



RAINFALL INTENSITY CHARACTERIZATION IN SEMI-ARID REGIONS: DERIVATION OF IDF CURVES USING MULTI-MODEL APPROACHES FOR HILLA CITY, IRAQ

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ABSTRACT

This study aims to develop a formula to estimate rainfall intensity depending on Intensity Duration Frequency (IDF) curves. The rainfall IDF relationship is one of the tools used in water resources engineering to classify rainfall intensity for a given return period. Daily rainfall data for 20 years from (2003 to 2022) from the Iraqi Metrological Organization and Seismology was used to generate IDF curves for Hilla City. Three methods, namely, Gumbel, Log Normal, and Log Pearson III, were used to derive IDF curves using MATLAB software for six durations (1, 2, 3, 4, 5, and 6 hr) and six return periods (2, 5, 10, 25, 50, and 100 years). Then, empirical equations were developed to estimate rainfall intensity for the various rainfall durations and frequency periods. The results showed an excellent correlation coefficient (R^2) for these empirical equations with an average (94.4 %) the maximum rainfall intensity was 48.6 mm/hr during a 1 hr return period and a 100-year return period. However, the 2.7 mm/hr was the minimum rainfall intensity that occurred during the 6-hour duration period and 2-year return period.

KEYWORDS

Intensity duration frequency curve, Hilla City, Rainfall, Hydrological data analysis, Gumbel Distribution.



1. INTRODUCTION

The IDF curve is a function of the fundamental framework for the drainage system design; therefore, it helps to design secure flood-controlled structures (Alam et al., 2021). It determines the frequency of precipitation intensity that occurs during a designated timeframe (Campos et al., 2020). IDF relationships illustrate the highest intensity of rainfall occurring during the designated timeframe. Accurate assessment is important for water resources management. On the other hand, inaccurate precipitation intensity has serious consequences. Underestimation leads to insufficient, failing infrastructure, while overestimation results in unnecessarily expensive systems.

Under-estimating or over-estimating participating intensity can lead to important consequences, manifesting as inadequate infrastructure that can fail during extreme rainfall events or lead to unnecessary excessive costs to the system. Therefore, undertaking the system through uncertainty analysis can lead to substantially reducing the gap between the particle model and the theoretical model. Compos et al. (2020) studied the relationship between equations used to determine rainfall IDF and the partial area effect, which occurs when the precipitation time to reach the outflow is greater than the rainfall duration. Predicting monthly rainfall for a region studied by (AL-Dulaimi et al., 2020; Al-Sulaiman et al., 2025) by analyzing the effect of seasonal variation, long-term trend, and random fluctuation on time series data and applying it to daily, monthly, and annual precipitation in northern Iraq.

Severe rainfall events can significantly influence social structures and economic systems. The highest rainfall was reported over the past 8500 years, spanning the last century (Wang 1987; Hussein and Alfatlawi 2024). Furthermore, the period between 2000 and 2009 has shown the most extreme rainfall intensity in different areas around the world, according to the Climate Change Report (IPCC. (2007). Therefore, evaluation and statistics of rainfall intensity data are significant in water resources engineering management and planning, where they are used to determine the demanded flow capacity in channels and pumping stations (Al Hassoun, 2011; Hussein & Kasim, 2024; Abed, 2023; Assi, 2025). Therefore, they contribute to controlling flooding and saving lives and property. Rainfall intensity is generally determined by considering the rainfall duration and its return periods by a mathematical form called IDF (Abd Alelah, 2016; Al-Awadi & Affairs, 2016; Amin et al., 2016). The IDF relationship is mathematically expressed as follows: $I = f(T,t)$

Where: I: rainfall intensity (mm/hr); T: return period (year); and t: duration (hr).

