BILINGUAL PUBLISHING CO.
Pioneer of Global Academics Since 1984

**Journal of Environmental & Earth Sciences**
https://ojs.bilpublishing.com/index.php/jees

ARTICLE

# Projected Rainfall Intensity Duration Frequency Relationships under Climate Change: A Case Study of Thane City

**S. S. Pujari*  A. S. Wayal**

Veermata Jijabai Technological Institute, Civil and Environmental Engineering Department, Mumbai, Maharashtra, India

ARTICLE INFO

*Article history*
Received: 21 August 2022
Revised: 23 September 2022
Accepted: 30 September 2022
Published Online: 19 October 2022

*Keywords*:
Climate change
Rainfall analysis
Projected IDF relationships
IDF curves
Thane city

ABSTRACT

Climate change is the most important factor to increase in short-duration high-intensity rainfall and consequent flooding. Intensity-Duration-Frequency (IDF) curves are commonly used tools in Stormwater design, so a method to derive future IDF curves including climate change effects could be necessary for mainstreaming climate change information into storm water planning. The objective of the present study is to define a mechanism to reflect the effect of climate change on the projected rainfall IDF relationships. For this, the continuously observed hourly rainfall data from 1969 to 2018 were divided into five subgroups. Then the IDF curve of each subgroup is defined. The rainfall intensity for the next 30 years was then estimated using a linear regression model. The obtained result indicates that for the same duration and for the same return period, the rainfall intensity is likely to increase over time: 17% (2019-2028), 25% (2029-2038) and 32% (2039-2048). However, the findings presented in this paper will be useful for local authorities and decision makers in terms of improving stormwater design and future flood damage will be avoided.

## 1. Introduction

An increase in the occurrences of heavy rainfall events and high tide indicates the risk of flooding in many coastal cities. The annual economical expenditure on flooding is much higher than the other annual disasters [1]. Flooding in urban areas now become a major concern and poses a challenge to the urban planner [2]. The rainfall Intensity-Duration-Frequency (IDF) relationships are essential for stormwater design and planning [3]. Accurate and recent rainfall analysis is an important device for water-related system design [4]. The first step of hydraulic design in the stormwater drainage system is to construct IDF curve [5]. The rainfall IDF relationship gives information about location rainfall characteristics. The rainfall IDF relationships provide logic to find out the intensity of rainfall for a particular duration and return period [6]. The three essential

*Corresponding Author:
S. S. Pujari,
Veermata Jijabai Technological Institute, Civil and Environmental Engineering Department, Mumbai, Maharashtra, India;
*Email: sspujari_p18@ci.vjti.ac.in*

DOI: https://doi.org/10.30564/jees.v4i2.4995

rainfall depths, that is, $R_1^{10}$ (1 h, 10-year rainfall depth), $R_{24}^{10}$ (24 h, 10-year rainfall depth), and $R_1^{100}$ (1 h, 100-year rainfall depth) used to derive IDF formula for any United States location [7,8]. Ram Babu has studied rainfall data of 42 rain gauge stations all over India and developed IDF equations and nomographs [9]. Kothyari and Garde have studied rainfall data of 78 rain gauge stations all over India and developed IDF equation using rainfall depth $R_{24}^{2}$ (24 h, 2-year rainfall depth) [10]. The IDF curves for Abha region in Saudi Arabia were established using Gumbel, Log normal and Log Pearson Type III distribution frequency analysis techniques for different return periods [11].

Thane city situated near to creek and heavy rainfall coincides with high tide then the risk flooding increases. Therefore, to avoid flood risk proper knowledge of IDF curves is required. Zope has studied 40 years of rainfall data from Santacruz rain gauge station and developed IDF relationships by using Gumbel's method [12]. Further it is felt that, IDF curves need to be updated as per the change of climate effect for a given area [13].

The present paper aims to perform statistical analysis of rainfall data to define projected IDF relationships by using the linear regression model, which reflects the changing trend in rainfall intensity.

## 2. Study Area

Thane is a metropolitan city in Maharashtra, India. It is placed on the North-East of Salsette Island and shares a boundary connecting to Mumbai city (Figure 1). The city placed at 19° 10' 19" and 19° 14' 56" North and 72° 55' 50" and 73° 00' 32" East have an area of 127 $km^2$ [2,14]. The population of Thane city is 1890000 according to the 2011 census and ranked 15th most populated city in India.

The population of Thane city increases due to industrialization, urbanization and city connecting to Mumbai. Thane city has roadside drains and minor nallas (streams) discharging stormwater into major nallas or directly into creek. On 26th July 2005 in Thane created unpredictable situation due to extreme rainfall coinciding with the highest tide level [16]. Due to urbanization and city situated near to creek experiencing flood risk, especially at heavy rainfall, high tide. Now every year the trend of flooding in Thane city is increasing. The minor flooding problem is water entering the basement of few buildings for short duration and major problem is flooding the area for several days. It leads to relocation of population, damage to infrastructure services and risk of epidemics [16]. Hence, considering the city's importance and risk of flooding, knowledge of proper rainfall intensity is necessary.

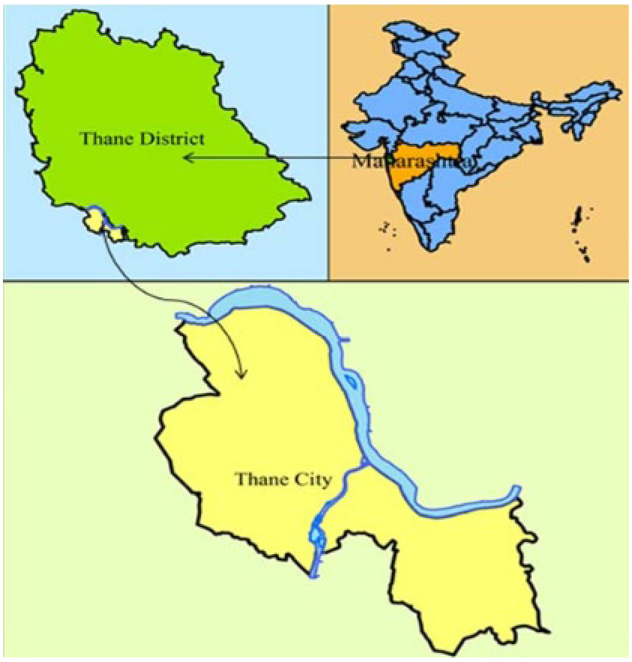


**Figure 1.** Location map of Thane City, India.

Source: [15].

