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Full Length Research Paper

Intensity duration frequency relationship of maximum rainfall in a data scarce urbanized environment: A case study of the Guma Catchment in Sierra Leone

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Rainfall intensity for a particular frequency and duration is one of the most important parameter for the hydrologic design of dam, reservoirs, storm sewers, culverts and many other hydraulic structures. This can be obtained from Intensity-Duration-Frequency (IDF) relationship, which is determined by frequency analysis of rainfall data. The goal of this research is to develop rainfall intensity-duration frequency relationship for the data scarce urbanized Guma catchment in Freetown the capital city of Sierra Leone using the Gumbel and Pearson Type III distributions. To achieve this goal, daily rainfall data for the period of 1991 to 2018 for the Guma catchment rainfall station was obtained from the Guma Valley Water Company and were converted to shorter duration (hourly) using the Indian Meteorological Department (IMD) method. Twenty-eight maximum daily rainfall events were converted to hourly rainfall events. Frequency analysis was conducted to develop the rainfall intensity-duration-frequency relationships using the Gumbel and Pearson Type III distributions. The Kolmogorov-Smirnov (K-S) goodness of fit test was utilized to determine which of the distributions have a better fit at 5 and 10% significant levels. The frequency analysis results show that the Gumbel distribution gives higher intensity for all return periods and durations than the Pearson Type III distribution. The result of the K-S goodness of fit test shows that all of the data fit the Gumbel distribution for different return periods (2, 5, 10, 25, 50 and 100 years) at the level of significance of $\alpha = 0.05$, which yield $\Delta_0 < 0.24$, and $\alpha = 0.01$, which yield $\Delta_0 < 0.29$, while the data do not give good fit using the Pearson Type III distribution at both levels of significance for the different return periods.

Key words: Rainfall, Intensity-duration-frequency relationships, probability distributions, goodness of fit test.

INTRODUCTION

In many parts of the world, the change in rainfall pattern is one of the major factors causing flooding which are the most dreadful natural hazards. Guma catchment is of great concern because it hosts the Guma Valley dam that supply water for the residents in the Municipality of Freetown in Sierra Leone. The Guma catchment is

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harms by threats of floods, natural water retention, water scarcity and water availability. The hydrology of the study area is adversely affected due to the rapid change in landuse and landcover caused by conversion of forest to agricultural land, residential building construction, coal mining, bush stick and timber harvesting. People are continuously encroached in the forested areas and waste lands, cleared them for different uses highlighted above, and expanding it in the built up areas.

The most important input for the design of stormwater drainage system for urbanized cities and environs are rainfall Intensity-Duration-Frequency (IDF) relationships (Chawathe et al., 1977). In order for water resources engineers to effectively and efficiently plan, design and operate all related water resources projects, they need to developed IDF relationships for the facilities of the projects (Koutsoyiannis et al., 1998). Sherman (1931) and Bernard (1932) assessed extreme precipitation in the development of IDF curves in order to determine the associated hydrologic risks. Kuichling (1889) demonstrated the relationship between rainfall intensity and duration using maximum discharges of runoff.

Chow et al. (1988), Stedinger (1993) and Smith (1993) established that the frequent cause of social, environmental and economic disasters are extreme rainfall events which are very significant in risk assessments and hydrologic designs, that has yield dividend in recent hydrologic science and engineering studies which modeled extreme rainfall events quantitatively. One of the most significant tools used for planning, designing and operating of water resources development infrastructures is the rainfall IDF relationship (Chawathe et al., 1977; Koutsoyiannis et al., 1998). The IDF relationship gives an idea of the rainfall intensity return period which can be expected within a defined period (Sherman, 1931; Bernard, 1932; Kuichling, 1889; Bell, 1969; Chen, 1983). The IDF relationship also provides precise information of the maximum intensity of rain that falls within a given period of time

Chow (1964), Dupont and Allen (1999) established that the development of IDF relationships requires historical data of good quality and long term continuity was done as early as 1931 and these type of historical data are not normally available in most countries, especially the Guma catchment in Sierra Leone which is greatly affected by data scarcity. Koutsoyiannis et al. (1998) established that since 1931 numerous IDF relationships have been developed for many catchments of countries in the world, but many of these IDF relationships were not constructed accurately for some of the developing countries.

The Guma catchment has been affected by human activities that have lead to the rapid increase in human settlements that produce negative impacts on water resources. The continuous misuse of the available factors affecting water resources in the catchment has resulted into water shortage during the dry season and flooding during the monsoon period. Water shortage in a tropical rainfall municipality can be managed, but flooding within a data scare urbanized environments are difficult to manage. Residents living along the flood plain and coastal areas subjected to runoffs from the Guma catchment are experiencing floods more than once in a year. Two of such events are the September 16, 2015 and August 14, 2017 flooding which were the most devastating flooding in the history of Sierra Leone that lead to the displacement of thousands, significant property damage and loss of lives. With the frequent occurrence of flooding due to poor drainage design and anthropogenic activities affecting the landuse and landcover of the Municipality of Freetown, rainfall intensity-duration-frequency curves are vital tool to help mitigate such problems of designing, management and planning of drainage structures. The objective of this paper is to develop RIDF relationships for the Guma catchment by statistical method.

MATERIALS AND METHODS

Data availability

District boundary map, streams map, landuse-landcover map and 50k toposheet of Sierra Leone in GIS layer were obtained from the Ministry of Environment and Country Planning, while daily rainfall data from 1991 to 2018 for the Guma catchment was obtained from the Sierra Leone Meteorology Agency (SLMet). Apart from daily rainfall and temperature data, no other data are available for the Guma catchment.

The method applied in this study is purely frequency analysis. Daily rainfall data of the Guma catchment were collected from the Sierra Leone Meteorological Agency and the maximum daily rainfall data for each year are converted to shorter duration using semi-empirical method of the India Meteorological Department (IMD). The districts boundary map and 50k toposheet of Sierra Leone were utilized in the Spatial Analyst Tools in the ArcGIS Software in order to delineate the Guma catchment. These converted rainfall data were used to develop the RIDF relationships and curves for Guma catchment using Microsoft Excel Spreadsheet.