Therefore, it helps to design secure flood-controlled structures to prevent flooding and protect people and property. First IDF curve was established in 1932. Since then, many IDF curves

have been formed in many places worldwide (Obeid & Elkholy, 2021; Saad et al., 2022; Jalee and Farawn, 2013). Hinckley (1991) studied a model to find the short-term rainfall amount in the United States with various return periods from 2 to 100 years using the Bell ratio; furthermore, they determined the rainfall depths for different rainfall durations and return periods using rainfall contour maps. El Hannoun et al., (2023) studied the fluctuation of rainfall intensity variability across a variety of durations. Their novel model accounts for how participation intensities vary during short bursts and longer storms. To precisely examine and depict these interactions, a D-vine copula statistical approach was used.

There are three steps to estimating IDF curves. The first step is estimating the hourly duration of rainfall from the maximum rainfall record. The second step is to set up a return period for each duration. Then, in the final step, the IDF relationship can be determined by fitting the rainfall intensities with the rainfall duration and its return period (Al Hassoun, 2011; Wolff et al., 2024). This paper aims to set up IDF curves for daily rainfall data in Al Hilla city.

2. MATERIAL AND METHODS

2.1. Study area

Hilla city is middle of Iraq, located at $32^{\circ} 27' 22''$ N latitude and $44^{\circ} 24'39''$ E longitude, as shown in Fig.1. The maximum monthly air temperature is 45.3°C in June, while the minimum monthly air temperature is 4.1°C in January. The city gains an annual rainfall depth of around 170 mm.



Fig. 1. Location of Hilla City, Iraq

2.2. Historical Rainfall Data and Analyses

The available data for upstream Babylon City, Iraq, is daily for 20 years from (2003 to 2022) which has been obtained from the Iraqi Meteorological Organization and Seismology. Then, the maximum daily rainfall intensity is shown in Fig. 2. This figure shows that the maximum daily rainfall depth occurred in 2013, which is (98.6 mm).

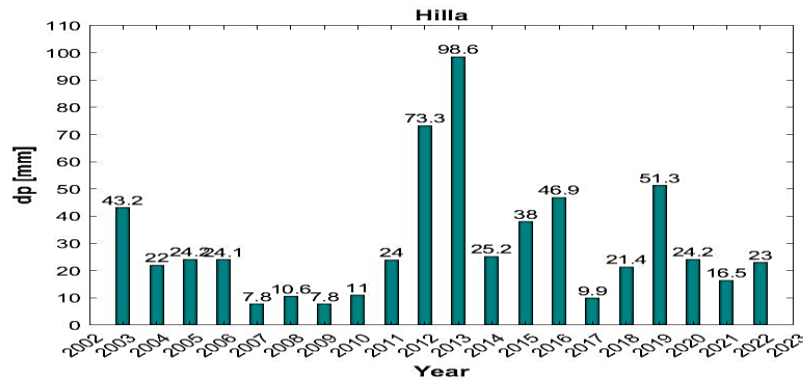


Fig. 2. The maximum daily rainfall depth from the years (2003 to 2022)

2.3. Generation hourly duration

According to the Indian Meteorology Department (Nyamathi & Arelt, 2013), rainfall duration events can be converted to a shorter duration (in this work, hourly duration) by using an empirical equation Eq.1 to determine rainfall intensity depth for various hourly durations (1, 2, 3, 4, 5, 6 hr).

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

Where:

P_h : Hourly rainfall depth

P_{24} : Daily rainfall depth

t : Time duration in an hour

Fig.3 shows the distribution of maximum precipitation depth (mm) derived by Eq.1 for the six hourly durations mentioned above. Table 1 shows the maximum hourly rainfall depth for the abovementioned selected hourly durations.

