



Analysis of Rainfall Intensity Duration Frequency Curves for Zaria-Nigeria

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ABSTRACT

Analysis of a design storm, explained as the expected rainfall intensity for a given storm duration and return period was carried out to establish Rainfall Intensity Duration Frequency (IDF) relationships. The IDF relationships are essential for the designing of hydraulic structures for future planning and management. The intent was to determine IDF relationship for Zaria in Kaduna State. This region receives heavy rainfall and rain gauge stations are not so frequent. Under this condition, the engineers are bound to use IDF for design of hydraulic facilities. Using the 24-hour annual maximum rainfall and disaggregated hourly maximum rainfall as a measure of rainfall intensity for each station, IDF curves of rainfall intensities of 30-minute to 24-hour durations were generated. Analysis was done using the Gumbel distribution functions. The IDF relationship developed can be used as valuable information for the planning and management of hydraulic structures in the region.

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INTRODUCTION

Precipitation intensity duration frequency curves relationship is one of most usually helpful apparatus in hydraulic and engineering hydrology for plan, design, operation and maintenance of hydraulics structures (Yasin *et. al.*, 2019). The utilization of an intensity duration frequency curves relationships have normal practice for many years in favor of design in an open drain channels with additional water resources projects. It provide the idea about rate of recurrence or return period of a signify rain strength or precipitations capacity to be estimated in definite episode, that is rainstorm period (Hatem *et. al.*, 2018). In common logic the snowstorm period is a reproduction factor that can contain any part of a rain occurrence. Also, during computer era it supplies a set of information on the rainwater and they can be used for the strength of mind of storms design. A motive is that there is a physical base relation between hydrological analysis and hydraulic plan which is the application point in time (Woyal and Kiran, 2014).

Moreover, in various countries flood is the most likely major vulnerability among the natural

hazards occurring due to change in precipitation pattern. The construction and analysis of rainfall intensity duration frequency curves relationship is a key vital input for the blueprint of rainwater drainage systems for urban areas (Zope and Eldho, 2016). Therefore, generating an intensity duration frequency curves relationships is a very good idea. In conducting the task, it is essential to compute the yearly maximum rainfall intensities for various durations (Roberto *et. al.*, 2020). Then, in most urban catchment IDF values are notably different. This difference has the ability to change a magnitude of rainwater system design and construction (Lauren *et. al.*, 2020).

Furthermore, in hydrologic studies, the estimation of extreme rainfall is significant, analysis of return periods and design values are also very essential in planning and management of hydraulic structures and forecast of weather conditions associated with difficulty resting on understanding of the occurrence of these excessive actions. Therefore, intensity duration frequency curves present helpful information on what time the flooding in a region and precipitation rate will come



MATERIALS AND METHODS

Rainfall records were collected from the IAR Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria for 36 years from 1978 to 2013. The IDF curves relationships were obtained through frequency analysis of rainfall data observations using the following process:

1. The rainfall records were arranged in descending order.
2. Rank number was assigned starting from 1.
3. The frequencies factors linked with the desired return periods were computed.
4. The average and standard deviation of succession yearly maxima were determined.
5. A rainfall intensity related with each return period was calculated.
6. The results were plotted to produce the IDF curves.

Theoretical Extreme Value (EV) Distribution Approach

The Gumbel extreme value distribution, at times called the double exponential distribution of extreme values, is found fit for the available data and consequently was used to illustrate the distribution of hydrologic variables, particularly peak discharges. Gumbel extreme value distribution analysis is adopted here for daily extreme design rainfall analysis. Here, the rainfall data were evaluated to reach the respective design rainfall of the project area.

The Gumbel Type I distribution was selected as our EV distribution function.

The function is given by:

$$G(x, \mu, \beta) = \frac{1}{\beta} e^{\frac{x-\mu}{\beta}} e^{-e^{\frac{x-\mu}{\beta}}} \quad (1)$$

Where;

x = Rainfall depth

μ = Location parameter

β = Scale parameter

Average value as well as standard deviation was obtained from the following relationships;

$$\bar{X} = \frac{\sum X}{n} \quad (2)$$

$$\sigma = \sqrt{\frac{\sum X^2 - \frac{1}{n}(\sum X)^2}{n-1}} \quad (3)$$

Where;

\bar{X} = Mean value of rainfall data (daily) [mm]

n = Total number of X (individual data)

X = Rainfall depth [mm]

σ = Standard deviation [mm]