## 3. Data Used in the Analysis

Collected continuously observed hourly rainfall data from 1969 to 2018 for Santacruz rain gauge station from India Meteorological Department (IMD). Thane Municipal Corporation (TMC) helped to collect rainfall data.

## 4. Methodology

Firstly, the IDF curve was constructed by Ram Babu's equation, Kothyari and Garde's equation and then Gumbel EV-I distribution equation by using hourly rainfall data from 1969 to 2018. Each IDF curve constructed was compared for a return period of 5 years return period and then an appropriate method for projection was selected based on the results of rainfall intensity and previous studies. Secondly, 50 years of hourly rainfall data were divided into 5 subgroups and IDF curves were developed for each subgroup according to the chosen method. After that, the projected rainfall intensity for different duration and different return periods was found for the next 30 years using linear regression model. The rainfall IDF relationships are found using the method described below.

### 4.1 IDF Curves by Ram Babu Equation

Ram Babu in 1979 studied the available data from 42 rain gauge stations across India and then after analyzing the rainfall data came up with the IDF formula and nomographs [9]. The general form of IDF equation written as,

$$I = \frac{KT^a}{(t+b)^n} \quad (1)$$

where, I is the rainfall intensity (cm/hr.), T is the return period (years), t is the storm duration (hours) and K, a, b & n are constants depending on geographical location developed for 42 rain gauge stations. Thane city area comes under western zone. The values of K, a, b and n are taken as 7.787, 0.2087, 0.5 and 0.8908 respectively for analysis of rainfall [17].

## 4.2 IDF Curves by Kothyari and Garde's Equation

Kothyari and Garde studied 80 rain gauge stations across India in 1992 with data available at that time and then provided an empirical equation [10]. The empirical equation developed for the Indian zones is as follows:

$$i_t^T = c\frac{T^{0.20}}{t^{0.71}}\left(R_{24}^2\right)^{0.33} \quad (2)$$

where, $i_t^T$=maximum rainfall intensity (mm/hr.) for T years return period and t hour duration, C=constant depends on Geographical zones of India proposed by them are given in Table 1 and $R_{24}^2$= depth of precipitation for 2 years returns period 24-hour duration (mm). From Figure 2, Thane city comes in western zone, the value of C taken as 8.3 for analysis of rainfall.

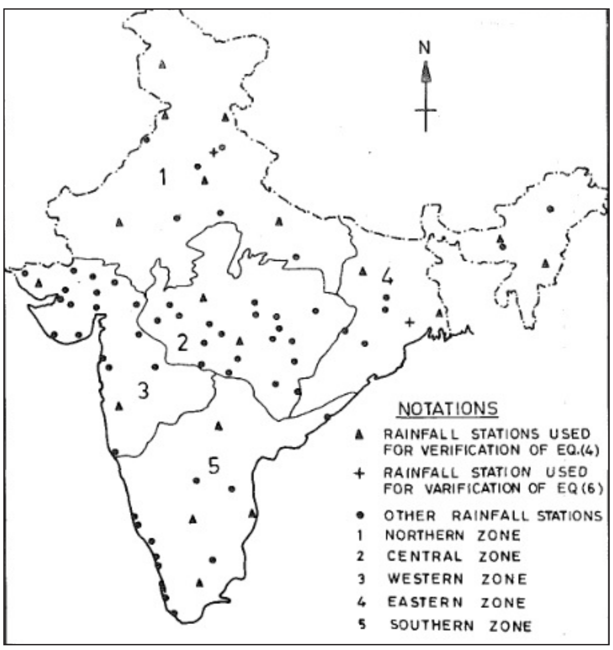


**Figure 2.** Location of rain gauge stations and zonal boundaries in India.

Source: [10].

**Table 1.** C values for geographical zones of India.

| Zones | Zones in Figure 1 | Value of C |
|---|---|---|
| North Zone | 1 | 8 |
| East Zone | 4 | 9.1 |
| Center Zone | 2 | 7.7 |
| West Zone | 3 | 8.3 |
| South Zone | 5 | 7.1 |

Source: [10]

## 4.3 IDF Curves by Gumbel Extreme Value Type-I Distribution (EV-I) Method

Gumbel's EV-I distribution method is mainly used for short duration rainfall data analysis [17]. Also, Gumbel's EV-I method is used for flood analysis. This method is comparatively simple and used to calculate maximum rainfall depth [11]. Zope studied rainfall data from 1969 to 2008 for the Santa Cruz rain gauge station and in 2012 developed a rainfall IDF relationship using Gumbel's EV-I method [12].

In this method, the hourly observed rainfall data were used to compute the maximum rainfall depth (X) and the statistical variables, (arithmetic mean and standard deviation) for each duration (1, 2, …., 24 hours) [11]. Frequency of precipitation $X_T$ (in mm) for each duration having the specified return period T (year) is given by Equation (4) as below [18].

$$x_T = \bar{x} + ks \quad (3)$$

where, $\bar{X}$ is the mean, S is the standard deviation and k is the Gumbel's Frequency factor for return period T.