Description of study area

The Guma catchment area is located within the Freetown peninsula and with a total area of 8.344 km^2. The Freetown peninsula which is situated within the Western Urban Area of Sierra Leone which is a mountainous peninsula and lies between latitudes 8°29’13.7’’N and longitudes 13°14’8.2’’W, covering an area of approximately 663 km^2. The Guma catchment is unique in Sierra Leone as it is the only mountainous region by the coast.

The Guma catchment enclosed the Guma dam which is an embankment dam (earth and rock fill) constructed in February 4, 1967 for water supply to the Freetown and environ of a population of 169,000 and a catchment area of 8.66 km^2. The full storage level of the reservoir is 261.12 m above sea level with a maximum height of 67.64 m above the river bed. The embankment volumes of earth and rock fills were approximately 723,000 and 324,000 Cumecs respectively, with a filter material of approximately 324,000 Cumecs. The mountain stretch which is mainly underlain by a relatively impermeable intrusive body of layered gabbros with

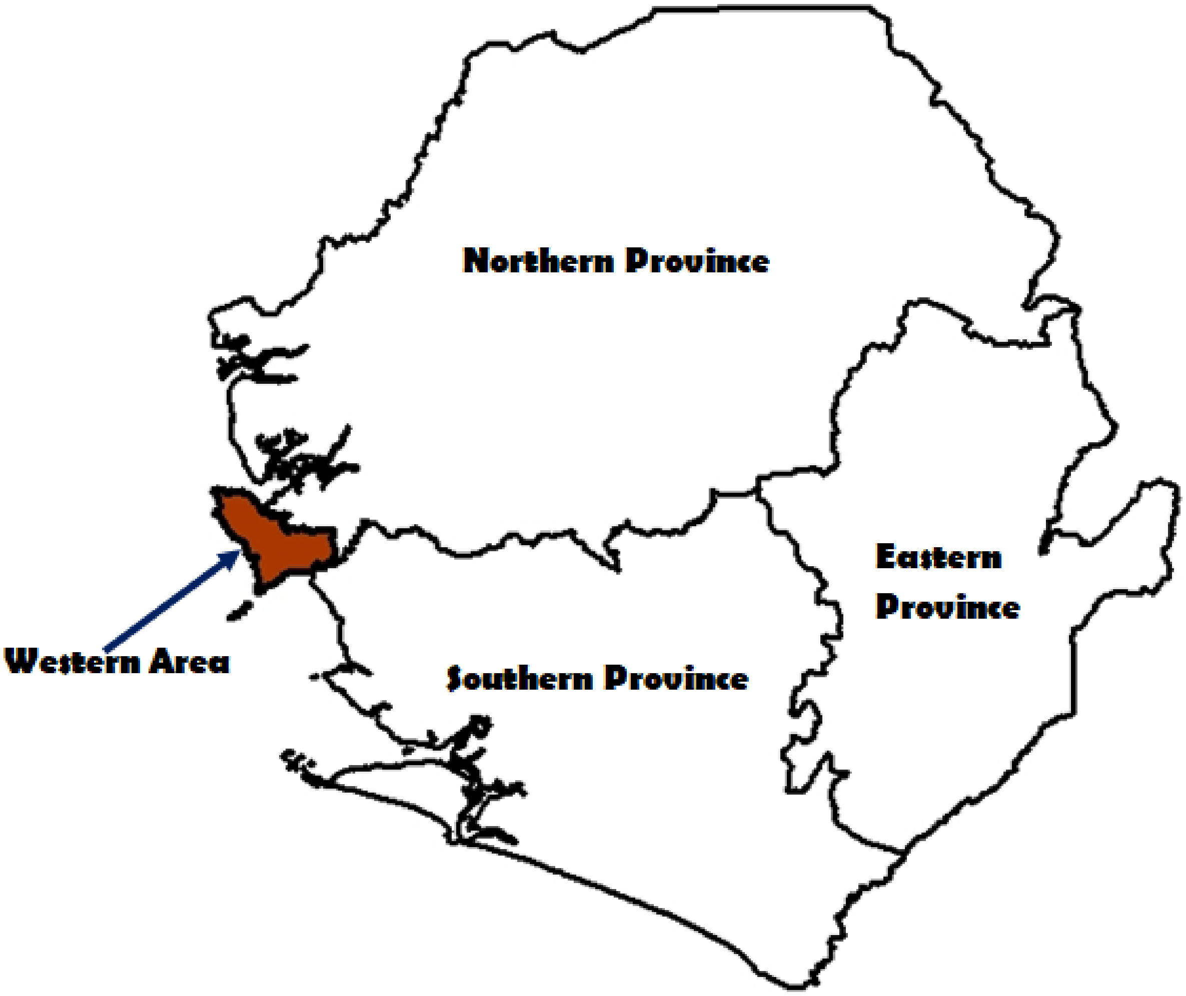

Figure 1. Provincial map of Sierra Leone.

laterite soil at the top constitutes the steep topography of the area. This stretch which is about 37.0 km^2 and about 14.5 km^2 wide at its widest is marked with narrow valleys and few plunging waterfalls.

Just at the foot of the mountains along the coastline of the peninsula area series of outcrops of relatively flat but well drained lands and a number of raised beaches. Several streams and rivers flow from the mountains in the peninsula and these streams have been the source of water supply for Freetown and the surrounding villages. The river Guma which was dammed during the early 1960's now supplies Freetown and some of the surrounding seaside villages with good pipe-borne water supply. The Guma catchment is mainly covered by secondary forest, but a substantial amount of the forest reserves have becomes denuded due to increased farming and residential activities on the slopes of the mountains.

The spine of the peninsula comprises of hard rock formed by mountains of heights about 914.4 km and drop steeply to the sea on the west where the mountains have founded. The foot of the hills comprises of excellent beaches and the indication of old shoreline is due to the presence of coastal platforms at several levels. The provincial map of Sierra Leone indicating the location of Guma catchment is shown in Figure 1, while the Western Area map and delineated Guma catchment are shown in Figure 2 and the drainage network map of the Guma catchment is shown in Figure 3.

Data analysis

Data analysis involves the conversion of maximum daily rainfall data to hourly rainfall data, discussion of the probability distributions, development of the IDF relationships and performing goodness of fit test for the probability distributions.

