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# Developing Rainfall Intensity-Duration-Frequency Relationship for Central Zone of Surat City, Gujarat, India

Ajay Gamit[1], P.P.Lodha[2],Indra Prakash[3]&Khalid Mehmood[4]

[1]ME (Final), L. E. College, Morbi
[2]HOD, Civil Department, L. E. College, Morbi
[3]Faculty, BISAG&[4]Manager, BISAG, Gandhinagar

***Abstract***—*Intensity–Duration–Frequency (IDF) relationship of rainfall amounts is one of the mostCommonly used tools in water resources engineering for planning, design and operation of waterResources projects. Historical rainfall records for the most of towns and urban areas in India are available only from non–recording rain gauges .These are measurements of daily/24 hours storm depths. The objective of this study is to derive IDF relationship of rainfall at central zone of Surat city from daily/24 hours rainfall data. These relationships are useful inthe design of urban drainage works, e.g. storm sewers, culverts and other hydraulic structures.Gumbel distribution and the Log Pearson Type III distribution (LPTIII) techniques are commonly used to develop the IDF curve from rainfall data. In the present study Gumbel distribution method has been used to derive IDF curve.*

***Keywords:*** *IDF curve,Rainfall intensity, Rainfall duration, Rainfall frequency relationships.*

## I. INTRODUCTION

Rainfall intensity–duration–frequency IDF curves are graphical representations of the amount of water that falls within a given period of time in catchment areas (Dupont and Allen,2000). IDF curves are used to aid the engineers while designing urban drainage works. The establishment of such relationships was done as early as 1932 (Chow (1988) and Dupont andAllen (2006)). Since then, many sets of relationships have been constructed for several parts of the globe.In some study IDF curves havebeen used in conjunction with runoff estimation formulae such as Rational Method, to predict the peak runoff amounts from a particular watershed. The information from the curves is then used in hydraulic design to size culverts and pipes (Dupont and Allen, 2000). Further studies by Ilona and France´ s (2002) performed rainfall analysis and regionalization of IDF curves for different regions.AlHassoun (2011) developed an empirical formula to estimate the rainfall intensity in Riyadh region. He found thatthere is not much difference in the results of rainfall analysis of IDF curves in Riyadh area between Gumbel and LPT III methods. He attributed this to the fact that Riyadh region has semi-arid climate and flat topography.In the lower reaches of Tapi River topography is almost flat similar to Riyadh region. Therefore, in this study we have used Gumbel distribution method.

## II. STUDY AREA

Surat City (Latitude 21.1702°N and longitude 72.8311°E) is situated on bank ofTapiRiver is having flat topography. Coastline of Arabian Sea is at a distance about 19.4 km from the study area. Area of Surat city is 326.515 sq.km and population 44,66,826 (Census 2011).Surat city is divided in seven main zonesnamelyCentral zone, East zone , West zone, North zone, South zone, South east zone, Southwest zone. The study area is located in Central zone of Surat which is divided into 12 main wards having 19513 meters of storm water drainage network.

The summers are quite hot with temperatures ranging from 37.78 C to 44.44 C. The climate is pleasant duringthe monsoon while autumn is temperate. The winters are not very cold but the temperatures in January range from 10 C to 15.5 C. The average annual rainfall of the city has been 1143 mm

## III. DATA SOURCE

IRS P6 LISS-IV satellite image were used for the preparation of land-use/land-cover map of study area. Soil map and index map was collected from Bhaskaracharya Institute for Space Application and Geo-Informatics (BISAG), Gandhinagar, Gujarat. Daily rainfall data of 6 rain-gauge station were collected from the State Water Data Centre (SWDC), Gandhinagar, Gujarat. ArcGIS 9.3 is used at BISAG, Gandhinagar, Gujarat.


***Fig.1: Location map of the study Area***

## IV. Methodology and Analysis of data

Methodology of the study has been given as flow chart in Fig.2. Based on the hydrological data obtained from SWDC and generated using GIS tools have been analyzed for the development of IDF curve for different return period.

