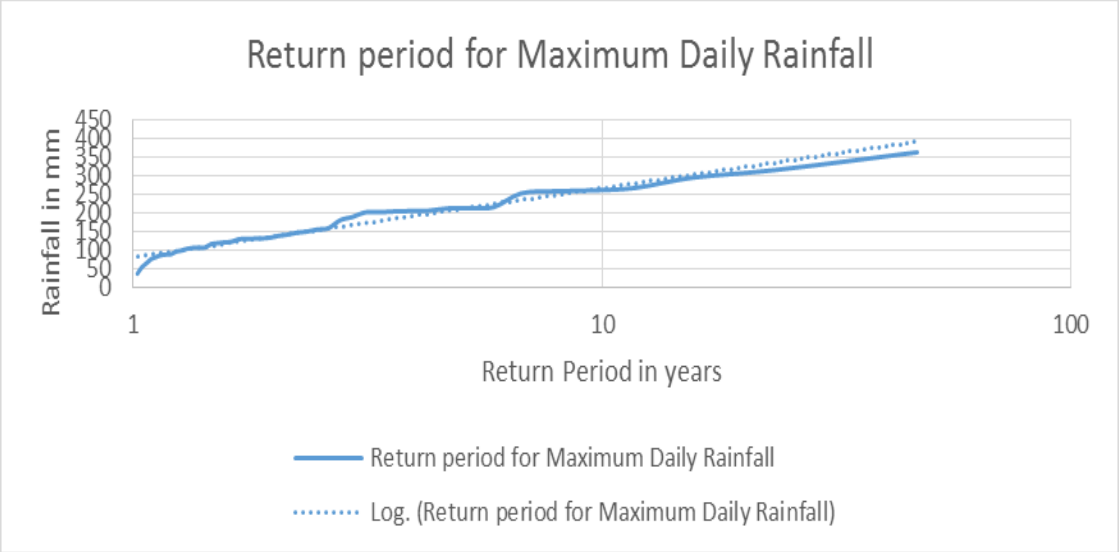

Figure 4.10 Return period for maximum Daily Rainfall

4.4 Development of IDF curves:

Derivation of IDF curves follow Gumbel's extreme value distribution, by applying equations (3.3), (3.4) the extreme value series (rainfall intensities) were presented for shorter duration series (60, 90, 120, 180, 240, 360, 480, 720, 1440) to have Mean and standard deviation. (Table 4.1)

Table 4.1 Mean and standard deviation values

Mean	54.607	41.673	34.400	26.252	21.670	16.538	13.651	10.418	6.5631
St Dev	24.621	18.789	15.510	11.836	9.771	7.456	6.155	4.697	2.959

These values of mean and standard deviation were applied in equation (3.5) to have rainfall intensities in mm/hr in which frequency factor can be obtained from equation (3.6) which are -0.450, -0.164 for 1 and 2 years return periods (Mentioned in CPHEEO journal, India for parameter considerations of storm water management system) respectively. Table 4.2 shows the intensity duration relationships for 1 and 2 year return periods.

Table 4.2 Intensity Duration Relationship for 1-2 year Return period (1970-2015)

Duration (Mins)	Rainfall Intensities (mm/hr)	Rainfall Intensities (mm/hr)
	For Year 1	For Year 2
60	43.520	50.560
90	33.212	38.585
120	27.416	31.851
180	20.922	24.307
240	17.271	20.065
360	13.180	15.312
480	10.880	12.640
720	8.303	9.646
1440	5.230	6.076

Values of Intensity and duration obtained in Table 4.2 were used in equation (3.7) and its log log plot gives constants 'a' and 'n' value '666.960' and '0.666' for 1 year return period & '774.818' and '0.666' for 2 year return period. (Figure 4.11)