Frequency factor is calculated for all the selected return periods based on selected distribution. Gumbel's frequency factor is given by the following equation:

$$k = \left(\frac{\sqrt{6}}{\pi}\right)\left\{0.577^2 + ln\left[1n\left(\frac{T}{T-1}\right)\right]\right\} \quad (4)$$

## 4.4 Linear Regression Method

Linear regression method is used for predicting future values based on previous values. This method is mostly used for climate prediction, business and many more [19]. The linear regression has the relationship between the dependent variable and another changing variable known as the independent variable. The linear regression is calculated by following equation [20].

$$Y = A + BX \quad (5)$$

Here, Y = Dependent variable;

X = Independent variable;

A, B = Regression parameters.

## 5. Results and Discussion

### 5.1 Comparisons of IDF Relationships

In the present study, some empirical relationships were used to derive IDF curves, especially for the Indian region by Indian researchers. From Equation (1), the rainfall intensity was determined for different durations and different return periods. Accordingly, the developed IDF curve by Ram Babu equation is shown in Figure 3. From Equation (2), the rainfall intensity is defined using the value of R (mean annual rainfall) for different durations and different return periods. The developed IDF curves by Kothyari & Garde's equation for the Santacruz rain gauge station are shown in Figure 4. From Equation (3), the rainfall intensity is determined for the different duration and for different return periods and developed IDF curves by Gumbel's EV-I method is shown in Figure 5. Similarly, comparing the IDF curves for 5-year return periods using different methods was shown in Figure 6. The results obtained indicate that the rainfall intensity for 1-hour duration is 55.23 mm/hr. according to Rambabu's equation while it is 64.8 mm/hr. according to Kothyari and Garde's equation and 74.8 mm based on the observed data by Gumbel's EV-I method. Hence, as time progresses more and more information is available and empirical relationships may change or used constant may change for the various regions. From above results, the rainfall intensities estimated by Gumbel's EV-I method are higher for the same duration and same return period than the Rambabu's and Kothyari & Garde's empirical equation. Goel and his associates concluded in 2007 that Gumbel's EV-I approach was most commonly utilized for analyzing short duration rainfall data [17]. Zope and his associates evaluated rainfall for the same Santacruz rain gauge station in 2012 and determined that the Gumbel EV-I approach would be suitable for analyzing short-duration rainfall data [12]. So, in present study Gumbel's EV-I method was selected for projected rainfall IDF relationships analysis.