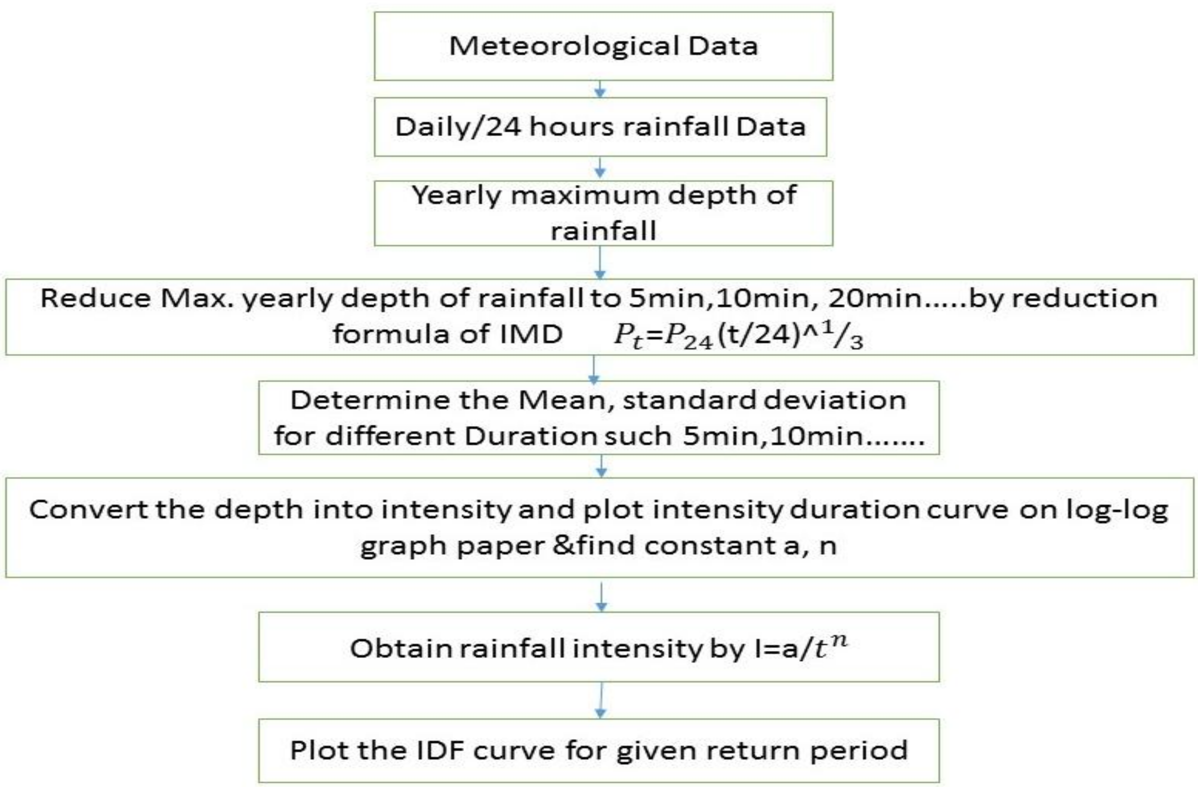



***Fig. 2: Methodology***

## V. GUMBEL DISTRIBUTION METHOD

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 each duration with a specified return period T (in year) is given by
The following equation.

$$P_T = P_{ave} + KS$$

Where K is Gumbel frequency factor given by:

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

Where Pave is the average of the maximum precipitation correspondingto a specific duration.
In utilizing Gumbel's distribution, the arithmetic average inEq. (1) is used:

$$P_{ave} = \frac{1}{n}\sum_{i=1}^{n} P_i$$

Where Pi is the individual extreme value of rainfall and n isthe number of events or years of record. The standard devotion is calculated by Eq. (4) computed using the following
Relation:

$$S = [\frac{1}{n-1}\sum_{i=1}^{n}(P_i - P_{ave})^2]^{1/2}$$

Where S is the standard deviation of P data. The frequencyfactor (K), which is a function of the return period and samplesize, when multiplied by the standard deviation gives the
Departure of a desired return period rainfall from the average.Then the rainfall intensity, I (in mm/h) for return period T is Obtained from:

$$I_t = \frac{P_t}{T_d}$$

Where Td is duration in hours. The frequency of the rainfall is usually defined by referenceto the annual maximum series, which consists of the largestvalues observed in each year. An alternative data format for rainfall frequency studies is that 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 (Borga, Vezzani and Fontana, 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, 1440 min) wereComputed. Tables 1 and 2 show the computed frequency precipitation (PT) values and intensities (IT) for different