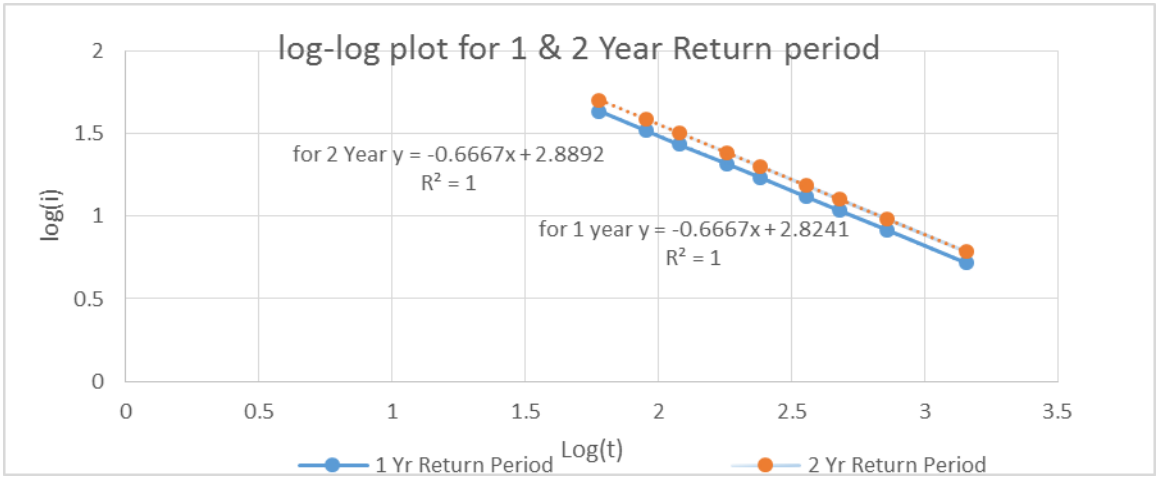

Figure 4.11 Log-Log plot 1-2 year Return period (SWDC Daily Data)

Using these constants, IDF curves were developed 10 mins and 30 mins intervals. (figure 4.12, 4.13)

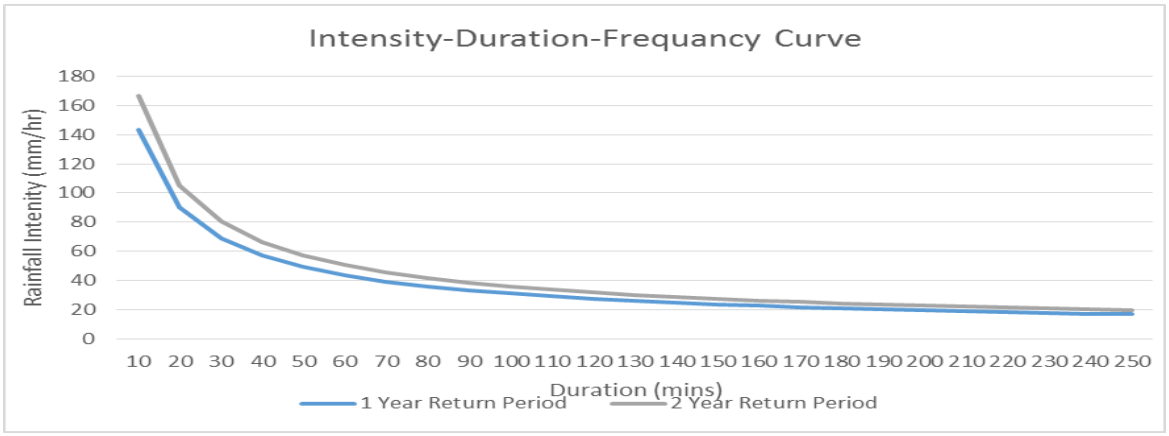

Figure 4.12 Intensity-Duration-Frequency Curve for 10 min interval (SWDC Daily Data)