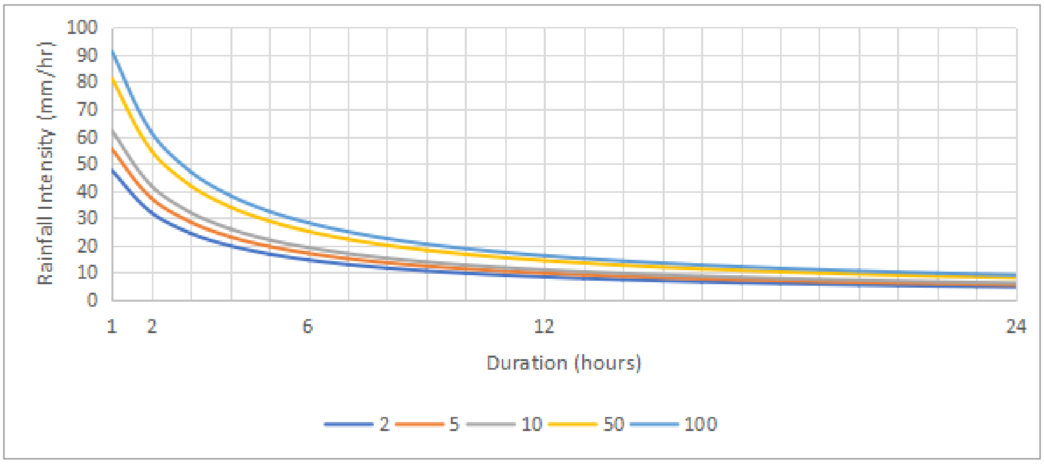


**Figure 3.** IDF curves by Ram Babu's equation.

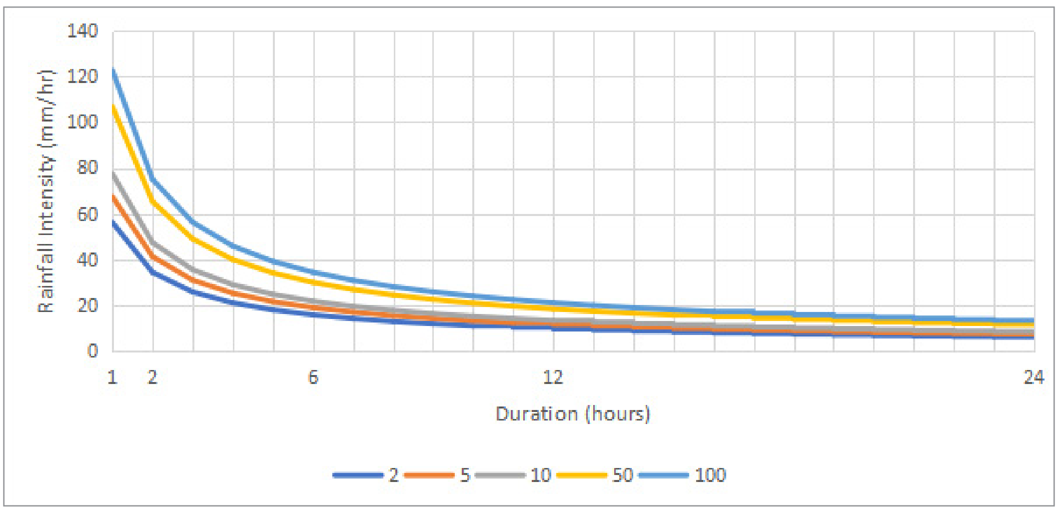


**Figure 4.** IDF curves by Kothyari & Garde's equation.

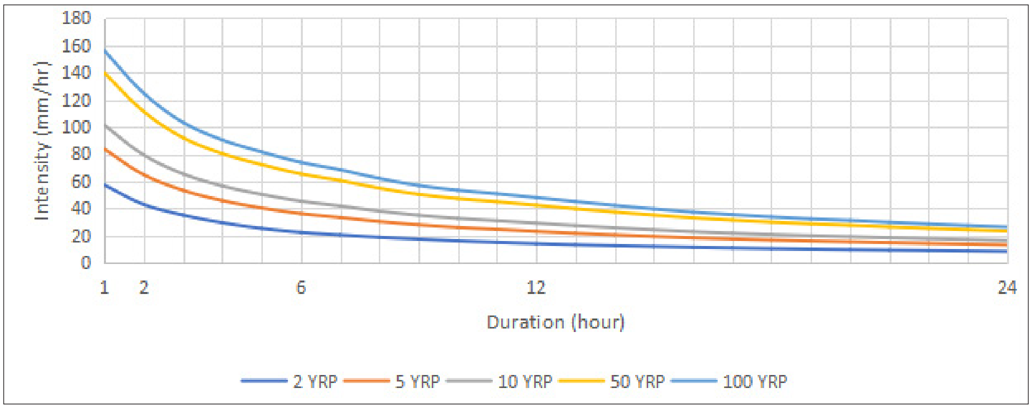


**Figure 5.** IDF curves by Gumbel's EV-I method.

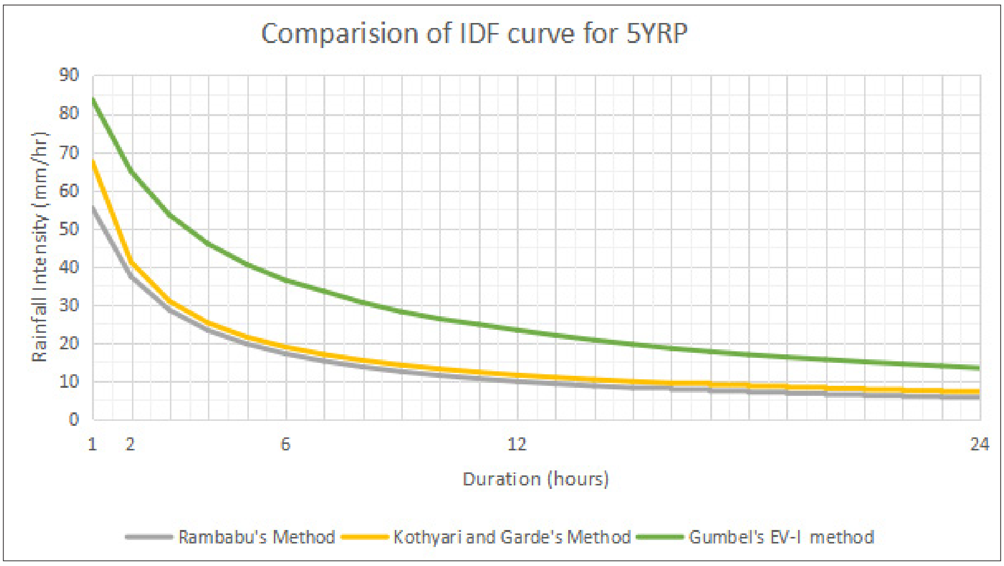


**Figure 6.** Comparisons IDF curves for 5 years return period.

## 5.2 Projecting IDF Relationships for Next 30 Years

Central Public Health & Environmental Engineering Organization (CPHEEO) guidelines recommend 30-year life expectancy for urban infrastructure [21]. Therefore, the estimated IDF relationship developed in the present study is limited to the next 30 years.

The updated IDF relationships must include in new storm water system and in existing storm water system as design criteria [13]. For rainfall intensity projection, 50 years of rainfall data were divided into 5 subgroups of 10-year periods and then the corresponding IDF relationship was developed for each sub-group period by Gumbel's EV-I method. The rainfall IDF relationships for each sub-group are shown in Table 2, Table 3, Table 4, Table 5 and Table 6 respectively.

The rainfall intensities for each sub-group period

**Table 2.** IDF relationships for sub-group period 1969 to 1978.

| Period | Duration (hour) | Rainfall Intensity (mm/hr.) | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 50 | 100 |
| 1969-1978 | 1 | 52.79 | 68.57 | 79.05 | 102.06 | 111.80 |
| | 2 | 37.69 | 48.43 | 55.56 | 71.22 | 77.85 |
| | 6 | 19.95 | 25.50 | 29.18 | 37.27 | 40.70 |
| | 12 | 13.57 | 18.05 | 21.02 | 27.54 | 30.31 |
| | 24 | 8.45 | 11.43 | 13.40 | 17.73 | 19.56 |

**Table 3.** IDF relationships for sub-group period 1979 to 1988.

| Period | Duration (hour) | Rainfall Intensity (mm/hr.) | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 50 | 100 |
| 1979-1988 | 1 | 48.38 | 57.48 | 63.52 | 76.78 | 82.40 |
| | 2 | 36.37 | 43.21 | 47.75 | 57.72 | 61.94 |
| | 6 | 19.53 | 22.38 | 24.27 | 28.42 | 30.18 |
| | 12 | 11.92 | 14.41 | 16.07 | 19.71 | 21.25 |
| | 24 | 7.75 | 9.18 | 10.13 | 12.21 | 13.09 |

**Table 4.** IDF relationships for sub-group period 1989 to 1998.

| Period | Duration (hour) | Rainfall Intensity (mm/hr.) | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 50 | 100 |
| 1989-1998 | 1 | 71.53 | 103.50 | 124.72 | 171.32 | 191.05 |
| | 2 | 60.43 | 88.34 | 106.86 | 147.53 | 164.76 |
| | 6 | 28.44 | 40.76 | 48.93 | 66.88 | 74.48 |
| | 12 | 15.71 | 22.24 | 26.57 | 36.08 | 40.11 |
| | 24 | 9.10 | 12.03 | 13.97 | 18.24 | 20.04 |