## VI. DEVELOPING OF IDF CURVES FROM DAILY/24 HOURS RAINFALL DATA

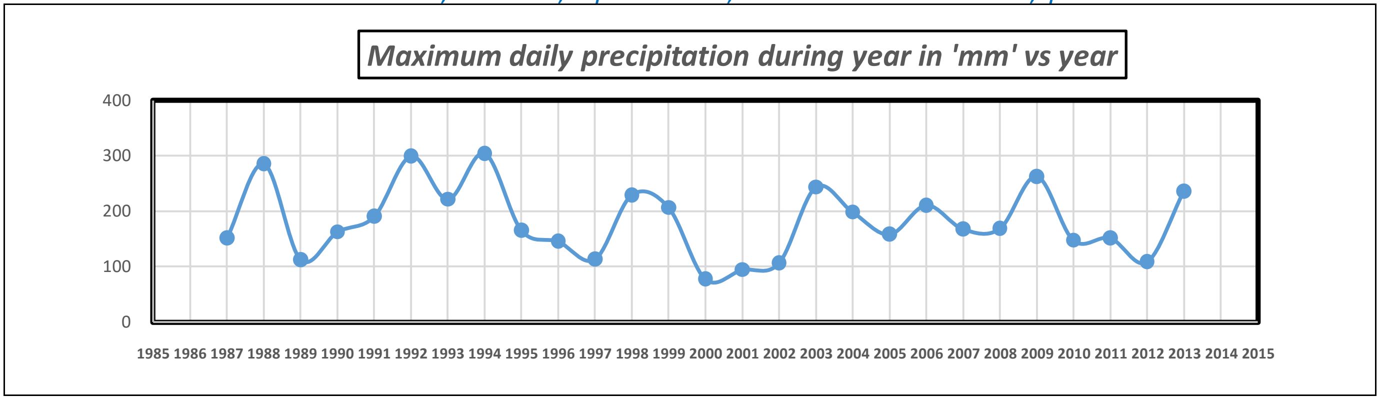
Daily rainfall data collected from SWDC (state water data center), Gandhinagar for 28 years

***TABLE-1: Yearly Max Depth mm***

| *Year* | *Maximum daily precipitation during year in 'mm'* |
|---|---|
| *1985* | *165* |
| *1986* | *93* |
| *1987* | *152* |
| *1988* | *286* |
| *1989* | *113* |
| *1990* | *163* |
| *1991* | *191* |
| *1992* | *300* |
| *1993* | *222* |
| *1994* | *305* |
| *1995* | *166* |
| *1996* | *145.8* |
| *1997* | *114* |
| *1998* | *230* |
| *1999* | *207* |
| *2000* | *77.8* |
| *2001* | *94.6* |
| *2002* | *107* |
| *2003* | *244* |
| *2004* | *199* |
| *2005* | *158.6* |
| *2006* | *211.4* |
| *2007* | *168.2* |
| *2008* | *169.2* |
| *2009* | *263.6* |
| *2010* | *148* |
| *2011* | *152* |
| *2012* | *109* |
| *2013* | *237* |




Reduced each of the maximum 24 hours depth series to 5min, 10min, 15min,20min, from reduction formula by IDM given below:

$$P_{t=P_{24}}(\frac{t}{24})\text{^}1/3$$

$P_t$=Required precipitation depth for t hours in mm,$P_{24}$=Daily precipitation in mm, t=time duration in hours for which the rainfall depth is required