Maximum daily rainfall data

The rainfall data for Guma catchment consists of the daily rainfall values from 1991 to 2018. The data is processed in order to obtain the maximum rainfall series. The extreme annual rainfall series for Guma catchment is shown in Table 1. The Indian Meteorological Department (IMD) formula used to convert extreme rainfall series presented in Table 4 to shorter duration series (1, 2, 3, 4,…………, 24 h series) is given as:

$$P_t = P_{24}\left(\frac{t}{24}\right)^{1/3} \quad (1)$$

where P_t is the rainfall of t hours duration in mm, P_{24} is the daily rainfall value in mm and t is the shorter duration in hours (1, 2, 3…).

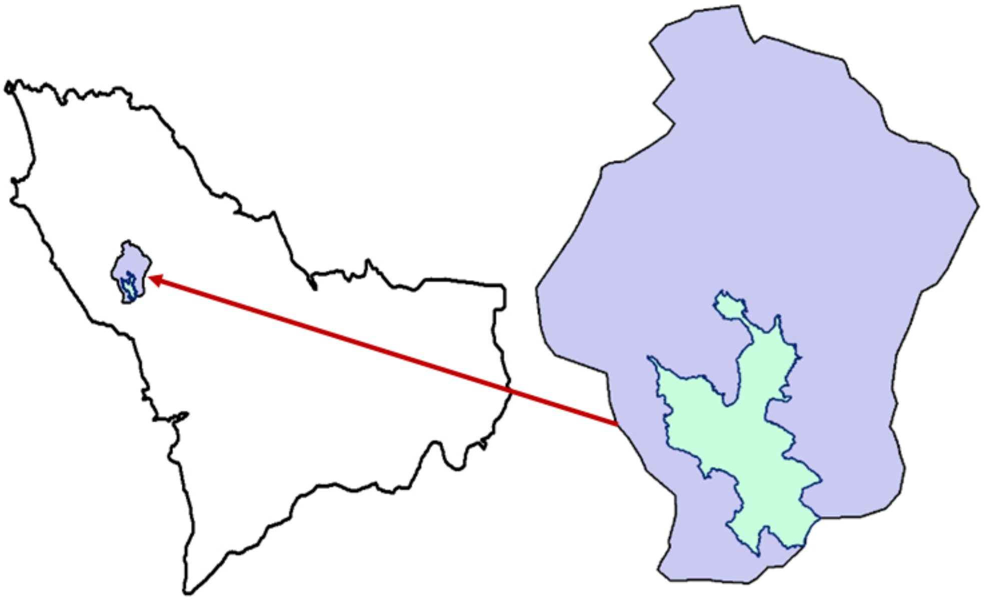

Figure 2. Western area boundary map and delineated Guma catchment.

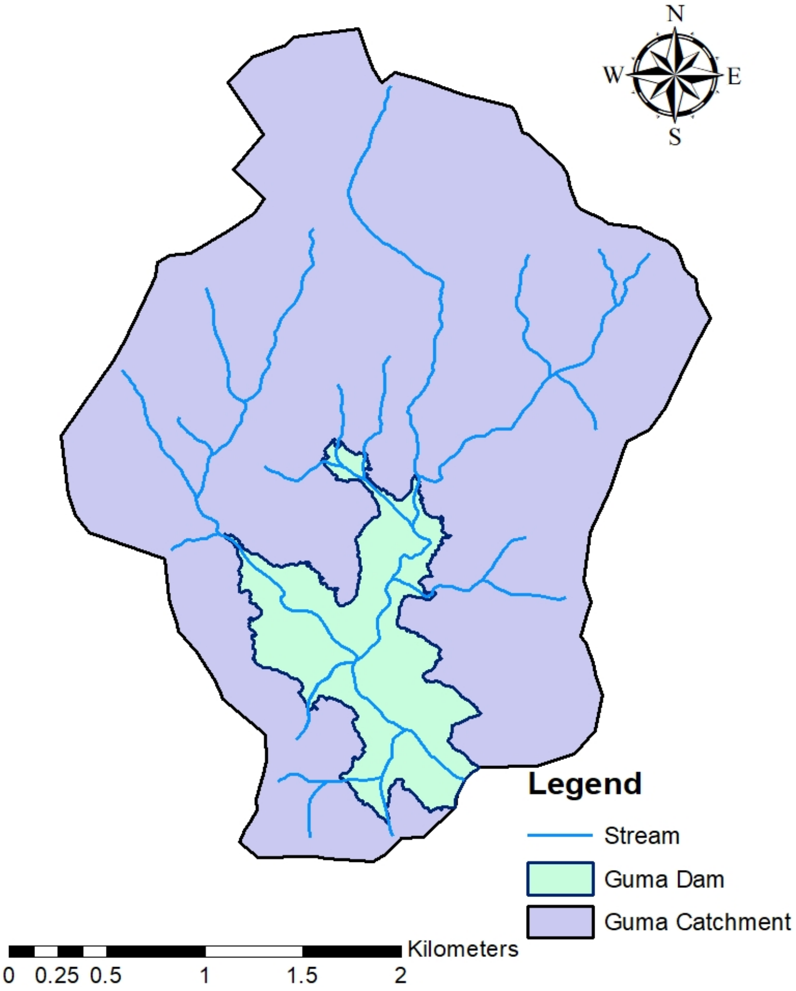

Figure 3. Delineated Guma catchment drainage network map.

Table 1. Maximum rainfall series data for Guma catchment.

S/N	Year	Maximum annual rainfall series (mm)
1	1991	285.00
2	1992	537.00
3	1993	176.00
4	1994	287.00
5	1995	306.00
6	1996	365.00
7	1997	352.00
8	1998	356.00
9	1999	279.00
10	2000	282.70
11	2001	231.14
12	2002	364.24
13	2003	308.61
14	2004	381.00
15	2005	393.70
16	2006	349.25
17	2007	497.84
18	2008	219.71
19	2009	230.63
20	2010	321.06
21	2011	396.75
22	2012	275.59
23	2013	283.97
24	2014	338.33
25	2015	527.56
26	2016	248.92
27	2017	359.20
28	2018	248.20

Table 2. Parameters for extreme rainfall data for Guma Dam catchment station.