**Table 5.** IDF relationships for sub-group period 1999 to 2008.

| Period | Duration (hour) | Rainfall Intensity (mm/hr.) | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 50 | 100 |
| 1999-2008 | 1 | 64.91 | 103.40 | 128.95 | 185.05 | 208.81 |
| | 2 | 45.07 | 75.43 | 95.57 | 139.81 | 158.55 |
| | 6 | 27.28 | 52.00 | 68.40 | 104.42 | 119.67 |
| | 12 | 18.20 | 34.91 | 46.00 | 70.36 | 80.67 |
| | 24 | 10.30 | 19.28 | 24.24 | 38.33 | 43.87 |

**Table 6.** IDF relationships for sub-group period 2009 to 2018.

| Period | Duration (hour) | Rainfall Intensity (mm/hr.) | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 50 | 100 |
| 2009-2018 | 1 | 50.97 | 71.53 | 85.18 | 115.16 | 127.85 |
| | 2 | 38.90 | 55.77 | 66.96 | 91.55 | 101.96 |
| | 6 | 19.93 | 28.77 | 34.64 | 47.53 | 52.98 |
| | 12 | 13.05 | 19.22 | 23.32 | 32.32 | 36.14 |
| | 24 | 7.64 | 11.12 | 13.44 | 18.51 | 20.66 |

for the 1-hour duration with different return periods are shown in Table 7. Each sub-group for the same location, for the same duration and same return period gets different intensities of rainfall. Hence, there is non-stationarity in the IDF relationships, and relationships cannot be held fix. Therefore, the linear regression method is used to access changing trend in rainfall intensity.

In this method, the 1-hour time rainfall intensity for the same return period from each sub-group is plotted. Then, using a linear regression model, the changing trend in rainfall intensity was estimated for different return periods. Linear regression equation obtained for 2 years, 5 years, 10 years, 50 years and 100 years return period are shown in Figure 7, Figure 8, Figure 9, Figure 10 and Figure 11 respectively can be used to calculate rainfall intensities for the next 30 years of each sub-group period (2019 to 2028), (2029 to 2038) and (2039 to 2048) for the same duration and same return period.

**Table 7.** Sub-groupwise rainfall intensity for return period.

| Sub-group Period | Rainfall Intensity (mm/hr.) | | | | |
|---|---|---|---|---|---|
| | **2** | **5** | **10** | **50** | **100** |
| **1969 - 1978** | 52.79 | 68.57 | 79.05 | 102.06 | 111.80 |
| **1979 - 1988** | 48.38 | 57.48 | 63.52 | 76.78 | 82.40 |
| **1989 - 1998** | 71.53 | 103.50 | 124.72 | 171.32 | 191.05 |
| **1999 - 2008** | 64.91 | 103.40 | 128.95 | 185.05 | 208.81 |
| **2009 - 2018** | 50.97 | 71.53 | 85.18 | 115.16 | 127.85 |