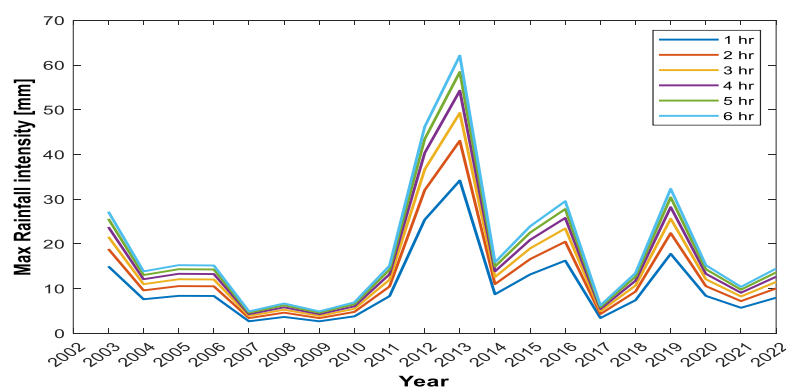


Fig. 3. The distribution of maximum rainfall depth for the six durations

Table 1. The maximum hourly rainfall depth (mm) for various durations

Year	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr
2003	14.98	18.87	21.6	23.77	25.61	27.21
2004	7.63	9.61	11	12.11	13.04	13.86
2005	8.39	10.57	12.1	13.32	14.35	15.25
2006	8.36	10.53	12.05	13.26	14.29	15.18

Year	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr
2007	2.7	3.41	3.9	4.29	4.62	4.91
2008	3.67	4.63	5.3	5.83	6.28	6.68
2009	2.7	3.41	3.9	4.29	4.62	4.91
2010	3.81	4.8	5.5	6.05	6.52	6.93
2011	8.32	10.48	12	13.21	14.23	15.12
2012	25.41	32.02	36.65	40.34	43.45	46.18
2013	34.18	43.07	49.3	54.26	58.45	62.11
2014	8.74	11.01	12.6	13.87	14.94	15.88
2015	13.17	16.6	19	20.91	22.53	23.94
2016	16.26	20.49	23.45	25.81	27.8	29.55
2017	3.43	4.32	4.95	5.45	5.87	6.24
2018	7.42	9.35	10.7	11.78	12.69	13.48
2019	17.78	22.41	25.65	28.23	30.41	32.32
2020	8.39	10.57	12.1	13.32	14.35	15.25
2021	5.72	7.21	8.25	9.08	9.78	10.39
2022	7.97	10.05	11.5	12.66	13.63	14.49

2.4. Hydrological data analysis

Hydrological data will be analyzed using three statistical distribution methods: 1-Gumbel method, 2- log-normal, and 3-log Pearson type III distributions. They are used to predict future rainfall models using available data.

Gumbel Distribution Method

The probability density function of the Gumbel method is estimated using Eq.2. Gumbel Distribution can be used to describe the extreme values (maximum and minimum) of random variables (Amin et al., 2016; Alam et al., 2018; Bhakar et al, 2008).

$$F(x) = \frac{1}{\sigma} \exp\left(-\frac{x-\mu}{\sigma} - \exp\left(-\frac{x-\mu}{\sigma}\right)\right) \quad (2)$$

Where: σ is the scale parameter and μ is the location parameter.

Gumbel distribution is the most generally used in IDF curve analysis, where it is appropriate for modelling excessive rainfall events. In this distribution, the hourly frequency rainfall depth for any precipitation duration at a known return period is calculated using the following equations (Wilson 1990):

$$Pt = (Pt)_{av} + KS \quad (3)$$

Where: Pt: is the maximum hourly rainfall depth; (Pt)_{av}: is the average of Pt; K is frequency factor; S: is the standard division

$$K = \frac{-\sqrt{6}}{\pi} \{0.772 + \ln[\ln\left(\frac{T}{T-1}\right)]\} \quad (4)$$

Where: T: is the return period

$$S = \left[\frac{\sum_{i=1}^n ((Pt)_i - (Pt)_{av})^2}{n-1} \right]^{0.5} \quad (5)$$