Parameter	Guma Dam rainfall station
Mean ($\bar{X}$)	328.62
Standard deviation (SD)	88.12
Coefficient of Variation (C_v)	0.27
Coefficient of Skewness (C_s)	0.88
Coefficient of Kurtosis (C_k)	0.703

Probability distributions

In probability theory, several distributions are generally considered for frequency analysis of meteorological variables. The frequency distribution parameters of the extreme rainfall data are computed in order to understand the general trends, suitability and adaptability in the data. Table 2 shows the frequency distribution parameters for the Guma Dam rainfall station. From Table 2, it was realized that the extreme data set for the Guma Dam rainfall station was skewed. In view of this, the normal and the log-normal distributions were not considered in the analysis. In this research, the two most popular probability distributions which are the Gumbel and Pearson Type III (Chow, 1964; Yevejevich, 1972) are used for the computation of maximum rainfall intensity for various return periods.

Gumbel's Distribution

This distribution utilizes the Fisher-Tippet extreme value function, which relates magnitude linearly with the logarithm of the reciprocal of the exceedance probability given as:

$$P_T = P_{ave} + K_T S \quad (2)$$

$$K_T = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right] \quad (3)$$

$$P_{ave} = \frac{1}{n}\sum_{i=1}^{n} P_i \quad (4)$$

$$S = \left[\frac{1}{n-1}\sum_{i=1}^{n}(P_i - P_{ave})^2\right]^{1/2} \quad (5)$$

where P_T is the probable rainfall at return period T, P_{ave} is the mean of the annual maximum rainfall series, S is the standard deviation of annual maximum rainfall series, K_T is the frequency factor at return period T, P_i is the annual maximum rainfall series, T is the return period and n is the number of years of record. The rainfall intensity, I_T in mm/hr for the return period T is given by:

$$I_T = \frac{P_T}{T_d} \quad (6)$$

where T_d is the duration in hours.

Pearson Type III distribution

Pearson Type III distribution is one of the members of the distribution suggested by Pearson with maximum series of rainfall data. The parameters used are the mean, standard deviation and coefficient of skewness. The simplified expression for the PT-III distribution is given as follows:

$$P_T = P_{ave} + K_T S^* \quad (7)$$

$$P_{ave} = \frac{1}{n}\sum_{i=1}^{n} P_i \quad (8)$$

$$S^* = \sqrt{\frac{\Sigma(P^* - P^*_{ave})^2}{N-1}} \quad (9)$$

$$C_S = \frac{N\,\Sigma(P_i - P_{ave})^3}{(N-1)(N-2)(S^*)^3} \quad (10)$$

where P_{ave} is the mean of the annual maximum rainfall series, K_T is the frequency factor which is a function of return period T and coefficient of skewness C_S, S* is the standard deviation of the annual maximum rainfall series, C_S is the coefficient of skewness of the annual maximum rainfall series, P_i is the annual maximum rainfall series, T is the return period and N is the sample size = number of years of record.

Derivation of IDF relationships

The IDF relationships are empirical equations representing maximum rainfall intensity, rainfall duration and recurrence interval. The derivation of an empirical relationship for the Guma catchment involved several steps. The power law relationship between rainfall intensity, frequency of occurrence and rainfall duration to be derived for the Guma catchment is given by Chow et al. (1988); Koutsoyiannis et al. (1998); AlHassoun (2011) and Elsebaie (2012):

$$I_T = \frac{CT^m}{t^n} = \frac{a}{t^n} \quad (11)$$

where I_T is the rainfall intensity in mm/hr, T is the frequency of occurrence in year, t is the duration of the storm in hours, and C, m and n are regional constants to be determined from the given precipitation data using logarithmic relationships (Elsebaie, 2012; Akpen et al., 2019). This approach is outlined below.

Goodness of fit test

The Kolmogorov - Smirov (K-S) goodness of fit test is an alternative to the chi-square test, but the advantage of the K-S test over the chi-square test is that it does not lump the data and compare only the discrete categories. It is easier to compute and more convenient to adopt when the sample size is small. The K-S test statistic Δ is expressed as:

$$\Delta = \text{Max}_{i=1}^{n}|P(x_i) - F(x_i)| \quad (12)$$

$$F(x_i) = e^{-e^{-\left(\frac{X-\mu}{\sigma}\right)}} \quad (13)$$

where $P(x_i)$ is the cumulative probability for each of the observations computed using the Weibull's formula, $F(x_i)$ is the theoretical cumulative probability for each of the observation obtained using the assumed distribution, X is the annual rainfall series, μ and σ are the mean and standard deviation of the annual rainfall series, respectively.

The critical value of K-S statistic Δ_o for a given significance value of α can be obtained from standard table form numerous hydrology references such as Chow et al. (1988). If $\Delta < \Delta_o$, accept the hypothesis that assumed the distribution is a good fit.

RESULTS AND DISCUSSION

From the converted hourly maximum annual rainfall series (P_i), the statistical parameters such as the average and standard deviation for the duration 10, 20, 30, 60, 120, 180, 360, 720 and 1440 min were computed. The computed probable rainfall (P_T) values and rainfall intensities (from Equation 6) for different durations and return periods using the Gumbel's and PT-III distributions are shown in Tables 3 and 4 respectively. From Tables 3 and 4, it can be seen that the Gumbel's and Pearson Type III distributions rainfall estimates increased with an increased in the return period and the rainfall intensities decreased with an increased in rainfall durations for all return periods. The rainfall intensities increased with an increased in rainfall return periods. The good consistency between the Gumbel's and Pearson Type III distributions is established from the computed results.

Determination of constants 'a' and 'n'

