

# A STUDY ON INTENSITY OF RAINFALL IN URBAN BANGALORE AREAS

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**Abstract:** The scope of this study was to develop IDF curve and to derive IDF empirical formulae for the 17 stations considered and to generate isohyetal and isopluvial maps for the study area – Urban Bangalore, so that the estimation of rainfall depth and intensity for any standard duration and return period in the study area considered can be obtained with minimum effort. Also to understand the areal distribution of rainfall with respect to duration, DAD curves were plotted. Daily rainfall data for 40 years i.e., 1972 to 2011 was collected for 17 stations in and around urban Bangalore from Indian Meteorological Department (IMD), Government of India. The missing rainfall values were calculated using the normal ratio method and the IMD empirical reduction formula was used to estimate the short duration rainfall. Using different probability distributions the rainfall depth was found out for different durations and standard return period, and subsequently the rainfall intensity was found out for calculated rainfall depths. The Chi-Square goodness of fit was used to arrive at the best statistical distribution among Normal, Log-Normal, Gumbel, Pearson, and Log-Pearson. IDF curve was plotted for short duration rainfall of 5, 10, 15, 30, 60, 120, 720 and 1440 minutes for a return period of 2, 3, 5, 10, 25, 50, 100 and 200 years for station with peak rainfall values. The use of IDF curves becomes cumbersome and hence a generalized empirical relationship was developed through method of least squares. Then isohyetal and isopluvial maps were generated for the study area, so that the rainfall depth and intensity for any location in the study area for a particular duration and return period can be found out easily. To analyse the spatial rainfall distribution better DAD curves were also plotted.

**Key Words:** IDF Curve, DAD Curve, Chi Square, isohyetal and isopluvial maps

## 1. INTRODUCTION

The scope of this study was to predict rainfall depth and intensity for 17 stations using the data of 1972 to 2011 spread in and around urban Bangalore by using the various distributions like normal, log-normal, Gumbel, Pearson and Log-Pearson distributions and select the best distribution using the Chi-square test. For the distribution giving the best results, short duration IDF curves and equations were derived for the station having maximum rainfall depth for various short durations and standard

return periods. To understand the effect of rainfall spatially, isohyetal and isopluvial maps were generated. By using these maps the total rainfall depth and intensity in a particular area, for different durations and return period can be determined easily. Further the Depth-Area-Duration curves were also plotted to know the areal spread of rainfall within the study area. Short-term, high-intensity rainfall that occurs in inland areas with poor drainage often produces urban flash floods. Densely populated areas have a high risk for flash floods. The construction of buildings, highways, driveways, and parking lots increases runoff by reducing the amount of rain absorbed by the ground. During periods of heavy rainfall, storm drains may become overwhelmed and flood roads and buildings. Low spots, such as underpasses, underground parking garages, and basements are especially vulnerable to flash floods. Subway stations and rail lines are also vulnerable to flash floods. (NHMP, 2009). Rainfall is an important component in the hydrologic cycle. Quantification of rainfall is needed for planning and designing of various water resource projects. Quantification of rainfall is generally done using isopluvial maps and intensity-duration-frequency (IDF) curves (Chow et al., 1988). The IDF relationship is a mathematical relationship between the rainfall intensity  $i$ , the duration  $d$ , and the return period  $T$  (the annual frequency of exceedance). (Eman, 2011). The IDF-relationships give an idea about the frequency or return period of a mean rainfall intensity or rainfall volume that can be expected within a certain period, i.e. the storm duration. In this sense the storm duration is an artificial parameter that can comprise any part of a rainfall event. (IDF-CURVE, 2012). Heavy rains accompanied by gusty winds and lightning lashed Bangalore on 1st June 2013, crippling normal life, inundating low-laying areas and throwing vehicular traffic out of gear across the city. "The city and surrounding areas received about 80-90mm rain in about three hours due to low pressure and surface winds across the region," a senior meteorological official told IANS (IANS,2013).According to the Indian Meteorological Department, rainfall in Uttarakhand during the week of 20<sup>th</sup> to 26<sup>th</sup> June 2013 has been in excess by 37 per cent of normal rainfall. During this period, the state received 73.3centimeters of rain while the normal rainfall is usually 53.6centimeters. The heavy rains in the region have led to extensive flooding, landslides and destruction to property and lives. (Unitedway,2013). Bangalore has emerged as industrial and commercial centre of India in recent times. Bangalore city in India has been subjected to intense urban growth and has led to sprawl. Due to this rapid

