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DEVELOPMENT OF INTENSITY-DURATION- FREQUENCY CURVES "IDF" FOR DOHUK CITY IN KURDISTAN REGION OF IRAQ

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ABSTRACT

Dohuk city is hydrologically located in a relatively narrow watershed bounded by mountain ridges with heavy rainfall seasons. Due to its topographical characteristics and rapid urban development, the city is prone to floods during intense rainfall events or storms and in need of a proper storm water drainage system and flood control hydraulic structures for managing intense storm rainfalls, avoiding urban flooding, property loss, and most importantly human casualties. Nevertheless, the local civil engineers are in need of having up-to-date hydrological formulas, relationships, and information in order to be able to adequately design the flood control hydraulic structures. One of these important relationships is IDF curves which correlates the Intensity, Duration, and Frequency of an observed rainfall event. The authors have been able to develop updated IDF curves and empirical intensity formulas for Dohuk city by converting maximum annual rainfall readings for 21 consecutive years (2000-2020) into sub-daily rainfall records for durations of 10, 20, 30, 60, 120, 180, 360, 720, 1440 minutes with recurrence intervals of 2, 5, 10, 25, 50, 100 years using Gumbel and Log Pearson distribution (LPT III). The accuracy and reliability of the results were statistically confirmed through applying coefficient of determination with the value of (R^2=1) and Goodness of fit test (Chi-square) with the confidence degree of (95%).

***KEYWORDS*:** IDF Relationship, Gumbel Method, Log Pearson Type III Rainfall Duration, Duhok City.

1. INTRODUCTION

The intensity-duration-frequency (IDF) curves are graphical illustrations of the probability that a given average rainfall intensity will happen in a specific period of time. Furthermore, IDF curves mathematically correlates the rainfall intensity i, the duration d, and the return period T (or annual frequency of exceedance f). IDF curves are convenient for obtaining return period and/or intensity for a recorded rainfall (Yabin Sun1, Dadiyorto Wendi2,3, Dong Eon Kim4,5 and Shie-Yui Liong4 (2019)). Basically, civil engineers use IDF curves for finding out the design storms required for designing of hydraulic structures[*] constructed for controlling and preventing floods in urban areas. The history of development of IDF curves goes back to 1932 when the first IDF curve was established. Later, many other IDF relationships had been constructed for different parts of the word. It is worth mentioning that the practice for deriving IDF curves, needs long-term rainfall records and history of rainfall observations. Nevertheless, lack of smaller timescale or sub-daily rainfall records result in less reliable IDF curves. (Yabin Sun1, Dadiyorto Wendi2,3, Dong Eon Kim4,5 and Shie-Yui Liong4 (2019)). The availability of extreme rainfall data is extremely important in water resources planning and management as well as finding the required discharge capacity of channels and pumping stations.

[*]Some examples of hydraulic structures that are used for controlling floods in urban areas include but not limited to the followings: dams, storm sewers and drainage systems, culverts, syphons, regulators, and canals.

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The frequency of rainfall is inversely related to its magnitude, for this reason extreme rainfalls are less frequent than mild rainfalls. Therefore, probability distributions like Gumbel and Pearson Type III distributions are widely used by engineers and hydrologists across the world to relate magnitude and frequency of rainfall storms. (Acar, R., & Senocak, S. (2008)). Elsebaie, I. H. (2012) performed an analysis for two provinces in Saudi Arabia found that Gumbel method was more useful than the LPT III distribution method. However, AlHassoun, S. A. (2011) found good conformity between Gumbel method with other distribution methods used to construct empirical intensity formulas for Riyadh region in Saudi Arabia.