In order to determine the constants 'a' and 'n' of Equation

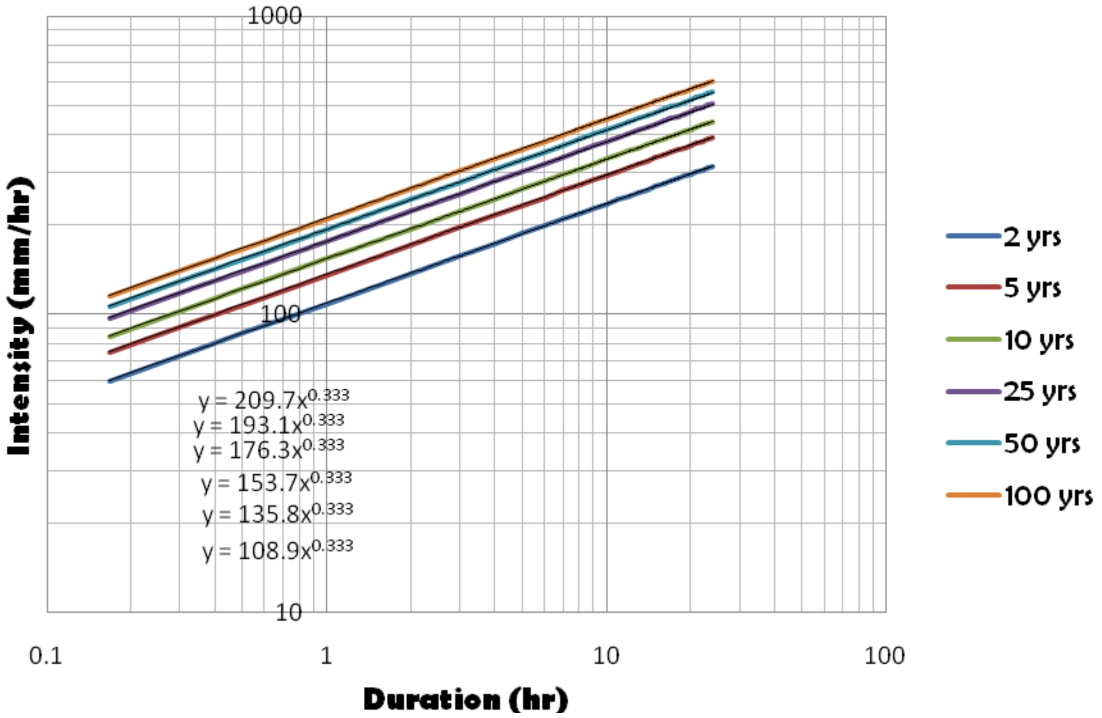

Figure 4. Values of ‘a’ and ‘n’ of rain storm for Gumbel distribution.

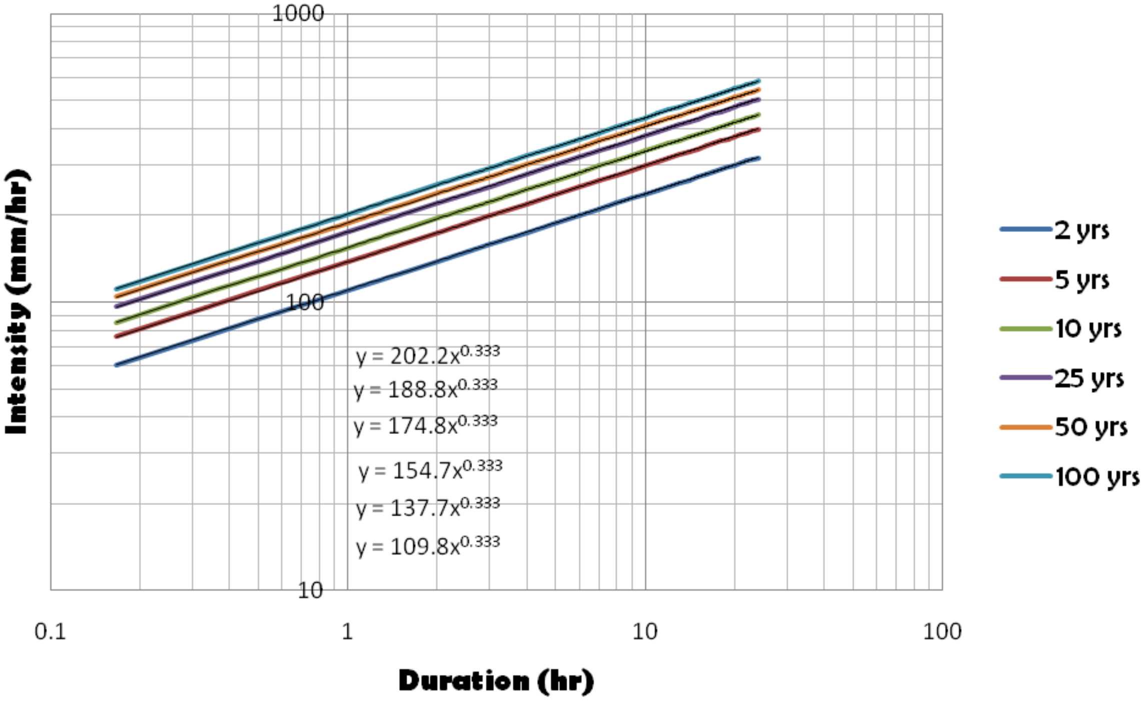

Figure 5. Values of ‘a’ and ‘n’ of rain storm for Pearson Type III Distribution.

11, the intensity duration of the rain storm is plotted on a log-log graph as shown in Figures 4 and 5 for the Gumbel and Pearson Type III distributions respectively. The data for the graph is taken from Tables 3 and 4 for the Gumbel

Table 3. Probable rainfall for different durations and return periods using Gumbel's distribution.

T (year)	10 min			20 min			30 min		
	P_{ave} = 67.74 S = 16.82			P_{ave} = 98.97 S = 21.17			P_{ave} = 90.42 S = 24.25		
	K_T	P_T	I_T	K_T	P_T	I_T	K_T	P_T	I_T
2	-0.164	59.98	359.87	-0.164	75.49	226.48	-0.164	86.45	172.89
5	0.719	74.83	449.00	0.719	94.19	282.57	0.719	107.86	215.71
10	1.305	84.69	508.15	1.305	106.60	319.80	1.305	122.07	244.13
25	2.044	97.12	582.75	2.044	122.25	366.74	2.044	139.98	279.97
50	2.592	106.34	638.06	2.592	133.85	401.55	2.592	153.27	306.54
100	3.137	115.51	693.07	3.137	145.39	436.17	3.137	166.49	332.97

T (year)	60 min			120 min			180 min		
	P_{ave} = 113.93 S = 30.55			P_{ave} = 143.54 S = 38.49			P_{ave} = 164.31 S = 44.06		
	K_T	P_T	I_T	K_T	P_T	I_T	K_T	P_T	I_T
2	-0.164	108.92	108.92	-0.164	137.23	68.61	-0.164	157.08	52.36
5	0.719	135.89	135.89	0.719	171.21	85.61	0.719	195.99	65.33
10	1.305	153.79	153.79	1.305	193.77	96.88	1.305	221.81	73.94
25	2.044	176.37	176.37	2.044	222.21	111.11	2.044	254.37	84.79
50	2.592	193.11	193.11	2.592	243.30	121.65	2.592	278.51	92.84
100	3.137	209.76	209.76	3.137	264.28	132.14	3.137	302.53	100.84