The value of the random variable X_T linked with a given return period was obtained from the following expression:

$$X_T = \bar{X} + K_T S \quad (4)$$

Where;

\bar{X} = Mean value

S = Standard deviation

The frequency factor connected with return period T , K_T , is given by

$$K_T = -\frac{\sqrt{6}}{\pi} [0.5772 + \ln(\ln(\frac{T}{T-1}))] \quad (5)$$

Where;

T = Return Period

RESULTS AND DISCUSSION

The rainfall analysis was carried using the Gumbel (Type I) distribution method based on the available data obtained. The table I shows the mean annual 24 hours heaviest rainfall series. Table II indicates the ranking arrangement of mean annual 24 hours heaviest rainfall data denoted as X (mm). The rainfall IDF curves relationships designed for project area was calculated based on 2, 5, 10, 25, 50, 100 and 1000 years return periods as depicted in Table III. Table VI gives the complete idea of relationship between return periods T , in years and durations in hours then, if the return period increase the intensity also increase for a given duration, if the durations increases likewise intensities



decreases. When the return period is 2 years the intensity is 131.071 mm/hr and when it is 1000 years return periods the intensity is 722.860

mm/hr. Also, for 0.08 hr duration the intensity is 131.071 mm/hr then, for durations of 24 hr the intensity is 3.131mm/hr.

Table I: Mean Annual 24 hours heaviest rainfall series

Year	Annual Daily heaviest(mm)	Year	Annual Daily heaviest(mm)
1978	77.7	1996	47
1979	101.6	1997	47.6
1980	70	1998	110
1981	100.7	1999	58
1982	59.7	2000	70.5
1983	48.4	2001	103.3
1984	53	2002	72
1985	104.2	2003	91
1986	110	2004	69.5
1987	81.6	2005	47.8
1988	114.7	2006	57.7
1989	56.6	2007	74
1990	46.5	2008	94.9
1991	52.5	2009	439.7
1992	91.6	2010	66.7
1993	75	2011	96.6
1994	53.5	2012	78
1995	90.5	2013	86.5

Table II: Annual 24 hours heaviest rainfall series

Rank	Year	X(mm)	X ²
1	2009	439.70	193336.1
2	1988	114.70	13156.1
3	1986	110.00	12100.0
3	1998	110.00	12100.0
5	1985	104.20	10857.6
6	2001	103.30	10670.9
7	1979	101.60	10322.6
8	1981	100.70	10140.5
9	2011	96.60	9331.6
10	2008	94.90	9006.0
11	1992	91.60	8390.6
12	2003	91.00	8281.0
13	1995	90.50	8190.3
14	2013	86.50	7482.3
15	1987	81.60	6658.6
16	2012	78.00	6084.0
17	1978	77.70	6037.3
18	1993	75.00	5625.0
19	2007	74.00	5476.0
20	2002	72.00	5184.0

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21	2000	70.50	4970.3
22	1980	70.00	4900.0
23	2004	69.50	4830.3
24	2010	66.70	4448.9
25	1982	59.70	3564.1
26	1999	58.00	3364.0
27	2006	57.70	3329.3
28	1989	56.60	3203.6
29	1994	53.50	2862.3
30	1984	53.00	2809.0
31	1991	52.50	2756.3
32	1983	48.40	2342.6
33	2005	47.80	2284.8
34	1997	47.60	2265.8
35	1996	47.00	2209.0
36	1990	46.50	2162.3
Σ		3098.60	410732.5

Table III: Design rainfall determination for the project area using Gumbel's distribution

Return Period (T_r)	Number of years of records, n	\bar{X} (mm)	$K(T, n)$	σ_x	X_T (mm)
2	36	86.07	-0.1643	66.5357	75.14
5	36	86.07	0.7194	66.5357	133.936
10	36	86.07	1.3044	66.5357	172.861
25	36	86.07	2.0436	66.5357	222.043
50	36	86.07	2.5920	66.5357	258.530
100	36	86.07	3.9209	66.5357	346.952
1000	36	86.07	4.9349	66.5357	414.418