| $p_{t}=p_{24}(\frac{t}{24})^{\wedge 1}/_{3}$ | | | | | | | | | | (Pi-Pavg)^2 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sr. no | Year | daily precipitation during year in 'mm' | 5min(0.083 hr) | 10min(0.166hr) | 20min(0.333hr) | 30min(0.5 hr) | 40min (0.66 hr) | 50min (0.833 hr) | 60min(1hr) | 5min(0.083 hr) | 10min(0.166hr) | 20min(0.333hr) | 30min(0.5 hr) | 40min(0.66hr) | 50min(0.833hr) | 60min(1hr) |
| 1 | 1985 | 165 | 25.43 | 31.96 | 40.22 | 45.99 | 50.40 | 54.43 | 57.81 | 4.67 | 7.38 | 11.71 | 15.28 | 18.37 | 21.45 | 24.19 |
| 2 | 1986 | 93 | 14.33 | 18.02 | 22.67 | 25.92 | 28.41 | 30.68 | 32.58 | 175.77 | 277.70 | 439.81 | 574.93 | 690.67 | 805.54 | 908.74 |
| 3 | 1987 | 152 | 23.42 | 29.44 | 37.05 | 42.37 | 46.43 | 50.14 | 53.26 | 17.35 | 27.41 | 43.44 | 56.74 | 68.18 | 79.56 | 89.74 |
| 4 | 1988 | 286 | 44.07 | 55.40 | 69.71 | 79.72 | 87.37 | 94.34 | 100.21 | 271.75 | 429.44 | 679.71 | 889.11 | 1067.77 | 1244.88 | 1404.50 |
| 5 | 1989 | 113 | 17.41 | 21.89 | 27.54 | 31.50 | 34.52 | 37.28 | 39.59 | 103.55 | 163.59 | 259.11 | 338.67 | 406.87 | 474.57 | 535.36 |
| 6 | 1990 | 163 | 25.12 | 31.58 | 39.73 | 45.43 | 49.79 | 53.77 | 57.11 | 6.10 | 9.64 | 15.28 | 19.95 | 23.98 | 28.00 | 31.58 |
| 7 | 1991 | 191 | 29.43 | 37.00 | 46.56 | 53.24 | 58.35 | 63.01 | 66.92 | 3.40 | 5.38 | 8.50 | 11.14 | 13.37 | 15.56 | 17.57 |
| 8 | 1992 | 300 | 46.23 | 58.11 | 73.12 | 83.62 | 91.64 | 98.96 | 105.11 | 347.54 | 549.19 | 869.29 | 1137.06 | 1365.55 | 1592.10 | 1796.22 |
| 9 | 1993 | 222 | 34.21 | 43.00 | 54.11 | 61.88 | 67.82 | 73.23 | 77.78 | 43.85 | 69.31 | 109.65 | 143.50 | 172.29 | 200.82 | 226.59 |
| 10 | 1994 | 305 | 47.00 | 59.08 | 74.34 | 85.01 | 93.17 | 100.61 | 106.86 | 376.87 | 595.53 | 942.64 | 1232.99 | 1480.77 | 1726.44 | 1947.78 |
| 11 | 1995 | 166 | 25.58 | 32.16 | 40.46 | 46.27 | 50.71 | 54.76 | 58.16 | 4.03 | 6.37 | 10.10 | 13.18 | 15.85 | 18.50 | 20.87 |
| 12 | 1996 | 145.8 | 22.47 | 28.24 | 35.54 | 40.64 | 44.54 | 48.10 | 51.08 | 26.22 | 41.42 | 65.64 | 85.76 | 103.05 | 120.23 | 135.62 |
| 13 | 1997 | 114 | 17.57 | 22.08 | 27.79 | 31.78 | 34.82 | 37.61 | 39.94 | 100.43 | 158.67 | 251.32 | 328.49 | 394.64 | 460.31 | 519.27 |
| 14 | 1998 | 230 | 35.44 | 44.55 | 56.06 | 64.11 | 70.26 | 75.87 | 80.59 | 61.70 | 97.51 | 154.29 | 201.89 | 242.42 | 282.58 | 318.83 |
| 15 | 1999 | 207 | 31.90 | 40.10 | 50.46 | 57.70 | 63.23 | 68.28 | 72.53 | 18.58 | 29.37 | 46.45 | 60.81 | 73.00 | 85.07 | 95.98 |
