Rainfall Trend Analysis and IDF Curve Generation for Bujumbura Mairie in East Africa

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This study aimed to analyse rainfall trends and IDF curve generation for Bujumbura Mairie using historical data for the past 30 years. In this study, the procedures adopted consisted of the statistical analysis of daily rainfall, rainfall anomaly, rainfall regression, Mann Kendall test, Sen's slope, and return period using: Gumbel Method, long Pearson method,log-normal method, and Normal method. To do so, rainfall data from 1991-2020 was employed. The data that we collected was analysed using SPSS software. Result showed that there were 88.97 non-rainfall days' means in the long-wet season FMAM (Feb, Mar, April, and May) and 294.67 non-rainfall days mean in 30 years from 1991 and 2020. After analysis, the excess rain years observed were 2020 for both the annual and long-wet seasons. Fourth deficit rain years **(**1994, 2005, 2006, and 2018) were observed for annual and long wet-season analysis. To quantify the possible effects of climate change and adapting to them is an important way of reducing vulnerability to them.The relationship between the IDF curves that is determined in this study is intended to use statistical analysis of the rainfall data observed for the past 30-year record.

Keywords: Keywords: Bujumbura, rainfall analysis, long wet Saison, climate change

1 Introduction

Climate change is the biggest issue today. Floods are observed all over the world and some regions of the world remain the most vulnerable like the city of Bujumbura Mairie(Kubwarugira et al. 2019).In Burundi, and especially in the economic capital Bujumbura, heavy rains have caused inestimable disasters over the past 30 years. In this city, more than 52,000 people are affected by floods due to the rising waters of Lake Tanganyika influenced by the rains that lead the water directly into the lake (Jooma 2005). Being a natural disaster, science nevertheless can suggest sustainable solutions. In the outskirts of this city, the clear formation of a landslide dam on the sides of the Kanyosha River, near the town of Bujumbura Mairie was observed, similarly, the interaction between the failure of the same landslide dam and the widespread flooding along the river (Nibigira et al. 2018). All of the above problems make the population uncertain and unable to cope with the dangers of flooding(Mzezewa et al. 2010). Therefore, the historical analysis of the data must help us understand the frequency, behaviour, and quantity of rainfall that this city has experienced over the past 30 years(Agarwal et al. 2021). This study is also very important to shed light on the rainfall regime as an important precondition for agricultural planning(Hossain et al. 2017). With this in mind, we have worked with 30 years of historical rainfall data from

Burundi to provide a clear assessment of the dangera clear idea of strategic adaptation and solutions for the future (Fentahun and Gashaw 2014).

It has been noticed that if applicable measures are not applied in time(Doorn 2016), floods caused by rainfall can cause enormous danger for the inhabitants of the area(Baker 2008). So, it is the responsibility of science and local government to find a sustainable solution (Manfredi et al. 2014). This work demonstrates in a way the possibilities of sustainable planning of the city's stratification, as the good urbanization of the city contributes to good housing of the population and avoids any danger related to landslides or flooding(Zwanenburg and Jardine 2015). Analysing this rainfall data is good, because we will suggest short, medium, and long-term measures, but involving all fields of science in this issue would be better(Mcknight 2000). In some African countries, hydrology has contributed significantly to the development of a clear system for flood management(Plisnier 2000). Similarly, the graphic information system with perfect visualization of the environment is a very important contribution to solving flood problems(Bigirimana et al. 2012). Geology and geotechnics are also involved in determining the infiltration about the quality and properties of the soils in place at the study site or the environment affected by this hazard(Eschenbach 2004).

Rainfall analysis is also about understanding the behaviour of rainfall in any city, with the clear objectiveof having reliable results that will lead to scientific, governmental, and metrological decision-making(Kim and Olivera 2012). In our case, the data analysed concerns a very specific period in Bujumbura. The city of Bujumbura is a city that started to be well urbanized in the years 1941, in these years the population started to live in the city and gradually approached Lake Tanganyika when land became very scarce in places appropriated for construction(Shukor et al. 2020). All these issues (urbanization, climate change, high-intensity rains) have one thing in common, the destruction of cities by recurrent floods(Agarwal and Kumar 2019, 2020).In this sense, this work shows in depth into the rains that this city has undergone over time and the years that are linked to them, even seasons(Ahmed and Kumar 2019). Our place of study has very varied seasons which are often rainy and dry.