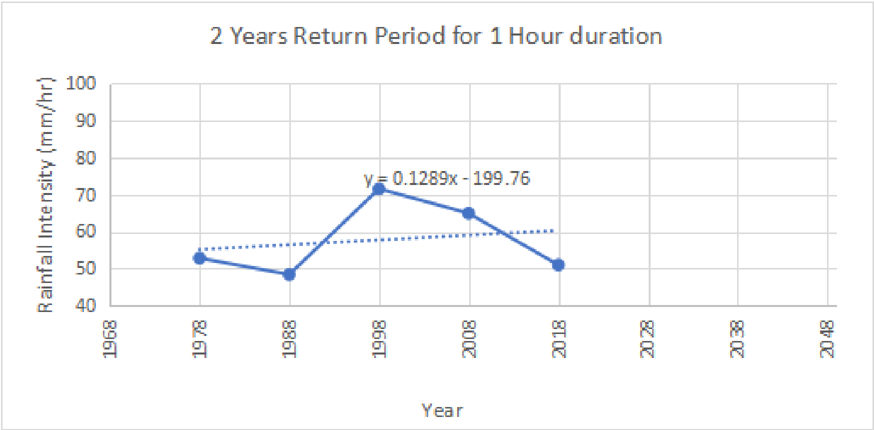


**Figure 7.** Linear equation for 2-year return period.

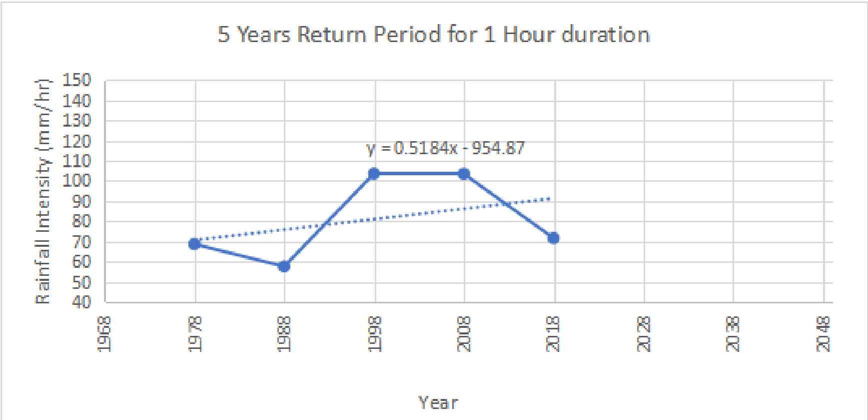


**Figure 8.** Linear equation for 5-year return period

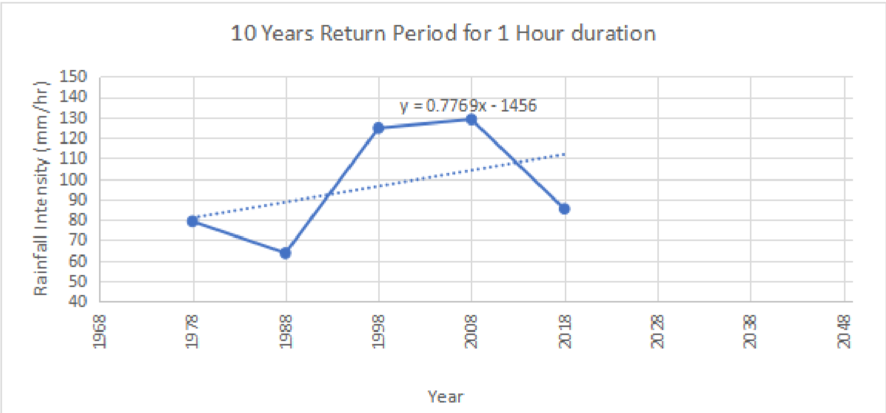


**Figure 9.** Linear equation for 10-year return period.

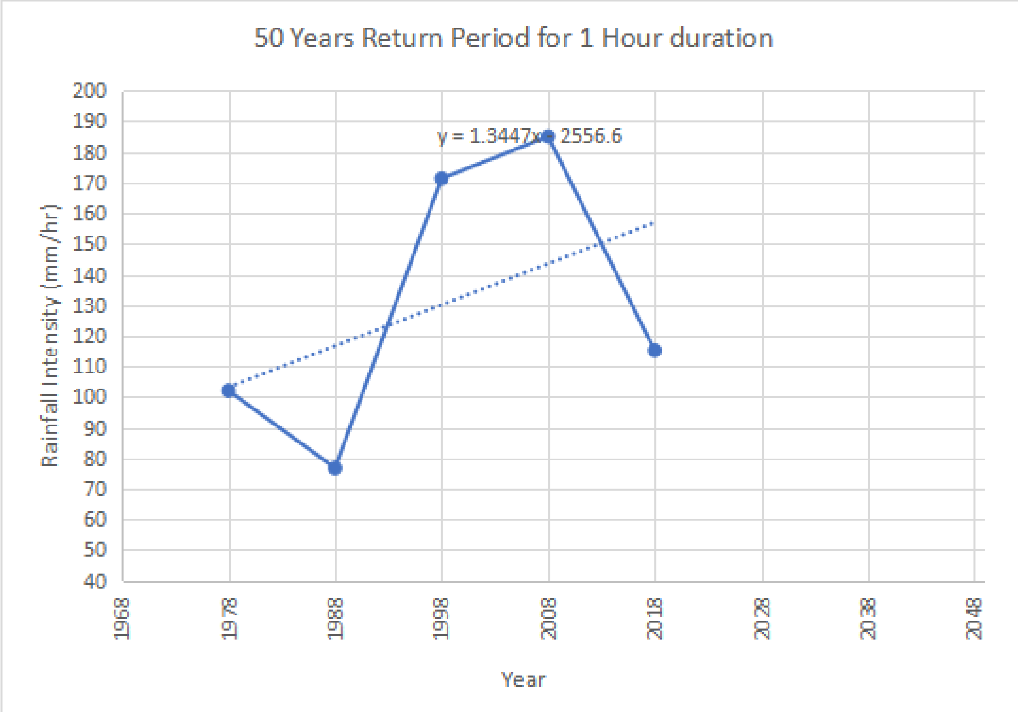


**Figure 10.** Linear equation for 50-year return period.

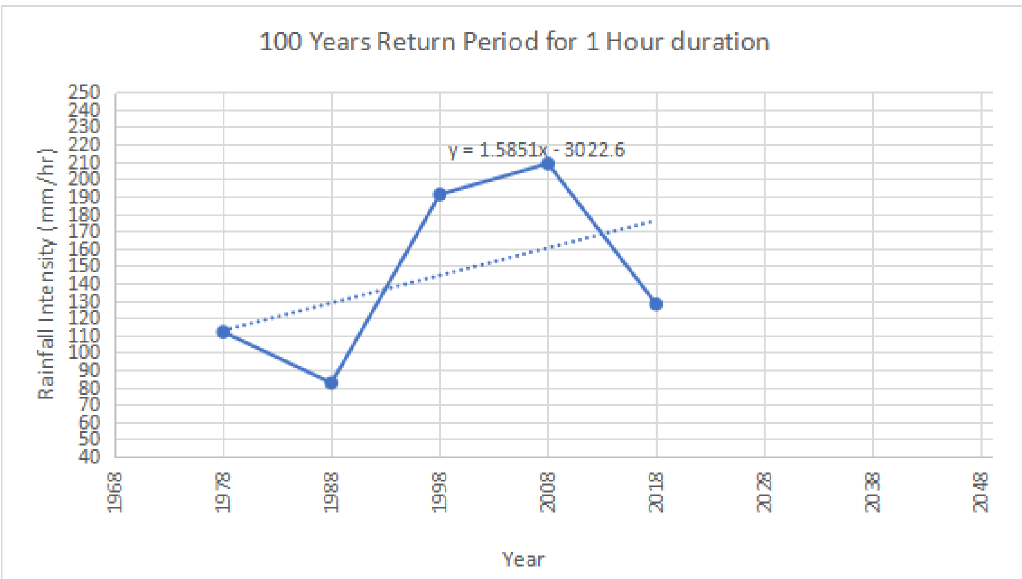


**Figure 11.** Linear equation for 100-year return period.

Rainfall intensities for predicted future are estimated by obtained linear equation each sub-group period (2019 to 2028), (2029 to 2038) and (2039 to 2048) are shown in Table 8, From Table 8 the result of this analysis indicates that the changing trend of rainfall intensity for the various durations and different return periods are likely to increase over time: 17% in (2019 to 2028), 25% in (2029 to 2038), and 32% in (2039 to 2048) with respect to Gumbel's EV-I method Rainfall IDF relationships. Similarly, results indicate that, for each projected sub-group period the defined average changing trend of rainfall intensity compared to the IDF relationship predicted by Gumbel's EV-I method will be the same for all duration and all return periods. Hence, projected IDF curve for the next 30 years is shown in Figure 12.