| 16 | 2000 | 77.8 | 11.99 | 15.07 | 18.96 | 21.69 | 23.77 | 25.66 | 27.26 | 243.37 | 384.51 | 608.93 | 796.06 | 956.28 | 1115.30 | 1258.19 |
| 17 | 2001 | 94.6 | 14.58 | 18.33 | 23.06 | 26.37 | 28.90 | 31.21 | 33.15 | 169.30 | 267.47 | 423.60 | 553.74 | 665.22 | 775.86 | 875.26 |
| 18 | 2002 | 107 | 16.49 | 20.73 | 26.08 | 29.82 | 32.69 | 35.30 | 37.49 | 123.22 | 194.67 | 308.33 | 403.02 | 484.17 | 564.72 | 637.06 |
| 19 | 2003 | 244 | 37.60 | 47.27 | 59.47 | 68.01 | 74.54 | 80.49 | 85.49 | 100.25 | 158.43 | 250.71 | 328.01 | 393.89 | 459.17 | 518.06 |
| 20 | 2004 | 199 | 30.67 | 38.55 | 48.51 | 55.47 | 60.79 | 65.64 | 69.72 | 9.47 | 14.97 | 23.67 | 31.00 | 37.21 | 43.35 | 48.92 |
| 21 | 2005 | 158.6 | 24.44 | 30.72 | 38.66 | 44.21 | 48.45 | 52.32 | 55.57 | 9.91 | 15.65 | 24.82 | 32.41 | 38.95 | 45.46 | 51.28 |
| 22 | 2006 | 211.4 | 32.58 | 40.95 | 51.53 | 58.92 | 64.58 | 69.73 | 74.07 | 24.89 | 39.33 | 62.22 | 81.44 | 97.77 | 113.95 | 128.57 |
| 23 | 2007 | 168.2 | 25.92 | 32.58 | 41.00 | 46.88 | 51.38 | 55.48 | 58.93 | 2.79 | 4.40 | 6.98 | 9.10 | 10.95 | 12.79 | 14.42 |
| 24 | 2008 | 169.2 | 26.08 | 32.78 | 41.24 | 47.16 | 51.69 | 55.81 | 59.28 | 2.29 | 3.62 | 5.75 | 7.50 | 9.02 | 10.54 | 11.88 |
| 25 | 2009 | 263.6 | 40.62 | 51.06 | 64.25 | 73.47 | 80.52 | 86.95 | 92.36 | 169.86 | 268.42 | 424.83 | 555.75 | 667.39 | 778.06 | 877.83 |
| 26 | 2010 | 148 | 22.81 | 28.67 | 36.07 | 41.25 | 45.21 | 48.82 | 51.86 | 22.87 | 36.12 | 57.24 | 74.78 | 89.86 | 104.84 | 118.26 |
| 27 | 2011 | 152 | 23.42 | 29.44 | 37.05 | 42.37 | 46.43 | 50.14 | 53.26 | 17.35 | 27.41 | 43.44 | 56.74 | 68.18 | 79.56 | 89.74 |
| 28 | 2012 | 109 | 16.80 | 21.12 | 26.57 | 30.38 | 33.30 | 35.96 | 38.19 | 116.47 | 184.01 | 291.44 | 380.95 | 457.66 | 533.80 | 602.18 |
| 29 | 2013 | 237 | 36.52 | 45.91 | 57.77 | 66.06 | 72.40 | 78.18 | 83.04 | 79.81 | 126.13 | 199.59 | 261.15 | 313.58 | 365.55 | 412.43 |
| | | **Average** | **27.59** | **34.68** | **43.64** | **49.90** | **54.69** | **59.06** | **62.73** | **2653.68** | **4193.03** | **6638.50** | **8681.14** | **10426.91** | **12158.56** | **13716.92** |
| | | **S** | | | | | | | | **9.74** | **12.24** | **15.40** | **17.61** | **19.30** | **20.84** | **22.13** |
| | | k2 | -0.16 | -0.164 | -0.16 | -0.16 | -0.16 | -0.164 | -0.164 | | | | | | | |
| | | pt | 26 | 32.673 | 41.11 | 47 | 51.5 | 55.64 | 59.1001128 | | | | | | | |
| | | k5 | 0.72 | 0.719 | 0.719 | 0.72 | 0.72 | 0.719 | 0.719 | | | | | | | |
| | | PT | 34.6 | 43.482 | 54.71 | 62.6 | 68.6 | 74.04 | 78.6451728 | | | | | | | |