2 Materials and Methods

2.1 Study area

The city of Bujumbura Mairie presently covers a space of 127 Km^2. BujumburaMairie has a wet and dry tropical climate. There are four seasons in this city: the long dry season (June–August), Short-wet season (September to December), Short dry season (mid-January-mid February), and long-wet season (February to May). Bujumbura is located near the equator, but for this reason, it is not as hot as one might expect, due to its altitude. Average temperatures are constant throughout the year, with a maximum temperature of about 29°C (84°F) and a minimum temperature of about 19°C (66°F). The altitude is 774m (2,539 ft) and its urban density is 8,500/km2 (22,000/sq mi) (Mairie Bujumbura et al 2021).In the city of Bujumbura Mairie, 835 mm of rain falls per year, with a peak in the two months of April and

May, where rainfall often reaches or exceeds 90 mm per month, and a minimum from June to August, where rainfall is rare and sporadic.

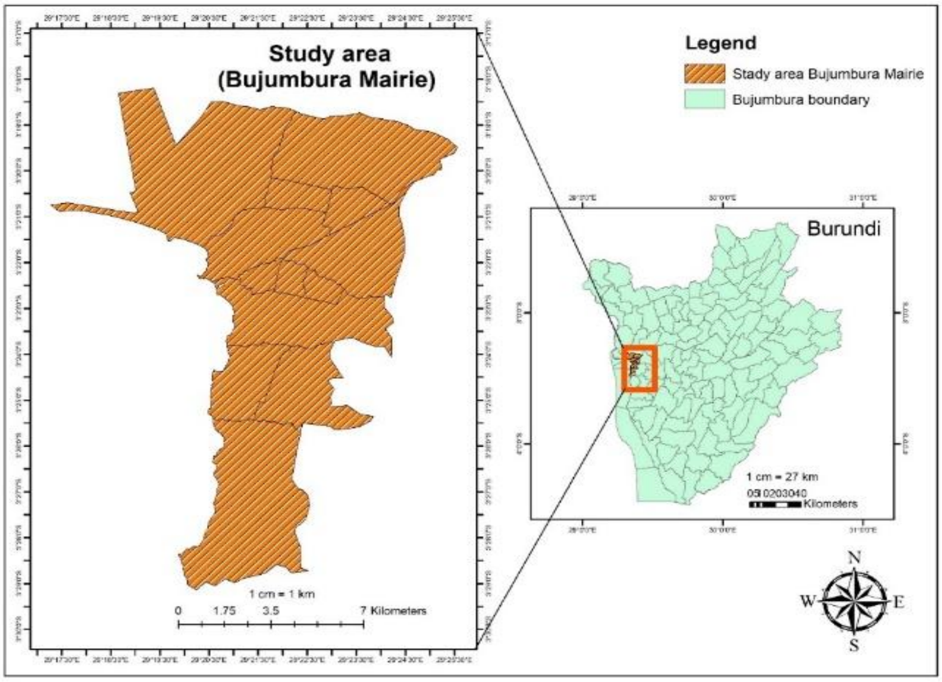

Fig. 1Study area map Bujumbura Mairie

2.2 Methods

This methodology gives rainfall analysis processes used to determine: Statistical analysis,rainfall anomaly, rainfall regression, Mann Kendal test, Sen's slope , return period by Gumbel Method, return period by long Pearson method,return period by log-normal method , Return period by Normal function.

(1) Statistical analysis of Daily Rainfall: from 1991-2020 result present in (Table 1), for the mean (mm), SD (mm), CV (%), and trend (mm/year) obtained by. Annual rainfall in mean was obtained by taking the sum of rainfall in all the twelve months of the year= to the annual rainfall

(2) Rainfall anomaly: The anomalies were calculated by taking the observed rainfall data for 30 years and then adding the monthly values for the base periodand taking an average of the monthly totals. Then, we subtract the observed values from the average values. In an algebraic demonstration $(X-\mu)/\sigma$

(3) Rainfall regression: Regression analysis was used in this study firstly to identify the factors governing flood generation and delivery. Secondly, to predict discharge volumes and flood peaks as a function of rainfall input and antecedent moisture.

The equation of regression is demonstrated as: (**$Y = a + bX + e$**)

Where: **Y** represent the value of the Dependent variable (Y), what's predicted. **a** or Alpha is only a constant which is equals to Y value when the value of X=0. b or Beta, the coefficient of X

(4) The Mann Kendall test: This method are used to analyze the trend in the time series, which is mostly used to detect a monotonic trendDue to the presence of outliers for extreme rainfall events, this test is therefore based on (+ or -) signs, even for the random variable it can be also used to determine the trends.