In the past few years, Dohuk city has experienced unexpected flash high intensity rainfall events in short duration of time (0.25 to 0.5 hrs)[**] causing floods in some residential areas for being located in the flood plain of the city's main river and due to rapid development of the city. The situation becomes worse due to the poor drainage system of the city which is inadequate for accommodating large volumes of rain pouring down in short durations. Due to that, floods are occurring frequently in the rainfall seasons causing countless property damages and posing life threatening situations to its residents *(announced by Dohuk Directorate of Sewerage and reported in local media)*

Kareem et al., (2022) have published a paper on deriving IDF curves and empirical intensity formulas for the city of Erbil[***] using Gumbel and Log-Pearson Type III (LPT III) statistical distributions. They have found a close match between results obtained from aforementioned distribution methods used for analysing maximum annual rainfall for 39 years (1980-2018). To highlight the reliability of their study, the researchers compared the results of their study with previously developed IDF curves for other Iraqi cities. Moreover, they've suggested that their findings could be used as a first initiative for developing guidelines and designing storm water infrastructures (Kareem, D. A., M Amen, A. R., Mustafa, A., Yüce, M. I., & Szydłowski, M. (2022)). Similarly, the authors of this research have decided to adopt the same approach for Dohuk city and derive up-to-date IDF curves and empirical intensity formulas using Gumbel and Log Pearson Type III distribution (LPT III). Apparently, the used approaches are standard and have been used by other researchers. However, the importance of this research is that there is no similar study carried out for Dohuk. Perhaps, the attained IDF curves and formulas might be useful for the local engineers to depend on while designing flood control hydraulic structures and/or improving the existing drainage system of Dohuk city.

2. METHODOLOGY

2.1. Location and precipitation data of the research area

The study area is located in Duhok City[****] shown in figure 1. Generally, Dohuk has four seasons with dry and warm summers with average temperature of 31.5°C, and cold and rainy winters with average temperature of 7.6°C (Abdulsattar.H.S. (2016)). According to Directorate of Dohuk Meteorology and Seismology, light rainfalls start in October and intensify during November to June. The average range of annual rainfall varying from 328mm to 848 mm in dry and wet years.

[**] The duration of high intensity rainfall events was obtained from Dohuk directorate of meteorology and seismology.

[***] Erbil is the capital of Kurdistan Region of Iraq, located at 36.1102800 latitude and 44.0003300 longitude, with an average elevation of 406 m above sea level. Erbil is 250 KM away from Dohuk city having almost the same climate and rainfall season.

[****] Dohuk city is one of the cities of North West of Iraq. Dohuk is positioned at latitude and Longitude of 36°52′36″ N, 42°59′56″ E correspondingly. The elevation of Dohuk city is 603m above sea level.