Determined mean and standard deviation of each series of 5min, 10min, 15min, 20min …..60min.rainfall depth for each min is calculating by Gumbel extreme event formula for given return period.
Converted the depth into intensity of rainfall for 2 year return period

| TIME DURATION | INENSITY |
|---|---|
| | 2 YEAR |
| 5min(0.083hr) | 313.1738 |
| 10min(0.166hr) | 196.8258 |
| 20min(0.333hr) | 123.4678 |
| 30min(0.5hr) | 94.02458 |
| 40min(0.66hr) | 78.06852 |
| 50min(0.833hr) | 66.79774 |
| 60min(1hr) | 59.10011 |

Plotting of the intensity duration curveon log -log graph paper to determine the value of a and n constants

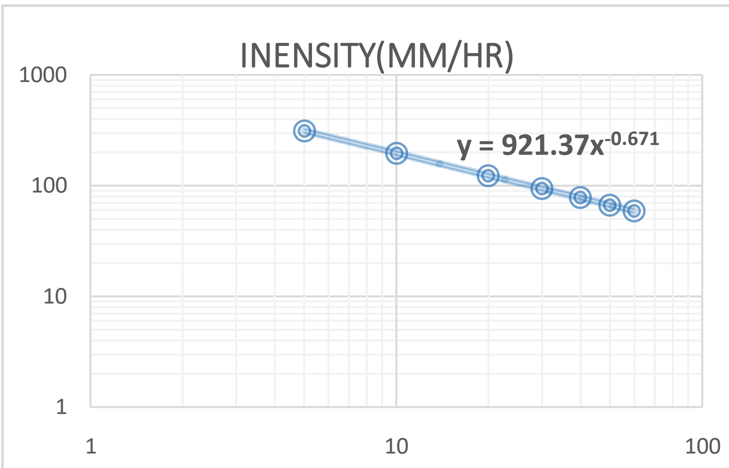
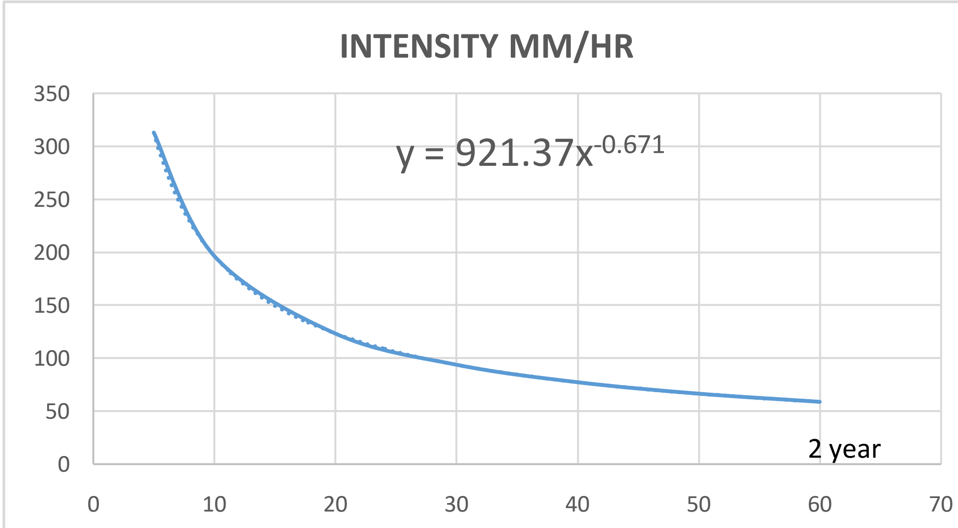



***Fig. 4: log-log graph of intensity vs duration for 2year***

Calculated rainfall intensity by $i = a/t^n$ for 5min 10min 20min…..60min for 2 year return period

| TIME DURATION (MIN) | A | n | INTENSITY MM/HR |
|---|---|---|---|
| 5 | 921 | 0.671 | 312.91 |
| 10 | 921 | 0.671 | 196.53 |
| 20 | 921 | 0.671 | 123.44 |
| 30 | 921 | 0.671 | 94.03 |
| 40 | 921 | 0.671 | 77.53 |
| 50 | 921 | 0.671 | 66.75 |
| 60 | 921 | 0.671 | 59.06 |

Plotof IDF curve for 2year return period




## VII. Plot of IDF curve for 5 year return period

Converted the depth into intensity of rainfall for 5 year return period
Plotting of the intensity duration curve on log -log graph paper to determine the value of a and n constants