To determine trend in the time series, Mann Kendal test statistic "S" is given as:

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} \text{sign } (xi - xj) \quad (1)$$

Where, 'X_i' and 'X_j' are sequential data for i^{th} and J^{th} terms, 'n' is only the sample size and

sign $(x_i - x_j)$ = {+1, if $(x_i - x_j)$> 1} (2a)

sign $(x_i - x_j)$ = {+0, if $(x_i - x_j)$= 0} (2b)

sign $(x_i - x_j)$ = {-1, if $(x_i - x_j)$< 1} (3c)

The "S" statistics is approximately Gaussian when n=18 with the mean E(s) and variance V(S) of the statistic "S" is given by the expression

E(S)=0 (3)

$V(s) = \frac{N(n-1)(2n+5)}{18}$ (4)

However, if the dataset exists, variance (S) is calculated by the equation below

$Va\ (S)=\frac{1}{18}\left[[n(n-1)(2n+5)] - \sum_{p=1}^{n} t_p (t_{p-1})(2t_p + 5)\right]$ ---------------(5)

The variable 'q' and 't_p ' are the tied group numbers and 'p^{th} ' group data value numbers, respectively. Th The normal Z-statistics is calculated as follows

W=$\frac{S-1}{\sqrt{var\ (S)}}$ (6a)

Z=0 (6b)

Z=$\frac{S-1}{\sqrt{var\,(S)}}$ (6c)

The trend is said to be decreasing or increasing if 'Z' is negative or positive and the Z-statistic that is calculated is greater or less than the Z-value corresponding to the 5% significance level, respectively. If the computed Z-statistics is Zero then, there are no trends.

(5) Sen's slope: is used to identify the trend existing in data sets of a particular time series. A slope estimator (m sub j) is considered ij as median for all data sets for various combination. The '+ve' value (m_j) indicates a reverse upward trend '-ve' indicates a decreasing trend. The slope (m_j) is calculated ij using the following equation

$$m_i = \frac{(Yj - Yi)}{(J-1)} \quad (7)$$

Where, 'Y_j' and 'Y_i ' are the time values at time 'j' and 'I' j i (j>i). The slope of Sen's estimator is exactly the median of these values 'N' values of 'm_{ij}'. The Sen's slope is calculated by using the following equation

m=$m\left[\frac{N+1}{2}\right]$ (8)

m=$\frac{1}{2}\left[\frac{m_N}{2} + \frac{m-_{N+1}}{2}\right]$ (9)

(6) Return period by Gumbel Method: After the name of developerGumbel, the functionality is termed and it is also called astype 1 distribution of maxima. Utilising the Gumbel distribution, the IDF curves are studied and assessed asfitting of maxima attain appropriateness. Utilisation of themaximum rainfall values and extreme data with ease is doneby the Gumbel method. This method can be used in another way to determine the frequency precipitation, but this time with a different frequency factor K which is given by:

$K_t = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + in\left[in(\frac{T}{T-1})\right]\right\}$ (10)

The Gumbel distribution uses the following equation proposed by chow:

$\boldsymbol{X_T = (X_{ave} + K_t S)}$ (11)

Where X_T is the intensity in mm/hr, X_{ave} is the Mean, S is the one standard deviation and K is the frequency factor

$\bar{x} = \frac{1}{m}\sum_{i=1}^{m} x_i$ (12)

$S = \frac{1}{m-1}\sum_{i=1}^{m}(x_1 - \bar{x})^2$ (13)

(7) Return period using long Pearson method: The Log-Pearson Type III distribution is a statistical technique that allows frequency distribution data to be fitted to predict the design flood of a river at any site. Once the statistical information is calculated for the river site, a frequency distribution can then be constructed.

This Log-Pearson Type III distribution is calculated using the following general equation:

$\log x = \overline{\log x} + K\sigma_{logx}$

Where x is a value of the flood flow of a certain specified probability,

$\overline{logx}$ represent the average of the *log x* discharge values, *K* is a frequency factor, and σ is the standard deviation of the *log x* values.

(8) Return period using log-normal method: By using the log-normal method with interference of logarithmic variables, the frequency precipitation can be calculated also as the normal method.The Calculations for average precipitation and standard deviations are done through logarithmically transformed data.