T (year)	360 min			720 min			1440 min		
	P_{ave} = 207.02 S = 55.51			P_{ave} = 260.83 S = 69.94			P_{ave} = 328.62 S = 88.12		
	K_T	P_T	I_T	K_T	P_T	I_T	K_T	P_T	I_T
2	-0.164	197.91	32.99	-0.164	249.36	20.78	-0.164	314.17	13.09
5	0.719	246.93	41.16	0.719	311.11	25.93	0.719	391.98	16.33
10	1.305	279.46	46.58	1.305	352.10	29.34	1.305	443.62	18.48
25	2.044	320.49	53.41	2.044	403.79	33.65	2.044	508.74	21.20
50	2.592	350.91	58.48	2.592	442.11	36.84	2.592	557.03	23.21
100	3.137	381.16	63.53	3.137	480.23	40.02	3.137	605.05	25.21

and Pearson Type III distributions respectively.

From Figure 2, n = 0.333 and values of a = 108.9, 135.9, 153.7, 176.3, 193.1 and 209.7 for 2-year, 5-year, 10-year, 25-year, 50-year and 100-year recurrence intervals. While from Figure 3, n = 0.333 and values of a = 109.8, 137.7, 154.7, 174.8, 188.8 and 202.2 for 2-year, 5-year, 10-year, 25-year, 50-year and 100-year recurrence intervals

Determination of constants 'C' and 'm'

The constants C and m of the IDF relationship are determined by plotting the computed values of 'a' against corresponding recurrence intervals on log-log Scale. The resulting graphs are shown in Figures 6 and 7 for the Gumbel and Pearson Type III distributions respectively. Values obtained for the Gumbel distribution are C = 101.7 and m = 0.164 and that for Pearson Type III Distribution are C = 104.6 and m = 0.151. The rainfall intensity frequency duration curve for both the Gumbel and Pearson Type III distributions are shown in Equations 14 and 15 respectively.

$$I_T = \frac{101.7T^{0.164}}{t^{0.333}} \qquad (14)$$

$$I_T = \frac{104.6T^{0.151}}{t^{0.333}} \qquad (15)$$

Plotting of RIDF curves

In order to plot the rainfall intensity – frequency – duration curves 2-year, 5-year, 10-year, 25-year, 50-year and 100-year recurrence periods for the Gumbel and Pearson Type III distributions, Equations 14 and 15 are employed respectively. The rainfall intensity – frequency – duration curves for the Gumbel and Pearson Type III distributions are shown in Figures 8 and 9 respectively.

Goodness of fit test was used to choose the best probability distribution among the two techniques. Results

Table 4. Probable rainfall for different durations and return periods using Pearson Type III distribution.

T (year)	10 min			20 min			30 min		
	P_{ave} = 62.74 S = 16.82			P_{ave} = 78.97 S = 21.17			P_{ave} = 90.42 S = 24.25		
	K_T	P_T	I_T	K_T	P_T	I_T	K_T	P_T	I_T
2	-0.132	60.52	363.10	-0.132	76.17	228.51	-0.132	87.22	174.45
5	0.78	75.86	455.16	0.78	95.48	286.45	0.78	109.34	218.67
10	1.336	85.21	511.28	1.336	107.26	321.77	1.336	122.82	245.64
25	1.993	96.27	577.60	1.993	121.17	363.50	1.993	138.75	277.50
50	2.453	104.01	624.03	2.453	130.91	392.72	2.453	149.90	299.80
100	2.891	111.37	668.24	2.891	140.18	420.55	2.891	160.52	321.04

T (year)	60 min			120 min			180 min		
	P_{ave} = 113.93 S = 30.55			P_{ave} = 143.54 S = 38.49			P_{ave} = 164.31 S = 44.06		
	K_T	P_T	I_T	K_T	P_T	I_T	K_T	P_T	I_T
2	-0.132	109.89	109.89	-0.132	138.46	69.23	-0.132	158.49	52.83
5	0.78	137.76	137.76	0.78	173.56	86.78	0.78	198.68	66.23
10	1.336	154.74	154.74	1.336	194.96	97.48	1.336	223.17	74.39
25	1.993	174.81	174.81	1.993	220.25	110.12	1.993	252.12	84.04
50	2.453	188.86	188.86	2.453	237.95	118.98	2.453	272.39	90.80
100	2.891	202.25	202.25	2.891	254.81	127.41	2.891	291.69	97.23

T (year)	360 min			720 min			1440 min		
	P_{ave} = 207.02 S = 55.51			P_{ave} = 260.83 S = 69.94			P_{ave} = 328.62 S = 88.12		
	K_T	P_T	I_T	K_T	P_T	I_T	K_T	P_T	I_T
2	-0.132	199.69	33.28	-0.132	251.59	20.97	-0.132	316.99	13.21
5	0.78	250.32	41.72	0.78	315.38	26.28	0.78	397.35	16.56
10	1.336	281.18	46.86	1.336	354.27	29.52	1.336	446.35	18.60
25	1.993	317.65	52.94	1.993	400.22	33.35	1.993	504.24	21.01
50	2.453	343.19	57.20	2.453	432.39	36.03	2.453	544.78	22.70
100	2.891	367.50	61.25	2.891	463.03	38.59	2.891	583.38	24.31