After that, the frequency of rainfall depth is calculated from rainfall depth and the duration as

in Eq.6:

$$I = \frac{Pt}{t} \tag{6}$$

2.4.1. Log Person type III method

Log Person type I distribution has been widely and regularly used in hydrologic frequency assessments and hydrology since U.S. federal agencies recommended it. The probability density function of the Log Person type III method is determined using Eq.7 (Amin et al., 2016):

$$F(x) = \frac{1}{x|\beta| \Gamma(\alpha)} \left(\frac{\ln(x)-y}{\beta}\right)^{\alpha-1} \exp\left(-\frac{\ln(x)-y}{\beta}\right) \tag{7}$$

In this distribution, the logarithm variables have been used to obtain the frequency of rainfall instead of the natural variables used in the Gumbel distribution.

$$P_t^* = (P_t^*)_{av} + KS^* \tag{8}$$

Where: P_t^* ; $(P_t^*)_{av}$; K; and S^* as defined above, the value of K can be obtained from different hydrology books (e.g., Wilson, 1990).

2.4.2. Log Normal Method

Log Normal distribution is the same procedure as Log Pearson type III, except for replacing the independent variable (x) with its logarithm. The logarithm of (x) is often the natural logarithm; therefore, variable x will follow the log-normal distribution. The probability density function of the Log-Normal method is determined using Eq .9.

$$F(x) = \frac{1}{\sqrt{2\pi\sigma^2} x} \exp\left(-\frac{(\log(x)-\mu y)^2}{2\sigma^2 y}\right) \quad 0 \leq x \leq \infty \tag{9}$$

Fig.4 shows the probability associated with the three statistical methods used in this research. Tables 2,3, and 4 show the calculated rainfall intensity corresponding to the K for six durations and return periods for three statistical distributions used in this work.

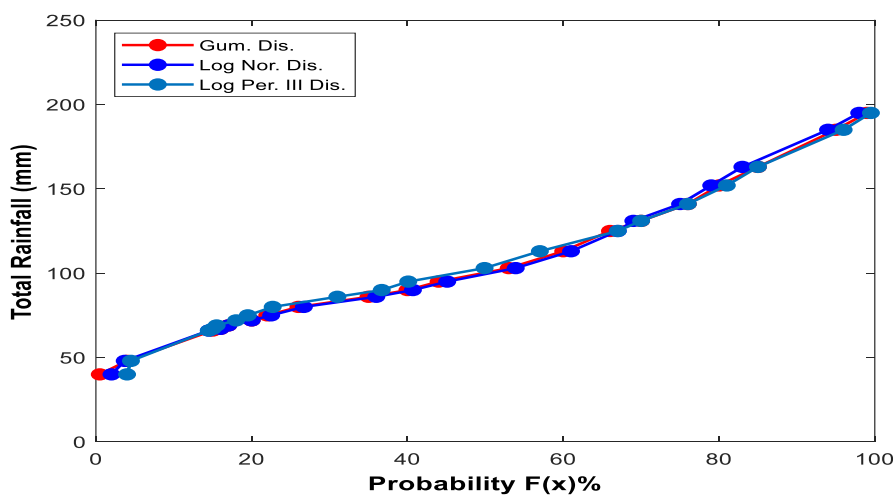


Fig. 4. The Probability distribution for Gumbel, Log Normal, and Log Person III distributions.

Table 2. Computed Rainfall intensity corresponding to frequency factor (Gumbel)

Return Period (yr)	K	I (mm/hr)					
2	-0.16	9.130	5.75	4.39	3.62	3.12	2.77
5	0.71	16.24	10.23	7.81	6.44	5.55	4.92
10	1.30	20.94	13.20	10.07	8.31	7.16	6.34
25	2.04	26.89	16.94	12.93	10.67	9.20	8.14
50	2.59	31.30	19.72	15.05	12.42	10.70	9.48
100	3.13	35.68	22.48	17.15	14.16	12.20	10.81

Table 3. Computed Rainfall intensity corresponding to frequency factor (Log Pearson III)