$P^* = Long(P_i)$ (14)

$\overline{P}^* = \frac{1}{n}\sum_{i=1}^{n} P_i^*$ (15)

$S^* = \left[\frac{1}{n}\sum_{i=1}^{n}(P_i^* - \overline{P^*})^2\right]^{0.5}$ (16)

The Frequency precipitation is calculated as:

$P_T^* = P + K_T S^*$ (17)

The intensity can be calculated by:

$I_t = P_T/t$ (18)

Here P_T is the antilogarithm of P_T^* calculated by equation.

(9) Return period using Normal function: In statistics the Normal (Gaussian) distribution is most prominent method. To obtain the rainfall intensities for a certain return period and every storm time period many calculations need to be carried out, like all other methods, this method also calculates rainfall intensities. Below mentioned is the equation to determine the P (in mm) using a specified time (T in years) T and the specific duration (t)

$P_T = P + K_T S$ (19)

Here, 'K_T' is the frequency factor and is equal to 'z' for log-normal and normal distribution which is calculated by:

$$Z=W - \frac{2.515517+0.802853w+0.010328\ W^2}{1+1.432788w+0.189629\ W^2+0.001308W^3} \quad (20)$$

Here, 'w' is given as:

$$W=\left[In\left(\frac{1}{P^2}\right)\right]^{0.5} \quad (21)$$

In the above equation, P is the probability of occurrence only in a given return period. And p is given as follows:

P = 1/T (22)

To the case of p > 0.5, 'p' in Eq. (21) is substituted as (1-p) and z gives directly a negative value. Considering Eq. (1), But for a single time 'p' is the present as the arithmetic average of the rainfall records Moreover, 'S' is the standard deviation. On multiplication of the 'S' and 'K' give the output as departure of a return period. To develop IDF calculation of precipitation and the intensity of rainfall I (in mm/hr) with respect to a period T is calculated.

I =Pt/t t Here, t represents duration in (hours). The following procedure utilised to find the intensity for fourteen durations and 6 return periods the calculations were made.

3 Results and Discussion

The analysis at the study area (Bujumbura Mairie) was considered for a period from 1991 to 2020, which allowed us to start with the analysis of rainfall data observed in the 30 years, the results described in (Table 1). After this observation, we determined the variability of rainfall in mm per year for the whole study period (Fig2). This allowed us to analyse the rainfall regression for its deviation from mean for all seasons present in Bujumbura Mairie in mm. To understand what represents a significant trend in the rainfall data (Table1), we then did the Mann Kendall test, Sen’s slope (Table2). To determine relationship between rainfall intensity, rainfall duration, and return period we present the IDF curves (Intensity-Duration-Frequency (Fig8,9,10 and 11)

Table.1Statistical analysis of 30 years observed rainfall data for Bujumbura, East Africa.

(1991-2020)	Annual	JJA	SON	DJ	FMAM
Means(mm)	1102.25	32.15	310.63	269	490.47
SD(mm)	290.55	18.16	107.12	63.41	171.41
CV(%)	26.36	56.48	34.49	23.57	34.95
Trend (mm/year)	-0.49	0.07	-0.4	0.04	-0.21

Table 1 represent result of statistical analysis of 30 years observed rainfall data in Bujumbura Marie city, East Africa. The study area received highest mean annual rainfall (1102.25mm) for observed daily rainfall event (1991-2020) and Long-Wet season (Feb, Mar, April and May) highest rainfall mean (490.47 mm). To obtain the amount of variation or dispersion of a set of value; SD (Standard deviation) was ben used as the measure. It is observed from the analysis that Bujumbura is having maximum mean annual rainfall deviation (290.55 mm) while in JJA (June, July, August) is experiencing least variation (18.16 mm).

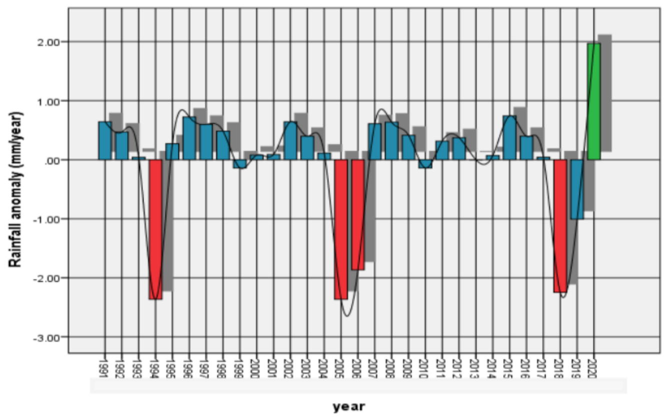

Fig. 2Bujumbura Mairie rainfall anomaly during the period (1991-2020)

Fig 2 represents the Annual rainfall anomalies time series. During the period (1991-2020) we observed only one excess rainfall years 2020 (1971.34mm) and fourths deficit years (1994, 2005, 2006, 2018). In those 4 deficit years the lowest value 2.36 mm are observed in 1994. On the recent flood fatalities in Bujumbura, the decade increasing rainfall trend observation due to climate change.