urbanization as many as 70 per cent of the 262 water tanks in Bangalore have disappeared; drains are choked with garbage leading to surface flooding. Rapidly increasing human population coupled with the increased urban concentration has escalated both the frequency and severity of disasters like floods, etc. With the tropical climate and unstable land forms, coupled with land use changes, unplanned growth proliferation non-engineered constructions make the disaster-prone areas more vulnerable. (Ramachandra and Mujumdar, 2006). Some of the impacts due to urban development include: reclamation of lakes, stream widening and bank erosion, stream down cutting, changes in the channel bed due to sedimentation, increase in the floodplain elevation. Urban floods differ from those in natural basins in the shape of flood hydrographs, peak magnitudes relative to the contributing area, and times of occurrence during the year. The imperviousness of urban areas along with the greater hydraulic efficiency of urban conveyance elements not cause increased peak stream flows but also more rapid stream response (WHGM, 2005). Summer floods resulting from high intensity thunderstorms are more common in urban areas. Infiltration and evapo-transpiration are much reduced at this time of the year under developed conditions. (Ramachandra, et al., 2006). Application of IDF curve, Isohyetal Maps, Isopluvial Maps and DAD curves in Water Resources Engineering. The rainfall IDF relationship in one of the most basic and important tools in water resource engineering to assess the risk and vulnerability of water resource structure as well as for planning, design and operation. Short-duration rainfall intensity statistics is often used for sizing and design of hydrological structures to structurally accommodate and carry water runoff from small catchments. Building roof rain loads and drainage systems, road culverts, and municipal storm sewer systems are examples where rainfall intensity is important. (Rashid et al, 2012) The intensities and the total amount of rainfall during flash floods are beyond any normal extreme values statistical computation. Flash floods are unexpected localized phenomena of a very short duration. Therefore, a very good estimation of the maximum probable rainfall is necessary for any urban drainage project. This value is generally the outcome of an IDF curve analysis. The statistical analysis of complete or partial annual extreme series, and the necessary probability curve fitting, gives for such extreme values important return periods. (Vafiadis, 2006). The isohyetal maps and isopluvial maps are helpful in estimating the rainfall depth and intensity for any location in the study area considered more easily and faster without having to go through the rigor of fitting probability distribution models all over again. These are very useful for design and planning purposes. (Olofintoye et al, 2009). In designing structures for water resources, one has to know the areal spread of rainfall within watershed. However, it is often required to know the amount of high rainfall that may be expected over the

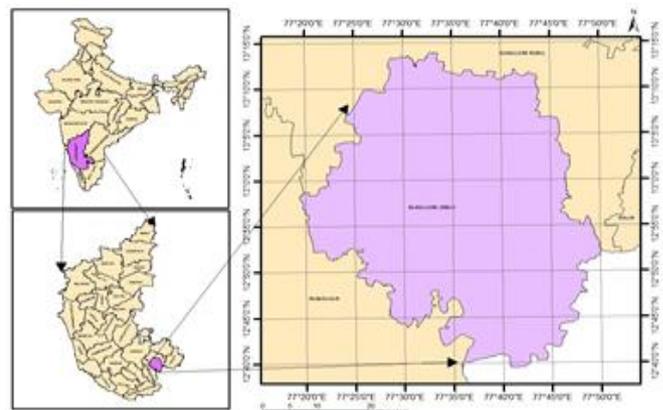
catchment. It may be observed that usually a storm event would start with a heavy downpour and may gradually reduce as time passes. Hence, the rainfall depth is not proportional to the time duration of rainfall observation. Similarly, rainfall over a small area may be more or less uniform. But if the area is large, then due to the variation of rain falling in different parts, the average rainfall would be less than that recorded over a small portion below the high rain fall occurring within the area. Due to these facts, a Depth-Area-Duration (DAD) analysis is carried out based on records of several storms on an area and, the maximum areal precipitation for different durations corresponding to different areal extents. (NPTEL-IITM, 2013).

## 2. OBJECTIVES

- To find the missing rainfall values.
- To estimate the depth and intensity of rainfall for standard short durations and return periods using various distributions.
- Determination of the best distribution using Chi-square goodness of fit test.
- Develop short duration IDF curve for the 17 stations.
- Derive IDF empirical equation for each station.
- Generate isohyetal and isopluvial maps.
- Develop the Depth-Area-Duration curve.