Return Period (yr)	K	I (mm/hr)					
2	0	6.47	4.08	3.11	2.57	2.21	1.96
5	0.842	13.44	8.46	6.46	5.33	4.60	4.07
10	1.282	19.68	12.4	9.46	7.81	6.73	5.96
25	1.751	29.56	18.62	14.21	11.73	10.11	8.95
50	2.054	38.45	24.22	18.49	15.26	13.15	11.65
100	2.326	48.68	30.67	23.4	19.32	16.65	14.74

Table 4. Computed Rainfall intensity corresponding to frequency factor (Log-Normal)

Return Period (yr)	K	I (mm/hr)					
2	0.008	6.52	4.11	3.13	2.59	2.23	1.97
5	0.844	13.46	8.48	6.47	5.34	4.60	4.08
10	1.276	19.58	12.33	9.41	7.77	6.70	5.93
25	1.730	29.03	18.29	13.96	11.52	9.93	8.79
50	2.031	37.66	23.72	18.10	14.94	12.88	11.41
100	2.289	47.15	29.70	22.67	18.71	16.12	14.28

3. RESULTS AND DISCUSSION

3.1. Intensity Duration frequency curves

The determined results of rainfall intensity from the previous section were used to plot IDF curves. Figs. 5-7 show IDF curves for three distribution methods used in this work: Gumbel, Log Pearson, and Log-Normal distributions. The findings are matched with Al-Awadi and Affairs (2016); results. They are studied the IDF curves in Baghdad City, which has similar climate conditions to Hilla City.

It was noticed that the rainfall intensity decreased with the increasing rainfall duration for the same return period. The three distribution methods used in this study is well calibrated to the calculated data and are usually used to examine the rainfall intensity (Nguyen et.al., 1998). Furthermore, from the figures, the rainfall intensity curve values are so close in Log Pearson and Log-Normal distributions, while there is a slight difference with the Gumbel distribution. Nonetheless, the Log Pearson III method is considered more accurate as it accounts for the asymmetry in the data distribution as explained in section (3.3). It is recommended for use in storm design applications and conducted when precision is required.