**Table 8.** Trend of increase projected rainfall intensities relationships.

| Sub-group Period | Rainfall Intensity (mm/hr.) | | | | | Increase trend of rainfall intensity (%) | | | | | Average Increase Trend (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 50 | 100 | 2 | 5 | 10 | 50 | 100 | |
| **1969 - 2018** | 57.3 | 83.6 | 101.1 | 139.5 | 155.7 | | | | | | |
| **2019 - 2028** | 61.6 | 96.3 | 119.6 | 170.5 | 192 | 1.08 | 1.15 | 1.18 | 1.22 | 1.23 | **1.17** |
| **2029 - 2038** | 62.9 | 101.5 | 127.3 | 183.9 | 207.8 | 1.10 | 1.21 | 1.26 | 1.32 | 1.33 | **1.25** |
| **2039 - 2048** | 64.2 | 106.7 | 135.1 | 197.3 | 223.7 | 1.12 | 1.28 | 1.34 | 1.42 | 1.44 | **1.32** |

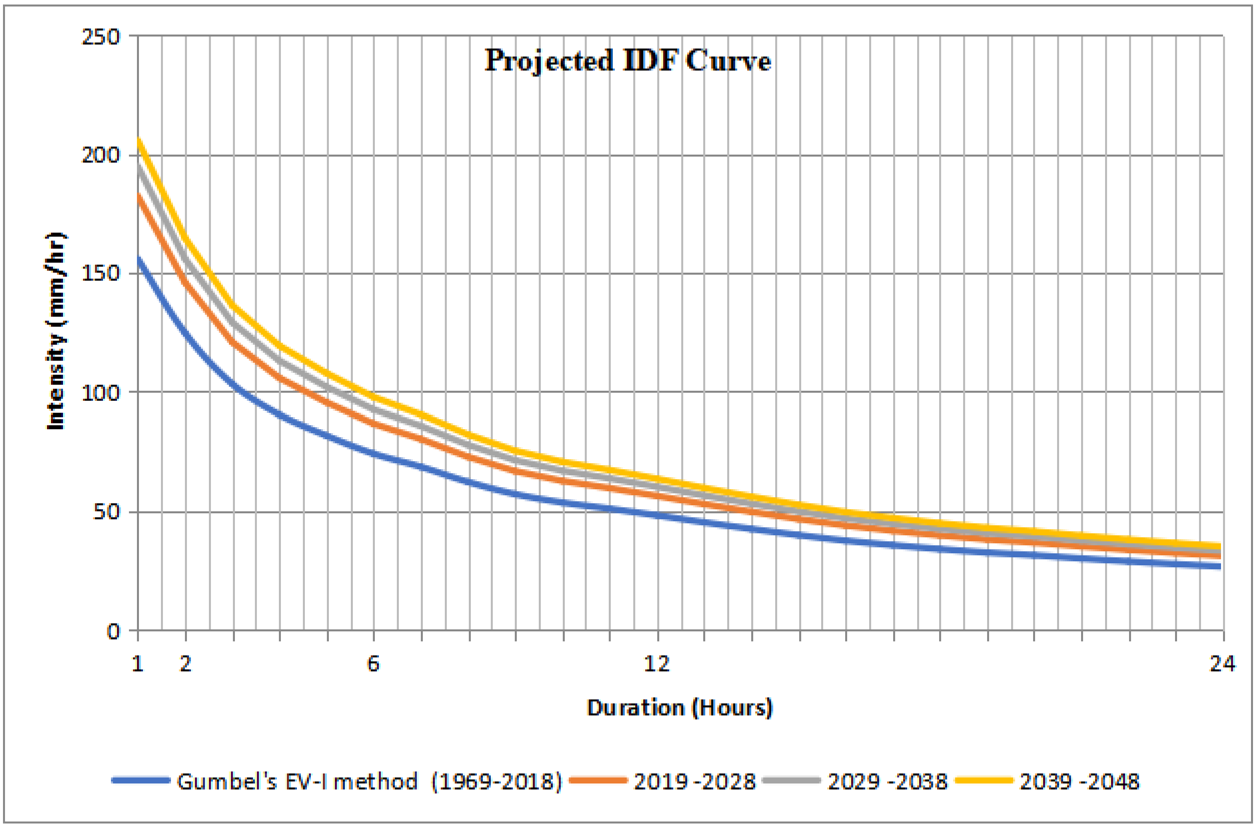


**Figure 12.** Projected IDF curves for 100 years return period.

In a drainage system, the storm return period is determined using risk analyses and economic evaluations (probability of damage, loss of life, etc., in case of failure) [22]. A significantly longer return time is used to build minor dams and airport drains (100 years and above), where there is a significant risk of life in case of failure, but a 2 or 5-year return period is used to construct urban roadside drains where the cost of failure is small.

Rainfall intensity for a return period of 100 years is shown by the IDF curve produced by Gumbel's EV-I method to be 155.7 mm/h. However, the July 2005 rainfall record for Thane indicates an intensity of 190 mm/hr. Therefore, the projected rainfall IDF curve would have a rainfall intensity of 223.7 mm/hr. during the coming 30 years (2019-2048) with a return period of 100 years. Which displays favorable outcomes in comparison to earlier Thane city rainfall records. In light of the changing hydrologic conditions witnessed on July 26th, 2005 in Thane, comparing the results with projected IDF curves reveals better outcomes.