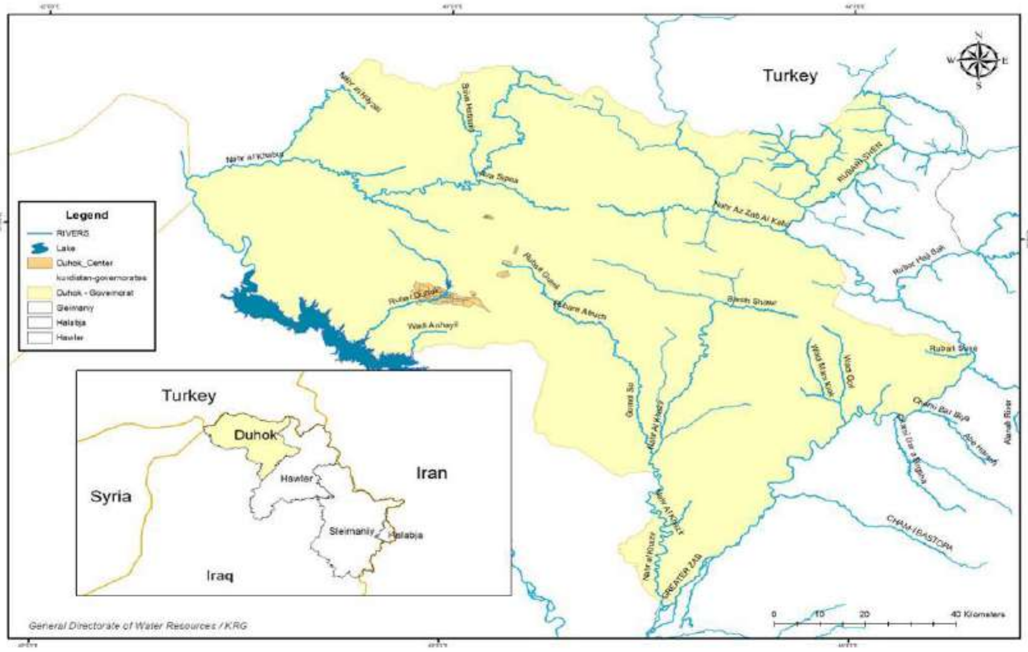

Fig. (1): Study Area (Source: General Directorate of Water Resources/KRG)

For this study, the data have been obtained from Dohuk directorate of meteorology and seismology. The highest annual daily maximum 24- hour rainfall data for 21 years (from 2000 to 2020) have been considered for deriving IDF curves and intensity formulas as illustrated in (Table 1) shown below.

Table (1): Duhok Maximum 24-h rainfall data for 21 years (2000-2020)

No	Year	24hr precipitation (mm)
1	2000	45
2	2001	38.4
3	2002	85.98
4	2003	55.28
5	2004	66.4
6	2005	54.5
7	2006	64.8
8	2007	35.76
9	2008	35.4
10	2009	70
11	2010	36
12	2011	69.3
13	2012	50.6
14	2013	89
15	2014	80
16	2015	29.2
17	2016	52
18	2017	39.6
19	2018	59.4
20	2019	73.8
21	2020	85.2

2.2. Conversion equation for decreasing precipitation times

The maximum 24-h precipitation data have been contracted to smaller time scales (10, 20, 30, 60, 120, 180, 360, 720 and 1440) minutes by using equation (1) (Koutsoyiannis, D., Kozonis, D., & Manetas, A. (1998)) which is recommended by Indian Metrological Department (Elsebaie, I. H. (2012)).

$$P_i = P_{24}[\frac{t}{24}]^{(\frac{1}{3})} \text{.......(1)}$$

Where: (Pi) represents rainfall depth for time steps less than (24 hrs) in mm, and (P24) represents daily rainfall depth in mm and (t) represents time in hrs.

2.3. Development of IDF curves and Frequency distribution

For deriving IDF curves for the study area, the rainfall data for the past 21-year period reflected in (Table1) shown above have been taken into consideration and analysed using Gumbel and Log Pearson type III distributions to represent the variation of the frequency parameters with time. Furthermore, estimation values of rainfall intensities of different timescales and return periods were calculated through using equation (1) shown above.

2.3.1. Gumbel Method

The Gumbel distribution has been established in (1958). Since then, it's been extensively used for developing IDF curves and used in modeling intensified rainfall storm events in hydrological studies. The Gumbel method is simple and easy to apply for extreme rainfall events (Jalee, L. A., & Farawn, M. A. (2013)). Below equation shows the probability of recurrence of precipitation (PT) in mm for every duration with determined return period (T) in years. (Chow, V.T., (1988)).

$$P_T = P_{ave} + SK \text{.........(2)}$$

Where: K is Gumbel frequency factor given by Eq. (3) (Rasel, M. M., & Islam, M. M. (2015); Zope, P. E., Eldho, T. I., & Jothiprakash, V. (2016)).

$$K = -\frac{\sqrt{6}}{\pi}\left[0.577 + ln\left[ln\left[\frac{T}{T-1}\right]\right]\right] \text{.......(3)}$$

Where; (Pave) is the average of maximum 24-h precipitations with respect to a defined duration. When applying Gumbel's distribution, the arithmetic average in equation (4) could be estimated through the following equation (Al-Awadi, A. T. (2016)).