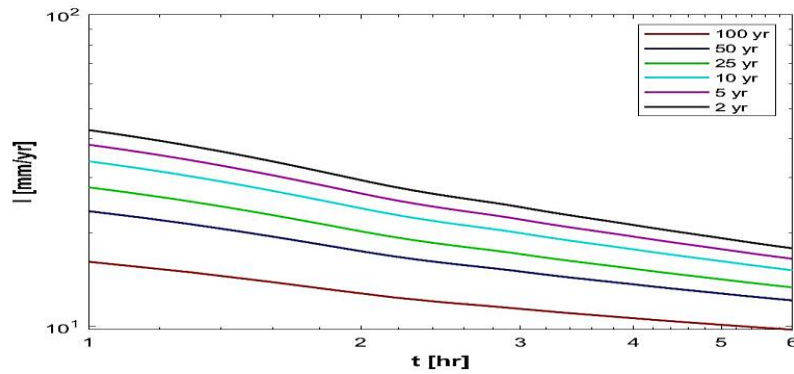


Fig. 5. IDF curves of Hilla City according to Gumbel distribution

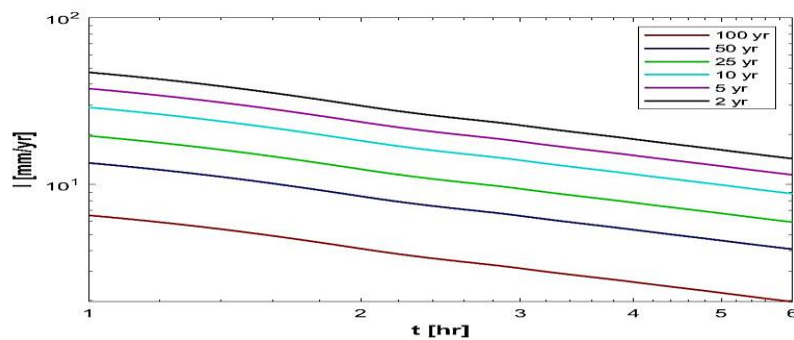


Fig. 6. IDF curves of Hilla City according to Log Pearson III Distribution

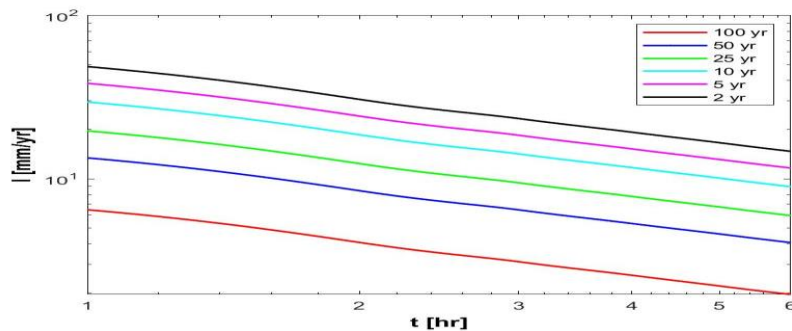


Fig. 7. IDF curves of Hilla City following Log Normal Distribution

3.2. Derivation of IDF empirical equation

Bernard equation is an empirical formula that states a general formula of TDF relationships between rainfall intensity, duration, and return period (Alam et al., 2021; Campos et al., 2020).

$$I = \frac{a T^b}{t^c} \quad (10)$$

Where: a, b, and c are coefficients

Then, the rainfall intensity was calibrated with rainfall duration and return period using multiple regression in MATLAB Software with an average correlation coefficient ($R^2=0.94$). The equation parameters a, b, and c were considered very close, especially between Log Pearson III and Log-Normal distributions, slightly varying with the Gumbel distribution. The values of the parameters for each return period are as in the Tables (5, 6 and 7):

Table 5. Coefficient values of Bernard equation (Gumbel Distribution)

coefficients	Return Periods					
	2	5	10	25	50	100
a	17.45	18.68	23.90	30.78	35.38	40.84
b	2.07	3.68	4.75	6.11	7.11	8.10
c	0.05	0.08	0.05	0.14	0.17	0.19

Table 6. Coefficient values of Bernard equation (Log Pearson Type III)

coefficients	Return Periods					
	2	5	10	25	50	100
a	7.46	15.41	22.71	33.23	43.11	53.97
b	1.48	3.06	4.48	6.59	8.56	10.71
c	0.04	0.07	0.10	0.16	0.20	0.25

Table 7. Coefficient values of Bernard equation (Log-Normal)

coefficients	Return Periods					
	2	5	10	25	50	100
a	7.40	15.38	22.53	33.38	44.01	55.72
b	1.47	3.05	4.47	6.70	8.74	11.06
c	0.03	0.07	0.1	0.16	0.21	0.27

3.3. The Goodness of Fit

The goodness of fit is one of the important statistical examinations to evaluate the accuracy and reliability of the three distribution models mentioned in section 2.4. Therefore, the significant statistical factors are examined to assess the statistical methods' performance as follows:

Correlation coefficient (R2)

$$R2 = \left[\frac{\sum(x_i - \bar{x}_i)(y_i - \bar{y}_i)}{\sqrt{\sum(x_i - \bar{x}_i)^2} \sqrt{\sum(y_i - \bar{y}_i)^2}} \right]^2 \quad (11)$$