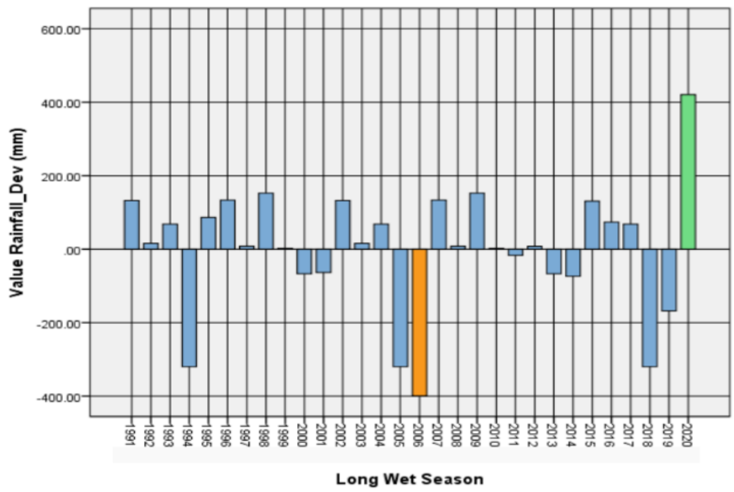

Fig. 3Bujumbura Mairie Long wet season regression for rainfall deviation from mean during the period (1991-2020)

Fig. 3 represents the Long-Wet season deviation from mean for Bujumbura Mairie. The deviation is calculated and a trend line is set using regression analysis. The Long-Wet Season in Bujumbura is the month of February, March, April and May. It is observed that there is a decreasing trend par year (2097mm/Year) in rainfall deviation from mean. The Highest rainfall positive deviation from mean of the past 30 years in this season on the period (1991-2020) is observed for 2020 (420.67mm) and maximum negative deviation is for 2006 (399.29mm)

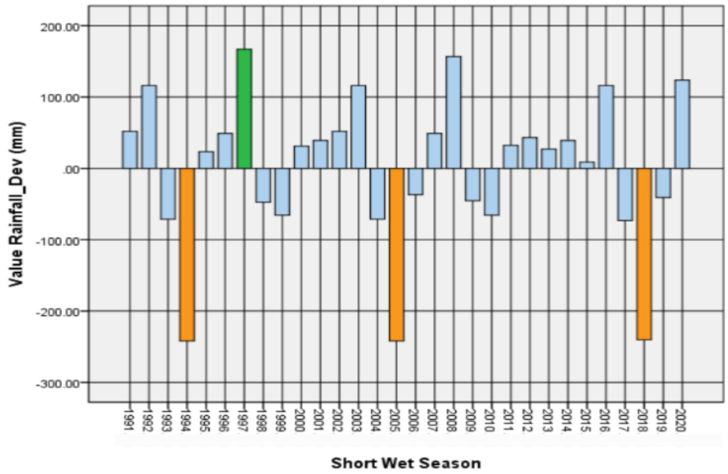

Fig. 4Bujumbura Mairie Short Wet Season regression for rainfall deviation from mean during the period (1991-2020)

Fig 4 represents the Short-Wet season deviation from mean observed in Bujumbura city during the period 1991 to 2020. This season concern the month of September, October and November in the study area. Trend line is set using regression analysis. We observed that the maximum highest rainfall positive deviation from mean of the past 30 years in this season is observed in 1996 (48.99mm). And the negative deviation is observed in the several years (1994, 2005 and 2018) the decreasing trend par year observed is (-04019mm/Year) in rainfall deviation from mean.