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

Where: S is the standard deviation of PT data, and could be calculated using the following relation:

$$S = [\frac{1}{n-1}\sum_{i=1}^{n}(P_i - P_{ave})^2]^{\frac{1}{2}} \text{ ....(5)}$$

The deviation from the average rainfall of a desired recurrence interval could be determined when (K) in equation (3) multiplied by (S) in equation 5. The intensity of rainfall IT (mm/h) for each return period Td is calculated afterwards by using equation (6) as shown below:

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

Where: Td is duration in hrs.

2.3.2. Log Pearson type III

Log Pearson type III is a statistical methos used for fitting frequency distribution of the rainfall for develop IDF curves and intensity formulas. The Log. LPT III contains logarithm of the measured rainfall values, the mean and the standard deviation are determined using the logarithmically transformed data. The simplified expression for this distribution is given as follows: (Chow, V.T., (1988)).

$$P^* = log(P_i) \text{..................................(7)}$$

$$P_T^* = P_{ave}^* + K_T S^* \text{..........................(8)}$$

$$P_{ave}^* = \frac{1}{n}\sum_{i=n}^{n} P^* \text{................................(9)}$$

$$S^* = [\frac{1}{n-1}\sum_{i=1}^{n}(P^* - P_{ave}^*)^2]^{\frac{1}{2}} \text{ .... (10)}$$

Where P*T, P*ave and S* are as defined previously but based on the logarithmically transformed Pi values; i.e. P* of Equation (7). KT is the Pearson frequency factor which depends on return period (T) and skewness coefficient (Cs). The skewness coefficient Cs, is required to compute the frequency factor for this distribution. The skewness coefficient is computed by equation (11) (Nhat, L. M., Tachikawa, Y., & Takara, K. (2006))

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$$C_s = \frac{n\sum_i^{ni}(P^* - P^*_{ave})^3}{(n-1)(n-2)(S^*)^3} \text{ ....}(11)$$

KT values could be obtained from tables in many hydrology books/references; for example (Dupont, B. S., Allen, D. L., & Clark, K. D. (2000)). By knowing the skewness coefficient and the recurrence interval, the frequency factor, KT for the LPT III distribution could be calculated. The antilog of the solution in Eq. (8) will give the estimated extreme value for the given return period.

2.4. Determination of IDF empirical formula

The intensity empirical formula correlates intensity (I), duration (t) and return period (T). The empirical equation could be used with both Gumbel and Log Pearson Type III distributions. Equation (12) is the common form of intensity empirical formula: (Chow, V.T., (1988)).

$$I = \frac{CT^m}{t^a} \text{ ....}(12)$$

Where: I is the intensity of rainfall (mm/hr), t is the duration of rainfall (minutes), T is the recurrence interval (years), and (C, m and a) are constants of the above formula which are related to rainfall data, shape, size, and location of the study area which can be obtained from logarithmic transformation of the equation (12). Equation (13) is the logarithmic transformation of equation (12).

$$logI = log(CT^m) - a\ logt \text{ ....}(13)$$

Assuming (CTm=K), equation (13) could be rearranged as in equation (14)

$$logI = log(K) - alogt \text{ ....}(14)$$

A linear correlation shall be obtained when plotting the logarithmic values of intensities (log I) versus logarithmic values of time (log t). For finding out the slope of the liner relationship the average values of constant (a) should be used in equation (13) and repeated for each return period. Whereas, the logarithmic value of (K) in formula (14) is the intercept for each recurrence intervals.

For knowing the values of C and m, equation (16) shall be plotted using the logarithmic values of intercept (log CTm) versus the logarithmic values of returning period (logT).

Assuming that:

$$K = CT^m \text{ ....}(15)$$

By taking logarithm of both sides of equation (15) the following equation will be obtained (16):

$$logK = logC + mlogT \text{ ....}(16)$$

When plotting (logK) and (logT) in equation (16) a linear correlation of the plot will be obtained. The slope of the linear relationship (m) could be calculated accordingly. The anti-log values of the intercept from the plotted curve illustrates the (C) coefficient in equation (12).