## 3. METHODOLOGY

Figure 1 gives the methodology to the development of IDF curve, short duration empirical formula, isohyetal map, isopluvial map and the construction of DAD curves.



**Figure 2:** Location map of the Study area: Urban Bangalore

### Study Area

Bangalore district is situated in the heart of the South-Deccan plateau in peninsular India to the South-Eastern corner of Karnataka State between the latitudinal parallels of 12° 39' N & 13° 14' N and longitudinal meridians of 77°

19° E & 77° 50' E at an average elevation of about 900 meters covering an area of about 2,188 km<sup>2</sup> as shown in Figure 2. The majority of the city of Bangalore lies in the Bangalore Urban district of Karnataka and the surrounding rural areas are a part of the Bangalore Rural district. (IISc, 2012).

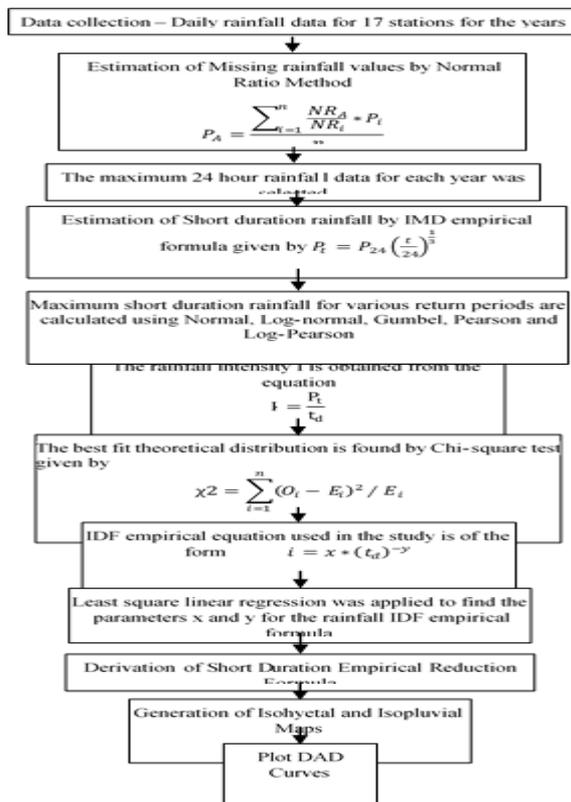


Figure 1: Methodology for development of isohyetal, isopluvial maps and DAD curves

### 3.1 Estimation of Short Duration Rainfall

The short duration rainfalls were calculated for 17 stations for the years 1972 to 2011, using the annual maximum 24 hour rainfall data. The short duration rainfall is estimated using equation 2.2.

### 3.2 Probability Distribution for the Estimation of Maximum Rainfall Intensity for Various Return Periods

In this study the maximum short duration rainfall depth and intensity for various return periods were estimated using different theoretical distribution functions like Normal, Two-Parameter Lognormal, Pearson Type III, Log Pearson Type III, Extreme Value Type I (Gumbel). The estimation was done for all 17 stations with 40 years data rainfall data.

### 3.3 Chi-Square Test

In order to determine the best-fit distribution i.e., to check in which probability distributions, the observed value and the calculated values showed the least deviations, the values obtained for each station from different probability distributions were subjected to chi-square test. The values having least deviations from the observed values are considered for the development of IDF curve and for the derivation of IDF empirical formula for each station. The rainfall depth and intensity obtained for each station is used for the development of isohyetal and isopluvial maps respectively.

### 3.4 Generation of IDF Curve

The best probability distribution from Chi-square test is used for the generation of IDF curve. IDF curves are generated for each station with duration on the abscissa and rainfall intensity on the ordinate, for standard return periods. IDF curves are used to find the rainfall intensity that is expected in a particular duration for a particular return period.

### 3.5 Derivation of Empirical Formula

The use of IDF curve becomes cumbersome. Hence empirical formulae can be developed for each station for standard duration and return periods. The empirical formula considered in this study is of the form

$$i = x * (t_d)^{-y}$$

Taking logarithms on both sides transforms the above equation into a linear form.

$$\log i = \log x + (-y) \log t_d$$

The best value of x and y are those for which the sum of the squared deviations is minimum.

i.e.,  $S = \sum [\log i - \{ \log x + (-y) \log t_d \}]^2$  should be minimum.

Partial differentiation of S with respect to a and b yields,

$$\sum \log i = n \log x - y \sum \log t_d$$

$$\sum \log i \cdot \log t_d = \log x \cdot \sum \log t_d - y \sum (\log t_d)^2$$

Where n is the number of observations and all the summations are over all the observed values. After obtaining the required summations, the above equations may be solved to provide the best values of x and y.