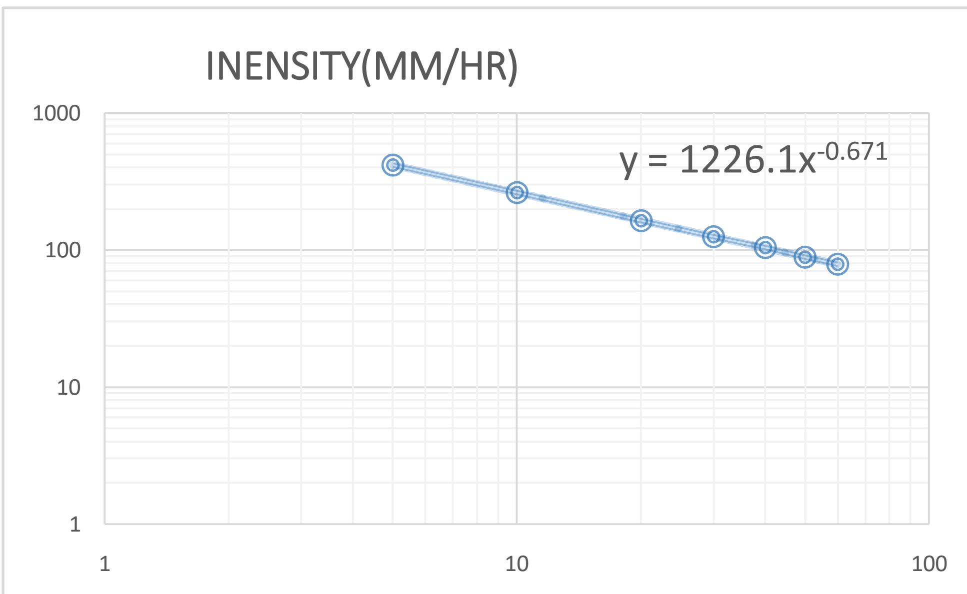



***Fig. 4: log-log graph of intensity vs duration for 5year***

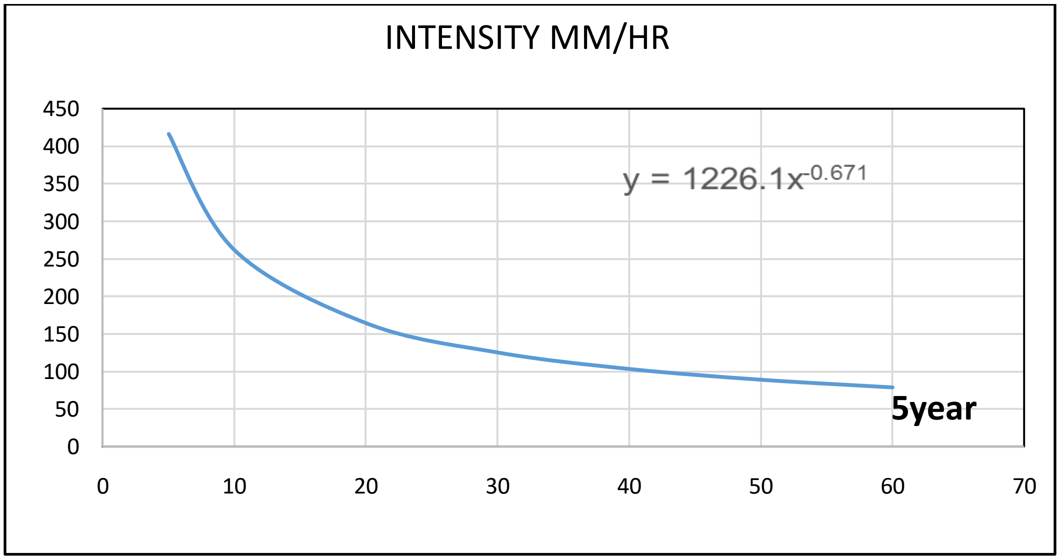
Calculated rainfall intensity by $i = a/t^n$ for 5min 10min 20min…..60min for 5 year return period

| TIME DURATION (MIN) | A | n | INTENSITY MM/HR |
|---|---|---|---|
| 5 | 1226 | 0.671 | 416.41 |
| 10 | 1226 | 0.671 | 261.53 |
| 20 | 1226 | 0.671 | 164.26 |
| 30 | 1226 | 0.671 | 125.13 |
| 40 | 1226 | 0.671 | 103.17 |

| | | | |
|---|---|---|---|
| 50 | 1226 | 0.671 | 88.82 |
| 60 | 1226 | 0.671 | 78.59 |

Plot of IDF curve for 2year return period




## VIII. Concluding Remarks

*IDF is a tool for planning, design and operation of water Resources projects such as storm water drainage system. With the help of this tool (IDF) relationship of rainfall has been established at central zone of Surat city from daily/24 hours rainfall data using Gumbel distribution method. These relationships are useful in the design of urban drainage works, e.g. storm sewers, culverts and other hydraulic structures.*

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