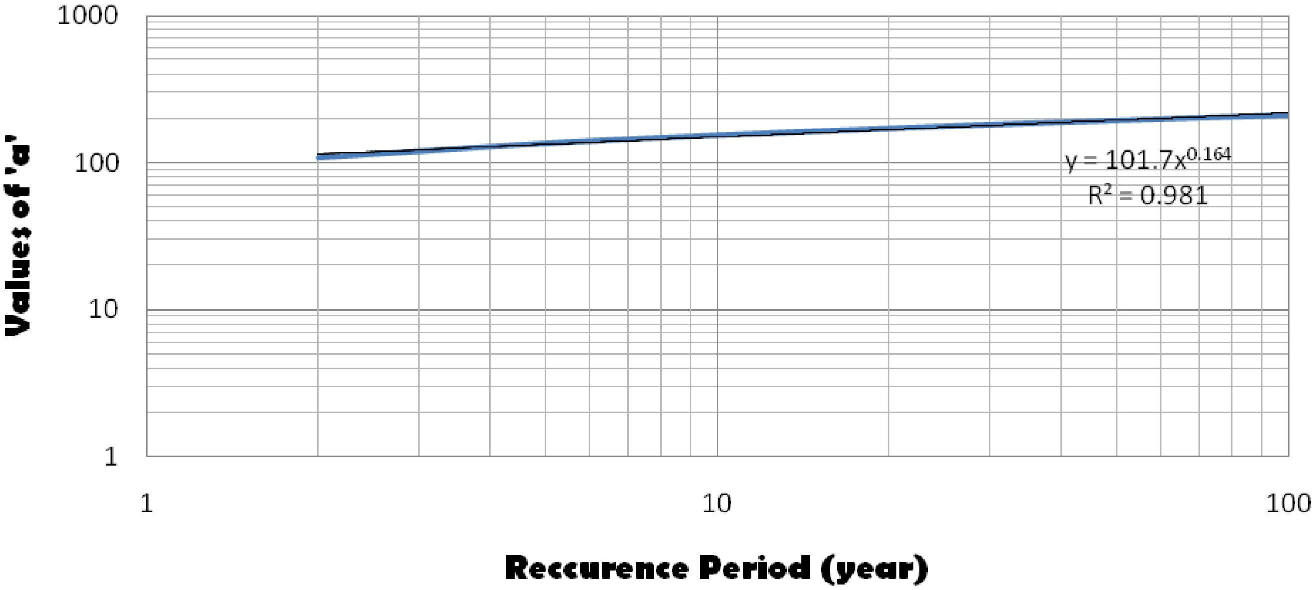

Figure 6. Values of ‘C’ and ‘m’ for storm rainfall for Gumbel distribution.

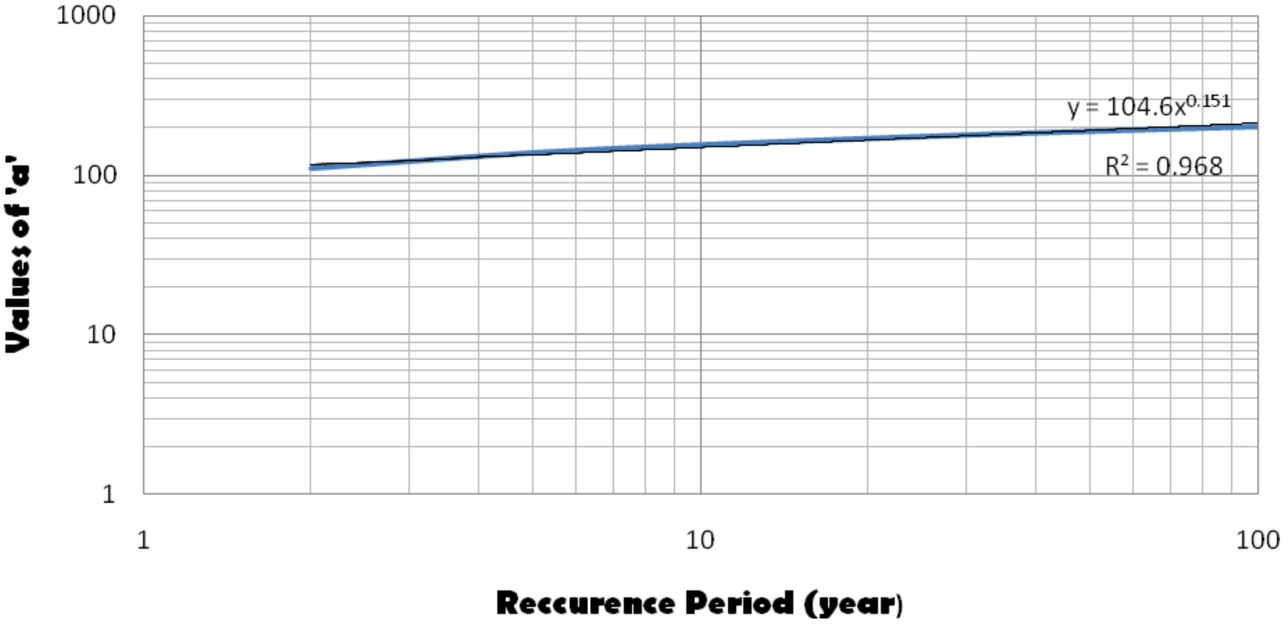

Figure 7. Values of ‘C’ and ‘m’ for storm rainfall for Pearson Type III distribution.