### 3.6 Development of Isohyetal Maps

In this study isohyetal maps were constructed using software (Surfer 9). Surfer is a contouring and 3D surface mapping program that runs under Microsoft Windows. Surfer version 9 is a product of Golden Software, Inc (www.goldensoftware.com) (Olofintoye, 2009). The isohyetal maps were generated for urban Bangalore

considering 17 stations with 40 years data, for various selected return periods such as 25, 50, 100 and 200 years based on design requirements. Considering lower return periods might not be appropriate considering the fact that, generally the life of a structure is more than 25 years. From the isohyetal maps, the rainfall depth for any location (longitude and latitude) in Urban Bangalore may be estimated more easily and faster without having to go through the rigor of fitting probability distribution models all over again. These are very useful for design and planning purposes.

### 3.7 Development of Isopleth Maps

The IDF curve and IDF empirical equations helps in the determination of rainfall intensity for a point location. Multiple graphs and formulae have to be used to find get an idea of the spatial distribution of rainfall intensity from an IDF curve and IDF empirical equations. Analysis of rainfall data requires handling of large volumes of data and repeated computation of a number of statistical parameters for distribution fitting and estimation of expected rainfall at different return periods. The use of rainfall frequency atlases may considerably reduce the computational tedium involved in the frequency analysis of rainfall to a greater extent, maps have been prepared. These are extremely useful for planning purposes (Edwards et al, 1983). In this study isopleth maps were constructed using software (Surfer 9). The isopleth maps were generated for urban Bangalore considering 17 stations with 40 years data, for various selected return periods such as 25, 50, 100 and 200 years based on design requirements. Considering lower return periods might not be appropriate considering the fact that, generally the life of a structure is more than 25 years.

### 3.8 Construction of DAD curves

From the data of rainfall in different stations of the study area, the isohyetal map is prepared. Then the areas between the isohyets are extracted using ArcGIS software (Version 9.3). Next the net incremental areas between two isohyets are calculated. Then the average depth of rainfall between the two isohyets is the average of the two. The rainfall volume is then calculated by multiplying net incremental area by average rainfall. Thus the cumulative rainfall volume is determined. This cumulative volume is divided by the area enclosed between two isohyets to give the average rainfall in that area. DAD curves are obtained by plotting the obtained average rainfall depth against areas.

## 4. RESULTS AND DISCUSSIONS

### 4.1 Missing rainfall values

The daily 24 hour rainfall data for the years 1972 to 2011 was collected from IMD for 17 stations located in and around urban Bangalore. The 17 stations are Anekal, Attibele, Jigani, Sarjapura, Bangalore city, Bangalore city railway, Hesaraghatta, Hebbal, Kammagondahalli, Soldevanhally, Yelahanka, GKVK Campus, Chickjala, Bangalore Airport, Kengeri, Krishnarajapura and Tippagondanahalli. The stations considered had more than 75% of available raw data. The rest of the values had to be calculated. The missing rainfall values for the years 1972 to 2011 were calculated using normal ratio method, which is one of the most widely, used methods. The annual maximum 24 hour rainfall values were then extracted. The summary of statistics for peak daily rainfall is presented in table 1. The annual maximum 24 hour rainfall data extracted for 17 stations for the years 1972 to 2011 were used for the calculation of short duration rainfall using the IMD empirical reduction formula given in equation 3.2. Short duration rainfall depths were calculated for durations of 5, 10, 15, 30, 60, 120, 720 and 1440 minutes.

Table.1 statistics for peak daily rainfall

Stations	Maximum Rainfall (mm)	Minimum Rainfall (mm)	Mean (mm)	Standard Deviation (mm)
Anekal	173.00	40.60	76.70	29.47
Attibele	163.00	5.40	73.55	30.10
Jigani	216.00	12.00	87.07	38.42
Sarjapur	161.01	17.40	67.81	25.62
Bangalore City	178.90	38.20	89.02	31.53
Bangalore City Railway	163.00	42.00	93.84	31.80
Hesaraghatta	154.00	28.00	74.99	26.51
Hebbal	203.20	20.00	83.55	36.71
Kammagondahalli	177.80	25.50	77.15	27.92
Soldevanhalli	900.50	20.00	87.41	135.00
Yelahanka	256.00	24.20	75.10	40.72
GKVK Campus	340.70	45.00	101.65	49.12
Chickjala	200.60	40.00	80.63	30.14
Bangalore Airport	145.40	40.30	82.02	24.25

Kengeri	137.00	26.00	77.66	22.81
Krishnaraja pura	236.40	9.80	66.59	47.04
Tippagonda halli	395.84	35.36	69.88	55.09

The mean and standard deviations of the short duration rainfall depths were then calculated. These values were used in various probability distributions to find the rainfall depth and intensity. The mean and standard deviation extracted from short duration rainfall.