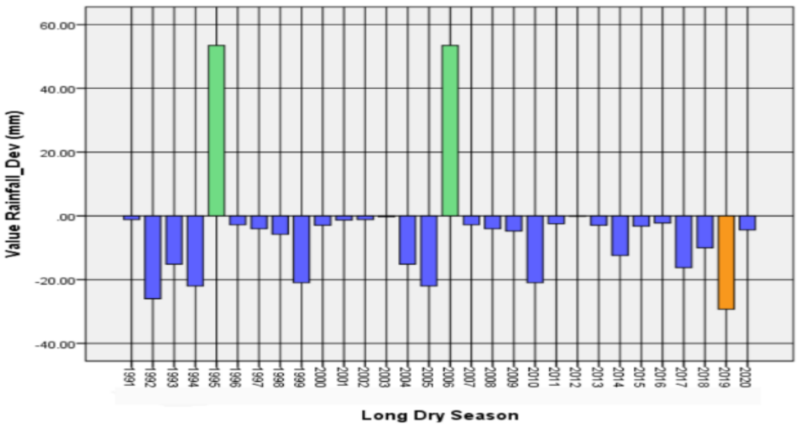

Fig. 5Bujumbura Mairie Long Dry season regression for rainfall deviation from mean during the period (1991-2020)

Fig 5 representslong dry season deviation from mean for Bujumbura Mairie city during the period 1991-2020. The deviation from mean is calculated and the trend line is set using regression analysis. This Long-Dry Season in Bujumbura concern the month of June, July and August (JJA). In JJA, the highest rainfall positive deviation from the mean of observed past 30 years in this season is observed for two years (1995) and (2005). The maximum negative deviation is observed for the year 2019 (25.23mm).

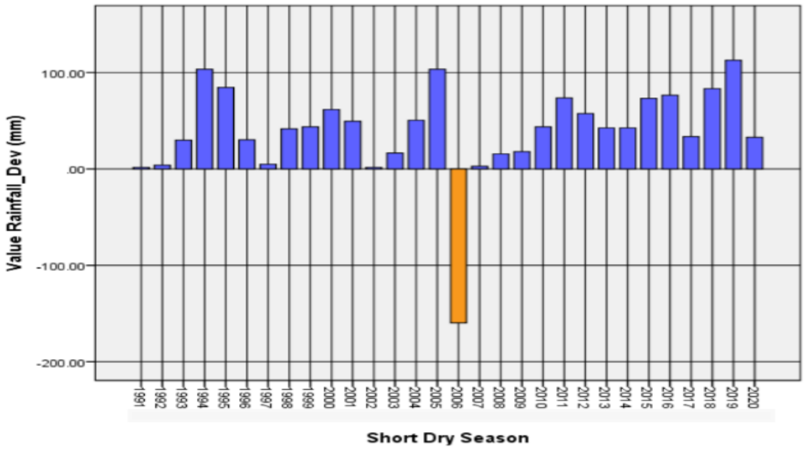

Fig. 6 Bujumbura Mairie Short Dry season regression for rainfall deviation from mean during the period (1991-2020)

Fig 6 represents the Short Dry season deviation from mean for Bujumbura city. The Short Dry Season in Bujumbura is the month of December and January. In those two months, we observed that there is an increasing trend par year (0.43mm/Year) in rainfall deviation from mean. The Highest rainfall positive deviation from mean of the past 30 years in this season on the period (1991-2020) is observed for 2019 (112.77mm) and maximum negative deviation is for 2006 (159.77mm)

Table.*2* MK (Mann Kendall test) and Sen's slope values for all the seasons in Bujumbura

Season	**Mann Kendall**	**Sens's slope**
Annual	-0.33	-40.11
JJA	-0.167	-2.585
SON	0.00	0.00
DJ	0.00	-1.08
FMAM	-0.33	-49.39

Table 2 represent Mann-Kendall test value and Sen's slope. The value (Z) represents a significant trend in the rainfall data. While Sen's slope estimator shows a decreasing or increasing trend for the different seasons (Table 2). During this analysis, Mann-Kendall test is only used for the sign test as well as the change in magnitude of the trend. In September, October, and November the results of MK (Mann Kendall test) show a significant positive trend on the rainfall distribution, also for the Sen's slope. In Bujumbura Mairie, what gives a maximum contribution to rainfall for the whole year mainly in February, March, April, and May.