## 6. Conclusions

Climate change is likely to increase the risk of flooding in cities with an increase in extreme rainfall events. Storm water planning requires an IDF relationship with climate change impacts. The result indicates that, as time progresses more and more information available and empirical relationships may change or used constant may change for the various regions. Even today Thane city still uses IDF relationships developed based on the empirical equation, even increases the evidence of heavy rainfall events and repetitive waterlogging in the city. The suggested mechanism for developing IDF relationship incorporating climate change in the present study can be helpful in new storm water design and in improving the existing drainage system. Additionally, IDF curves must be adjusted on a regular basis in order to take climate change's effects on rainfall and the resulting changes in design discharge into account. The technique used to estimate the changing trend of rainfall intensity gives good results in climate change conditions and shows the higher intensities of rainfall indicate the design would be safer to avoid flooding in the future.

## Conflict of Interest

Authors declare no conflict of interests.

## Acknowledgment

The authors are thanking the staff of Thane Municipal Corporation and IMD Pune for providing data related for this research.

## References

[1] Shahapure, S.S., Eldho, T.I., Rao, E.P., 2011. Flood simulation in an urban catchment of Navi Mumbai City with detention pond and tidal effect using FEM, GIS, and remote sensing. Journal of Waterway, Port, Costal, Ocean Engineering. 137(6), 286-299. DOI: https://doi.org/10.1061/(ASCE)0733-9429(1983)109:12(1603)

[2] Chacko, R., Kulkarni, A.T., Eldho, T.I., 2012. Urban coastal flood inundation modelling: A case study of Thane City, India. ISH Journal of Hydraulic Engineering. 18(3), 194-203. DOI: https://doi.org/10.1080/09715010.2012.721187

[3] Zope, P.E., Eldho, T.I., Jothiprakash, V., 2016. Development of rainfall intensity duration frequency curves for Mumbai City, India. Journal of Water Resource and Protection. 8, 756-765. DOI: http://dx.doi.org/10.4236/jwarp.2016.87061

[4] Dourte, D., Shukla, S., Singh, P., et al., 2013. Rainfall intensity-duration-frequency relationships for Andhra Pradesh, India: Changing rainfall patterns and implications for runoff and groundwater recharge. Journal of Hydrologic Engineering. 18(3), 324-330. DOI: https://doi.org/10.1061/(ASCE)HE.1943-5584.0000625

[5] Chawathe, S.D., Fadanvis, S.S., Goel, V.V., 1977. Rainfall analysis for the design of storm sewers in Bombay. The Institution of Engineers (India) Journal-EN. 58, 14-20.

[6] Chin, D.A., 2019. Relative performance of intensity-duration-frequency function. Journal of Hydrologic Engineering. 24(4), 04019006. DOI: https://doi.org/10.1061/(ASCE)HE.1943-5584.0001767

[7] Bell, F.C., 1969. Generalized rainfall-duration-frequency relationships. Journal of Hydraulic Division. 95, 311-327.

[8] Chen, C.L., 1983. Rainfall intensity-duration-frequency formulas. Journal of Hydraulic Engineering. 109, 1603-1621. DOI: https://doi.org/10.1061/(ASCE)0733-9429(1992)118:2(323)

[9] Babu, R., Tejwani, K.K., Agrawal, M.C., et al., 1979. Rainfall intensity-duration-return periodequations and nomographs of India, Dehradun: CSWCRTI, ICAR.

[10] Kothyari, U.C., Garde, R.J., 1992. Rainfall intensity-duration-frequency formula for India. Journal of Hydraulic Engineering. 118, 323-336. DOI: https://doi.org/10.1061/(ASCE)0733-9429(1992)118:2(323)

[11] Al-anazi, K.K., El-Sebaie, I.H., 2013. Development of intensity-duration-frequency relationships for Abha city in Saudi Arabia. International Journal of Computational Engineering Research. 3(10), 58-65.

[12] Zope, P.E., Eldho, T.I., Jothiprakash, V., 2012. Study of spatio-temporal varaitions of rainfall pattern in Mumbai City, India. Journal of Environmental Research and Development. 6(3), 545-553.

[13] Yiping, G., 2006. Updating rainfall IDF relationships to maintain urban drainage design standards. Journal of Hydrologic Engineering. 11, 506-509. DOI: https://doi.org/10.1061/(ASCE)1084-0699(2006)11:5(506)

[14] CDP, 2005. City Development Plan of Thane Municipal Corporation.

[15] Waghmare, J.S., 2017. GIS for urban air & noise pollution mapping - A Case study of Thane City, India. Population & Environment Bulletin. 13(4). Available from: https://iipsindia.ac.in/sites/default/files/project_report/Volume-13-No-4-2017.pdf

[16] Hariyali Team, 2006. Project report on repetitive water logging in Thane city: Engineering solutions and Environmental management plan. I & II.

[17] Goel, N.K., Sarkar, S., 2007. Regional rainfall intensity-duration-frequency relationship. NTPC Sponsored Training Course on Design Flood Analyses for Hydropower Projects, 2007 Aug 20-25, IIT Roorkee.

[18] Ibrahim, E.H., 2011. Developing rainfall intensi-

ty-duration-frequency relationship for two regions in Saudi Arabia. Journal of King Saud University-Engineering Science. 24, 131-140.
DOI: https://doi.org/10.1016/j.jksues.2011.06.001

[19] Sreehari, E., Ghantasala, P., 2019. Climate changes prediction using simple linear regression. Journal of Computational and Theoretical Nanoscience. 16, 1-4.
DOI: https://doi.org/10.1166/jctn.2019.7785

[20] Jain, S.K., Kumar, V., 2012. Trend analysis of rainfall and temperature data for India. Current Science. 102(1), 37-49.

[21] CPHEEO, 2019. Manual of Storm Water Drainage System, New Delhi: Government of India [Internet]. Available from: http://cpheeo.gov.in/cms/manual-on-storm-water-drainage-systems---2019.php

[22] Mirhosseini, G., Srivastava, P., Stefanova, L., 2013. The impact of climate change on rainfall Intensity-Duration-Frequency (IDF) curves in Alabama. Regional Environmental Change. 13, 25-33.
DOI: https://doi.org/10.1007/s10113-012-0375-5