#### 4.2 Rainfall depth and intensity

The short duration rainfall depths were calculated for the years 1972 to 2011 from IMD empirical reduction formula. Then the mean and standard deviations of short durations of 5, 10, 15, 30, 60, 120, 720 and 1440 minutes were estimated. These estimated mean and standard deviations were used in Normal, Log-Normal, Gumbel, Pearson, and Log-Pearson probability distribution methods to determine the rainfall depths and intensity for standard return periods of 2, 3, 5, 10, 25, 50, 100 and 200 years for 17 stations. It was found that the rainfall depths increased with the increasing time duration. But the rainfall intensity decreased appreciably with increasing duration. These distributions were subjected to chi-square goodness of fit test to find the best distribution.

##### 4.2.1 Chi-square goodness of fit test

The rainfall depth and intensity for various short durations and standard return periods were found out using various probability distributions. These distributions were subjected to chi-square test to find the best distribution in which there is minimum deviation between the observed and the calculated value. It is found in the study that  $\chi^2$  values for all probability distribution function, is increasing with increase in the rainfall duration. It is noticed that the Log-normal and Normal distribution shows the least deviations from the observed value. Normal distribution can also be considered as it is close to Log-normal distribution. But study showed that Log- Normal probability distribution function give the best estimation of the distributed predicted rainfall data as it has the smallest  $\chi^2$  value compared to other distribution functions for the data collected for Urban Bangalore for the years 1972 to 2011. The other distributions are not consistent and show a huge deviation from the observed value.

##### 4.2.2 IDF curve

It is noted from the IDF curves of that as the duration increases, the rainfall intensity decreases or in other words, for shorter duration the rainfall intensity is high.

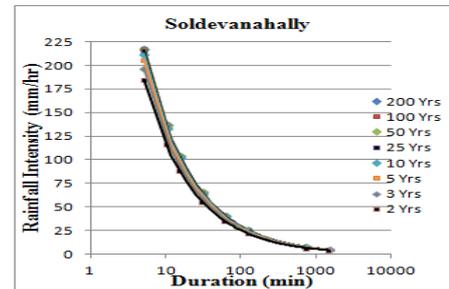


Fig.2. IDF curve for Soldevanahally

It was found from chi-square test that log-normal distribution gave the best results with minimum deviations from the observed values. Hence the IDF curve was plotted from log-normal values for each station considered.

#### 5. CONCLUSIONS

Bangalore has emerged as industrial and commercial centre of India in recent times. Bangalore city in India has been subjected to intense urban growth and has led to sprawl. Due to this rapid urbanization as many as 70 per cent of the 262 water tanks in Bangalore have disappeared; drains are choked with garbage leading to surface flooding. Rapidly increasing human population coupled with the increased urban concentration has escalated both the frequency and severity of disasters like floods, etc. Some of the impacts due to urban development include: reclamation of lakes, stream widening and bank erosion, stream down cutting, changes in the channel bed due to sedimentation, increase in the floodplain elevation. Urban flooding is not a new phenomenon. Increasingly, more and more cities and towns face waterlogged streets. Development and redevelopment of the district, by nature increases the amount of imperviousness in the surrounding environment. This increased imperviousness translates into loss of natural areas, more sources for pollution in runoff, and heightened flooding risks. In recent decades, storm water runoff has emerged as an issue of major concern. Storm water affects local waterways both in terms of the volume of runoff that is generated, and the nature of the pollutants that may be conveyed. Allowing storm water to infiltrate in urban residential areas is one of the major ways for urban floods.

#### 4.3 Scope for Future Work

This study is limited to the calculation of rainfall depth and intensity for selected duration and return periods for Urban Bangalore. This study can be improvised or made more realistic by considering the morphological information such as, stream segments, basin length, basin parameters, basin area, altitude, volume, slope, profiles of the land which indicates the nature of development of the

basin, land use / land cover, slope map, the changing weather conditions or long term climate cycles etc.

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