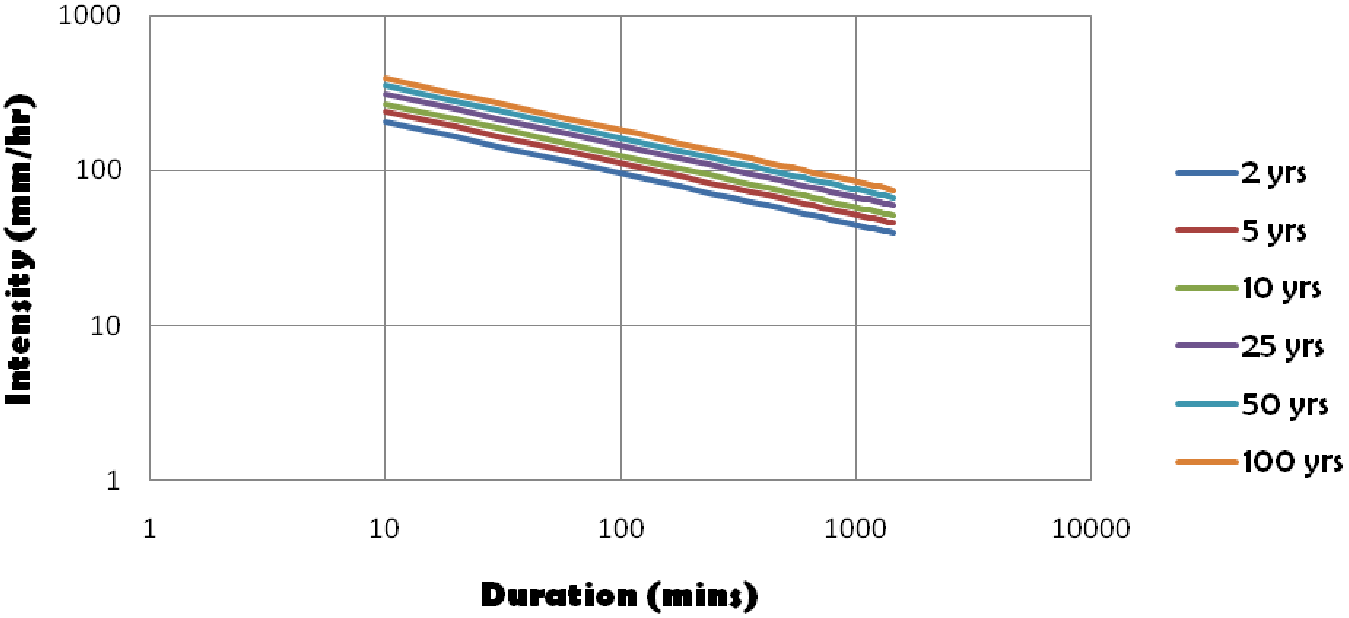

Figure 8. RIDF Curves for Guma catchment by Gumbel distribution.

of the Kolmogorov – Smirov (K-S) goodness of fit test on annual series for 2, 5, 10, 25, 50 and 100 yrs recurrence interval of rainfall are shown in Table 5. From the results of the K-S goodness of fit test on annual series of rainfall, it can be seen that the data fit the Gumbel distributions at the level of significance of $\alpha = 0.05$, which yields $\Delta_0 = 0.24 > \Delta$, and $\alpha = 0.01$, which yields $\Delta_0 = 0.29 > \Delta$ for a sample size of 30 for 2, 5, 10, 25, 50 and 100 yrs recurrence interval of rainfall. It can also be seen that the data do not give fit the Pearson Type III distribution at the level of significance of $\alpha = 0.05$, which yields $\Delta_0 = 0.24 < \Delta$, and $\alpha = 0.01$, which yields $\Delta_0 = 0.29 < \Delta$ for a sample size of 30 for 2, 5, 10, 25,

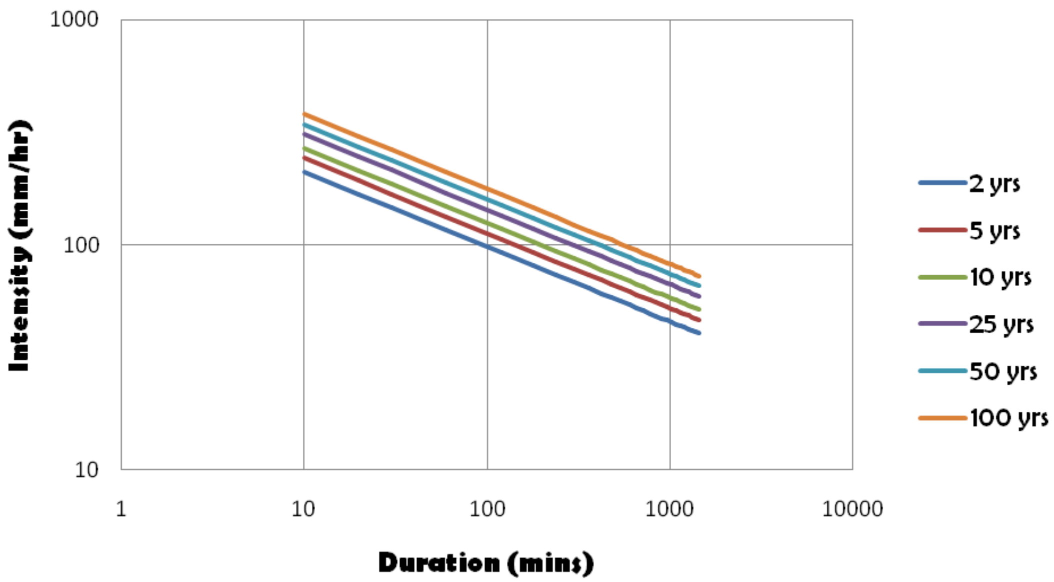

Figure 9. RIDF curves for Guma catchment by Pearson Type III distribution.

Table 5. K - S Goodness Values of Annual Maximum Rainfall at Different Return Periods for Gumbel's and Pearson Type III Distribution for Guma Catchment.

Catchment	Return period (Years)	Distribution	
		Gumbel	Pearson Type III
Guma	2	0.22127	0.36152
	5	0.22121	0.36149
	10	0.22122	0.36147
	25	0.22126	0.36148
	50	0.22123	0.36152
	100	0.22125	0.36149

50 and 100 years recurrence interval of rainfall.

Conclusions

This study has been conducted for the formulation and construction of IDF relationship using two probability distributions. Utilizing these methods, the IDF relationships developed can be used in other parts of Guma catchment. The following conclusions can be made from this analysis:

(i) That the adaptability of the Indian Meteorological Department (IMD) method for the conversion of daily rainfall data to hourly rainfall data for the Guma catchment rainfall station is unquestionable, especially when shorter duration rainfall data are not available.

(ii) The frequency analysis shows that the Gumbel distribution gives a maximum intensity of 393.05 mm/h at return period of 100 years with duration of 0.167 h and minimum intensity of 39.54 mm/h at return period of 2 years with duration of 24 h. The Pearson Type III distribution gives a maximum intensity of 390.76 mm/h at return period of 100 years with duration of 0.167 h and minimum intensity of 40.31 mm/h at return period of 2 years with duration of 24 h.

(iii) The K-S goodness of fit test shows that all of the data fit the Gumbel distribution at the level of significance of $\alpha = 0.05$, which yields $\Delta =< 0.24$, and $\alpha = 0.01$, which yields $\Delta =< 0.29$ for a sample size of 30 (as sample size of study was 28), while the data do not give good fit using the Pearson Type III distribution at both levels of significance for 2, 5, 10, 25, 50 and 100 yrs recurrence interval of rainfall.

(iv) The results obtained from the frequency analysis and K_S goodness of fit test shows that the IDF curves and relationships developed by the Gumbel distribution can be practically utilize for the design of drainage structures for the study area added as part of the conclusions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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