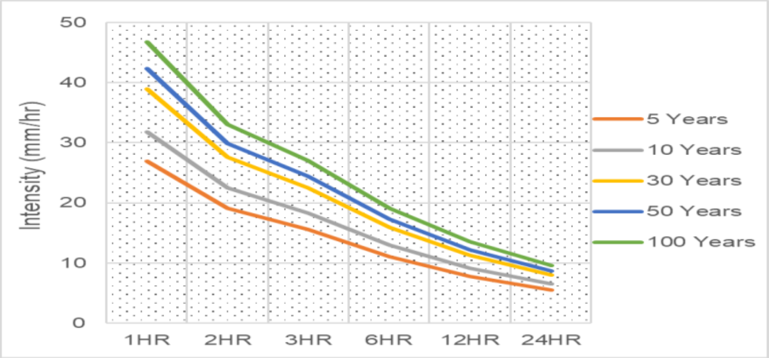

Fig. 7 IDF Curve using Gumbel method for historical rainfall events

Figure 7 represent the values of the intensities deduced by the Gumbel method are distinct and larger, although the parameters defined for this method are very similar to the parameters defined for the other methods mentioned above. The Gumbel method is used in a specific way to define the relationship between return period, storm duration and rainfall intensity.

Table 3The variation of intensity with duration using Gumbel method.

Gumbel	**RETURN PERIOD**				
DURATION	**5 Years**	**10 Years**	**30 Years**	**50 Years**	**100 Years**
1HR	26.97	31.76	38.98	42.29	46.75
2HR	19.07	22.46	27.57	29.90	33.06
3HR	15.57	18.34	22.51	24.42	26.99
6HR	11.01	12.97	15.92	17.27	19.09
12HR	7.79	9.17	11.25	12.21	13.50
24HR	5.51	6.48	7.96	8.63	9.54

Table3 represent the variation of rainfall intensity with duration for the given return periods using Gumbel method. The standard deviation and average of each duration (1,2,3,6,12 and 24 Hours) rainfall intensity for various return period (5 years,10,30,50 and 100 Years) is determined to analyse the coefficient of variation. The highest coefficient of variation of rainfall observed for the 24 Hours are 46.75 for (100) return period and the lowest 5.51 in 24 Hours for 5 return period.

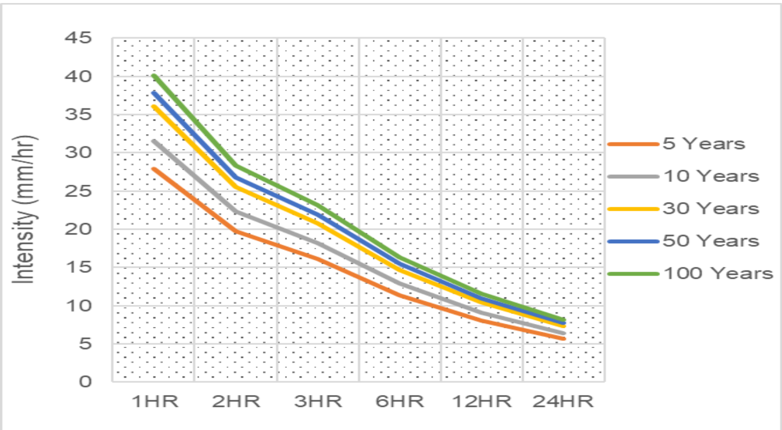

Fig. 8IDF Curve using normal method for historical, rainfall events

Figure 8 represent the intensity of precipitation and even its return period are directly proportional to each other. Therefore, if the return period has just increased, the duration of the storm also increases and vice versa. The graphs Intensity Duration Frequency show an important change in the return period is as well observed with the variation of the precipitation intensity when it reaches a duration of 2 to 6 hours and then slowly decreases with time.

Table. 4Rainfall intensity for observed rainfall events scenario using Normal method

Normal	**RETURN PERIOD**				
DURATION	**5 Years**	**10 Years**	**30 Years**	**50 Years**	**100 Years**
1HR	27.97	31.57	36.09	37.89	40.12
2HR	19.78	22.33	25.52	26.79	28.37
3HR	16.15	18.23	20.84	21.88	23.16
6HR	11.42	12.89	14.73	15.47	16.38
12HR	8.07	9.11	10.42	10.94	11.58
24HR	5.71	6.44	7.37	7.73	8.19

Table 4 represent values obtained along which the defined parameters which shows variation of rainfall intensity which duration for the given return period using normal method. The highest coefficient of variation of rainfall intensity for the past 30 years (40.12 %) and the lowest was observed in 24 Hours (5.71%).