Root Mean Square Error, RMSE

$$RMSE = \sqrt{\frac{\sum(x_i - y_i)^2}{N}} \quad (12)$$

Mean Square Error, MSE

$$MSE = \frac{1}{N} [\sum(x_i - y_i)^2] \quad (13)$$

Standard Error, SE

$$SE = \frac{\sigma}{N} \quad (14)$$

Skewness, Sk

$$Sk = \frac{(x - \mu)^3}{\sigma^3} \quad (15)$$

Kurtosis, Kr

$$Kr = \frac{(x - \mu)^4}{\sigma^4} \quad (16)$$

The evaluation of the statistical parameters of IDF curves is summarised in tables (8,9, and 10). All distribution methods showed an excellent (R^2) with very good (p -value < 0.05). The value of RMS, MSE, and SE are acceptable for the return periods (2,5,10 years); However, it is a little bit high for the return periods (25,50,100 years). Furthermore, the Skewness and Kurtosis statistics are within an excellent range of acceptance, and the Skewness values indicate that the distribution is asymmetry.

Table 8. Coefficient Parameters evaluating IDF curves (Gumbel Distribution)

Parameter	Return Period (year)					
	2	5	10	25	50	100
Correlation coefficient (R^2)	0.94	0.94	0.94	0.94	0.94	0.94
RMSE	0.72	1.29	1.66	2.13	2.48	2.83
MSE	0.52	1.66	2.77	4.57	6.16	8.05
SE	0.55	0.72	0.98	1.35	1.56	1.87
P Value	0.001	0.01	0.013	0.015	0.017	0.017
Sk	0.19	0.19	0.19	0.20	0.20	0.30
Kr	1.80	1.80	1.81	1.81	1.82	1.82

Table 9. Coefficient Parameters evaluating IDF curves (Log Pearson Type III)

Parameter	Return Period (year)					
	2	5	10	25	50	100
Correlation coefficient (R^2)	0.94	0.94	0.94	0.94	0.94	0.94
RMSE	0.51	1.01	1.5	2.30	2.99	3.75
MSE	0.26	1.14	2.43	5.33	8.98	14.0
SE	0.30	0.52	0.71	0.89	1.63	2.30
P Value	0.01	0.012	0.012	0.013	0.013	0.013
Sk	0.18	0.18	0.18	0.18	0.18	0.18
Kr	1.72	1.72	1.72	1.72	1.72	1.72

Table 10. Coefficient Parameters evaluating IDF curves (Log-Normal)

Parameter	Return Period (year)					
	2	5	10	25	50	100
Correlation coefficient (R^2)	0.94	0.94	0.94	0.94	0.94	0.94
RMSE	0.51	1.07	1.56	2.35	3.05	3.87
MSE	0.26	1.15	2.44	5.53	9.35	15.00
SE	0.31	0.63	1.01	1.40	1.61	2.34
pValue	0.01	0.012	0.012	0.013	0.013	0.013
Sk	0.20	0.20	0.20	0.20	0.20	0.20
Kr	1.73	1.73	1.73	1.73	1.73	1.73

4. CONCLUSION

This study aims to derive a relationship between rainfall intensities and durations through a calibration of generated IDF curves for Hilla City. The hourly duration was conducted in this work with six return periods to establish an empirical formula for IDF curves for Hilla City, Iraq. Three probability distributions were used: Gumbel, Log Pearson type III, and Log-Normal distributions, and no statistically significant difference was observed in the estimation of

rainfall intensities of IDF curves. Moreover, the Log Pearson type III is considered the most significant distribution due to asymmetric data.

The majority of hydrologists use 24 hr event to determine the most rational rainfall intensity for design engineers in rainfall storm analysis (Al Hassoun, 2011) . Therefore, it is recommended to use in design the effect of rainfall intensity on design structures in Al Hilla City. The maximum rainfall intensity occurred at a short duration (1 hr) and high return period (100 yr). However, the minimum rainfall intensity occurred at a long duration (6 hr) and low return period (2 yr).

The study developed an empirical equation for all probability distributions with an average $R^2=0.94$. The IDF formula will assist in determining the rainfall intensity for any return period in Hilla City. Generally, the rainfall intensity studies have to be updated for more reliability.

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