Table VI: Intensity-duration-frequency curve development

Duration (mins)	Duration (hr)	Intensity for given return periods (mm/hr)						
		2years	5years	10years	25years	50years	100years	1000years
5	0.08	131.071	233.621	301.518	387.305	450.947	605.181	722.860
10	0.17	109.805	195.715	252.595	324.464	377.780	506.988	605.574
15	0.25	94.711	168.812	217.874	279.863	325.850	437.298	522.332
30	0.50	67.600	120.490	155.507	199.752	232.575	312.121	372.814
60	1.00	43.669	77.836	100.458	129.040	150.243	201.630	240.838
120	2.00	26.132	46.577	60.114	77.218	89.906	120.656	144.118
360	6.00	10.552	18.807	24.273	31.179	36.303	48.719	58.192
720	12.00	5.778	10.299	13.293	17.075	19.881	26.680	31.868
1440	24.00	3.131	5.581	7.203	9.252	10.772	14.456	17.267

Similarly, Figure 2 shows the graphical representation of IDF curves for durations from 0.08 to 24hrs with the corresponding return

periods from 2 to 1000years; the curves looks like a crescent shape with intensity (mm/hr) on the ordinate and duration (hr) on abscissa axes. A

bottom red curve is 2 years return period against 0.08 to 24hrs duration. The same pattern was observed with the other curves, up to the sky blue

curve for 1000years return period vs. 0.08 to 24hrs duration.

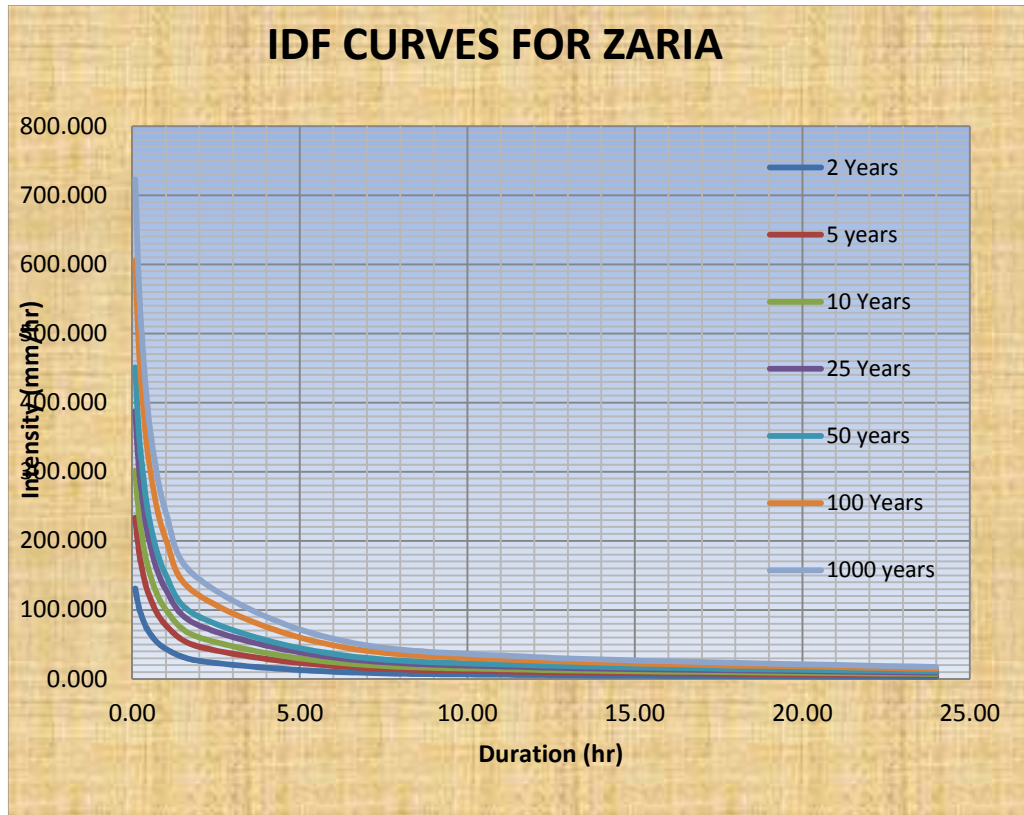


Figure 2: IDF Curve of Zaria Rainfall (1978 – 2013)

CONCLUSION

The study present a method in which the rainfalls intensities were obtained to derive the IDF curves for Zaria catchment. The developed IDF curves relationships for durations from 0.08 to 24hrs and return period from 2 to 1000 years could be used for the design of safe and economical drainage facilities and operation or maintenance of urban water resources administration structures such as drains, culverts, sewers, conveyance systems, bridges, roads and so forth for Zaria and its environs. In this way, high return period are usually selected for design of structures like bridges and dams, while small values of return periods are used for structures such as irrigation canals and drainages.

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