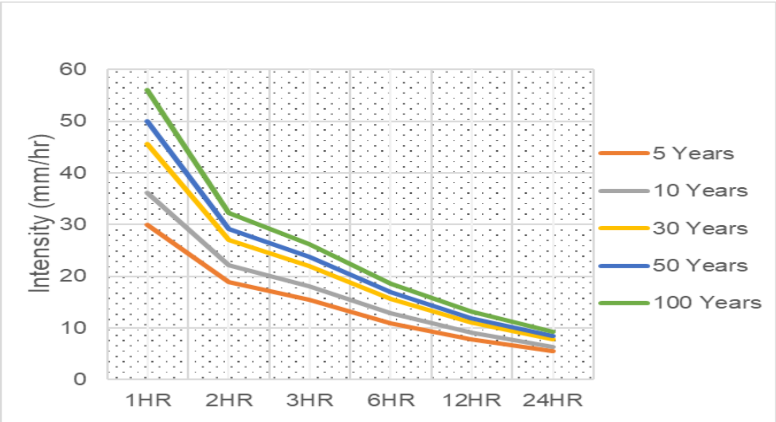

Fig. 9 IDF Curve using long normal method for historical, rainfall event (1991-2020)

Figure 9 represent the IDF curve using Long normal method for historical rainfall event from 1991-2021. Normal method has given highest rainfall intensity values among our four methods for all the return periods observed.

Table. 5 Rainfall intensity for observed rainfall event scenario using Long-Normal method

Log Normal	**RETURN PERIOD**				
DURATION	**5 Years**	**10 Years**	**30 Years**	**50 Years**	**100 Years**
1HR	29.98	36.09	45.55	49.97	56.05
2HR	18.91	22.13	26.98	29.19	32.18

3HR	15.44	18.07	22.03	23.83	26.27
6HR	10.92	12.78	15.57	16.85	18.58
12HR	7.72	9.04	11.01	11.91	13.14
24HR	5.46	6.39	7.79	8.43	9.29

Table 5 represents the variation of Rainfall intensity with duration for the given return period for observed rainfall event scenario using the Long-Normal method. The coefficient of variation (56.05%) is the highest observed for 1 Hour in 100 Years. The lowest in 5 years (5.46%) was observed for 24 Hours.

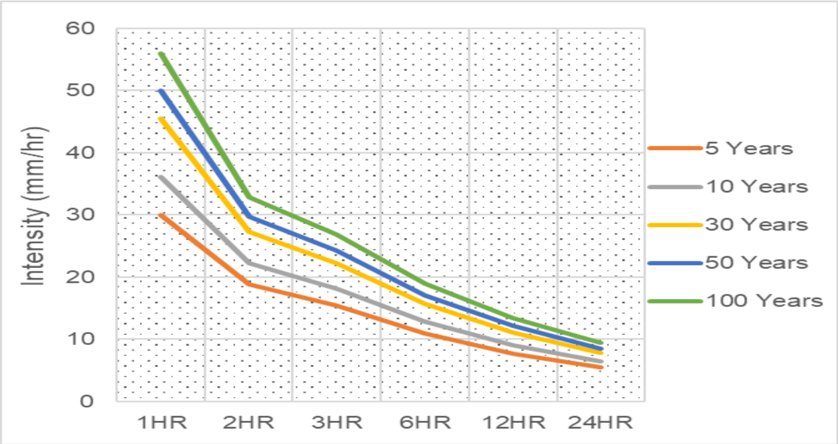

Fig. 10 IDF Curve using Long Pearson method for historical scenario and observed rainfall event

Fig 10 represents the values of rainfall intensity obtained for Long Normal person methods are close whit respect to each other. This IDF curve is obtained from the well-chosen methodology, then it relates relationship between the rain duration in (mm), the intensity in (mm/hr), and the return period par (years).

4 Conclusions

Based on the results obtained from clear and deep analysis of historical rainfall data, it can be concluded that the overall rainfall in Bujumbura Mairie has increased over the total period of 30 years, which may continue in the future. The part that approaches Lake Tanganyika will be more vulnerable to flooding than other parts. The months of February, March, April, and May of each year are the most affected by many of the high-intensity rains and deserve special attention to take appropriate measures to help the population. It is, therefore, necessary to adopt some short-term measures such as Risk assessment - including the regularization of views; the transition, in practice, of protection against floods, training of cadres on floods. In the medium term, flood management should be coordinated by a competent management cadre. In the long term, prohibit all construction within 300m of Lake Tanganyika and the rivers that carry water to it. Climate change is responsible in many ways for the observed changes in rainfall, similarly, we have observed that this rainfall being of high intensity is not well supported by the channels that lead to Lake Tanganyika, Lake

Tanganyika, in turn, does not have enough space to accommodate all the water and this causes the level of the lake to rise which leads to flooding in the outlying areas.

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