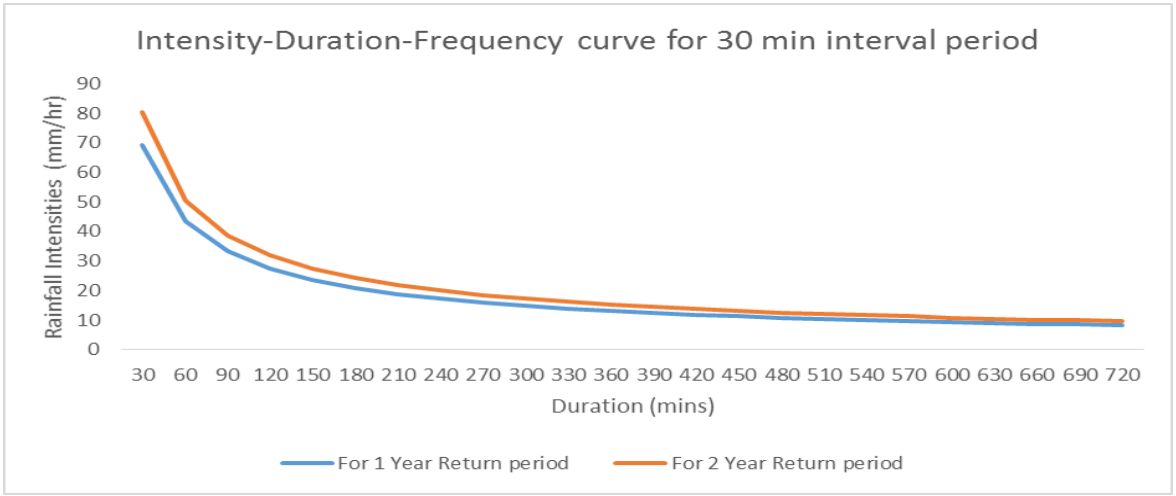

Figure 4.13 Intensity-Duration-Frequency Curve for 30 min interval (SWDC Daily Data)

V. CONCLUSION:

- Vadodara city has already suffered serious floods in past years specially in year 1970, 2005, also in 2014 heavy rainfall occurred on upstream (Ajwa reservoir area) results city suffered serious losses. Vadodara city, situated between river mahi and narmada and on banks of vishwamitri, is vulnerable to flooding due to many reasons such as high intensity of rainfall in city area as well as on upstream (Ajwa reservoir area), loss of drainage capacity due to design faults, development of reclaimed areas and improper adoption of intensity of rainfall in designing the drainage system.
- Annual Rainfall analysis results shows maximum rainfall occurred 2160.60 mm in 1970 and minimum rainfall occurred 303.60 mm in 1986, also an Average annual rainfall of Vadodara city is 947.36 mm.
- Monsoon of Vadodara city is very quite unusual and unsteady as 5 year and 10 year average rainfall for climate change analysis shows variability
- For first 11 years (1970-1980) total monthly rainfall was 10998 mm and total rainy days were 613, next 10 years (1981-1990) total monthly rainfall was 12723 mm and total rainy days 454, then next 10 years (1991-2000) it was 8386.70 mm total monthly rainfall and were 431 rainy days, from 2001 to 2010 total monthly rainfall was 11594 mm and total rainy days were 464, and from last five years (2001-2015) it was 5420 mm total monthly rainfall and 243 total rainy days ultimately this analysis proves that in front of gradual decrease in total rainy days for particular monsoon season there is extensive increase in total monthly rainfall shows maximum chances of flash floods in Vadodara city..
- One day Maximum rainfall was 315 mm in 9^{th} month of 2005 which was flood year and one day minimum rainfall was 31.6 mm in 7^{th} month of 1974 in which season of monsoon was below average. So, maximum recurrence interval is 47 years for probability of exceedance 0.0213 and minimum recurrence interval is 1 year for probability of exceedance is 0.9787.
- Results of log log plot shows very accurate linear relationships. This indicated that the empirical formula obtained to estimate intensity in the study area is good for short durations. Values of constants 'a' & 'n' are 666.960' and '0.666' for 1 year return period and '774.818' and '0.666' for 2 year return period with 1 R^2 error.
- As observed in this study, Gumbel's Extreme Value Distribution method shows the best approximation of rainfall intensity for return periods of 1 and 2 years, gives proper relationships of rainfall Intensity-Duration-Frequency. The results shows a good match as the correlation.
- For the design of appropriate drainage system, IDF curves are to be considered. The IDF relationships developed in the present study can be used effectively in designing an efficient River-Lake interlinking system.

VI. STUDY RESULT IMPLEMENTATION:

Results from this study which is IDF curves would become input parameter to design River-lake interlinking system using software SWMM (Storm Water Management Modelling) for entire Vadodara city. So, the design would be safer to avoid flooding in the future, In Lake interlinking system modelling Rainfall Intensities for 10 min & 30 min intervals will going to put down as an input in time series of rainfall gauge station model. As a result mode will gave time series pattern graphically for different scenarios and will also give rainfall-runoff relationships for Vadodara city.

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