3. RESULTS AND DISCUSSION

3.1. Developing IDF curves

In the Gumbel method, the calculations have been done by reducing the maximum 24-h annual precipitation data into nine smaller time scales (10, 20, 30, 60, 120, 180, 360, 720, 1440 min) with six return periods (2,5,10,25,50,100 years) as shown in (Table 2). Afterwards, equations (3) and (5) were used to compute Gumbel frequency factor (K) and standard deviation (S). In order to find out precipitation for each duration and return period (PT), equation (2) has been applied following calculation of (S and K). Subsequently, equation (6) was used to calculate the intensity for each duration and different return periods (IT) and also the intensity of the extreme values of precipitation for each standard duration and different return periods. Finally, the values of each return period (2, 5,10,25,50 and 100 years) frequencies were plotted on an ordinary scale to drive the IDF curves, as shown in (Figure 2), while (Figure 3) shows IDF curves on log-log scale for the same periods.

Concerning calculation procedures using Log Pearson Method (LPTIII), the same approach as Gumbel Method has been adopted. In LPT III, the extreme value precipitation for each return period has been determined by taking the logarithm of maximum rainfall values in data set (Eq. 7). For finding out the individual value of rainfall, equation (8) has been used. However, before using equation (8), the frequency factor (K) values were obtained from available tables in various hydrological references after calculating Skewness coefficient (CS) (Eq.11). (Table 3) shows all calculations of LPT III method. Finally, through knowing intensities of different durations, the intensity values were plotted for deriving IDF curves as shown in (Fig 4 and 5). The values were plotted on a normal and log-log scales respectively.

Table (2): Computed rainfall intensities using Gumbel approach for different recurrence intervals.

	10 min			20 min			30 min		
	Pave = 11.04		S=3.55	Pave = 13.91		S=4.47	Pave = 15.93		S=5.12
Tr	K=	PT	IT	K	PT	IT	K	PT	IT
2	-0.16	10.46	62.77	-0.16	13.18	39.54	-0.16	15.09	30.17
5	0.72	13.6	81.59	0.72	17.13	51.4	0.72	19.61	39.22
10	1.30	15.68	94.06	1.30	19.75	59.25	1.30	22.61	45.22
25	2.04	18.3	109.81	2.04	23.06	69.18	2.04	26.4	52.79
50	2.59	20.25	121.5	2.59	25.51	76.54	2.59	29.2	58.41
100	3.14	22.18	133.09	3.14	27.95	83.84	3.14	31.99	63.98
	60 min			120 min			180 min		
	Pave = 20.07		S=6.45	Pave = 25.28		S=8.13	Pave = 28.94		S=9.3
	K	PT	IT	K	PT	IT	K	PT	IT
2	-0.16	19.01	19.01	-0.16	23.95	11.97	-0.16	27.42	9.14
5	0.72	24.71	24.71	0.72	31.13	15.57	0.72	35.64	11.88
10	1.30	28.49	28.49	1.30	35.89	17.95	1.30	41.08	13.69
25	2.04	33.26	33.26	2.04	41.9	20.95	2.04	47.96	15.99
50	2.59	36.8	36.8	2.59	46.36	23.18	2.59	53.07	17.69
100	3.14	40.31	40.31	3.14	50.78	25.39	3.14	58.13	19.38
	360 min			720 min			1440 min		
	Pave = 36.47		S=11.73	Pave = 45.94		S=14.77	Pave =57.89		S=18.61
	K	PT	IT	K	PT	IT	K	PT	IT
2	-0.16	34.54	5.76	-0.16	43.52	3.63	-0.16	54.83	2.28
5	0.72	44.9	7.48	0.72	56.57	4.71	0.72	71.28	2.97
10	1.30	51.76	8.63	1.30	65.22	5.43	1.30	82.17	3.42
25	2.04	60.43	10.07	2.04	76.14	6.34	2.04	95.93	4.0
50	2.59	66.86	11.14	2.59	84.24	7.02	2.59	106.14	4.42
100	3.14	73.24	12.21	3.14	92.28	7.69	3.14	116.27	4.84

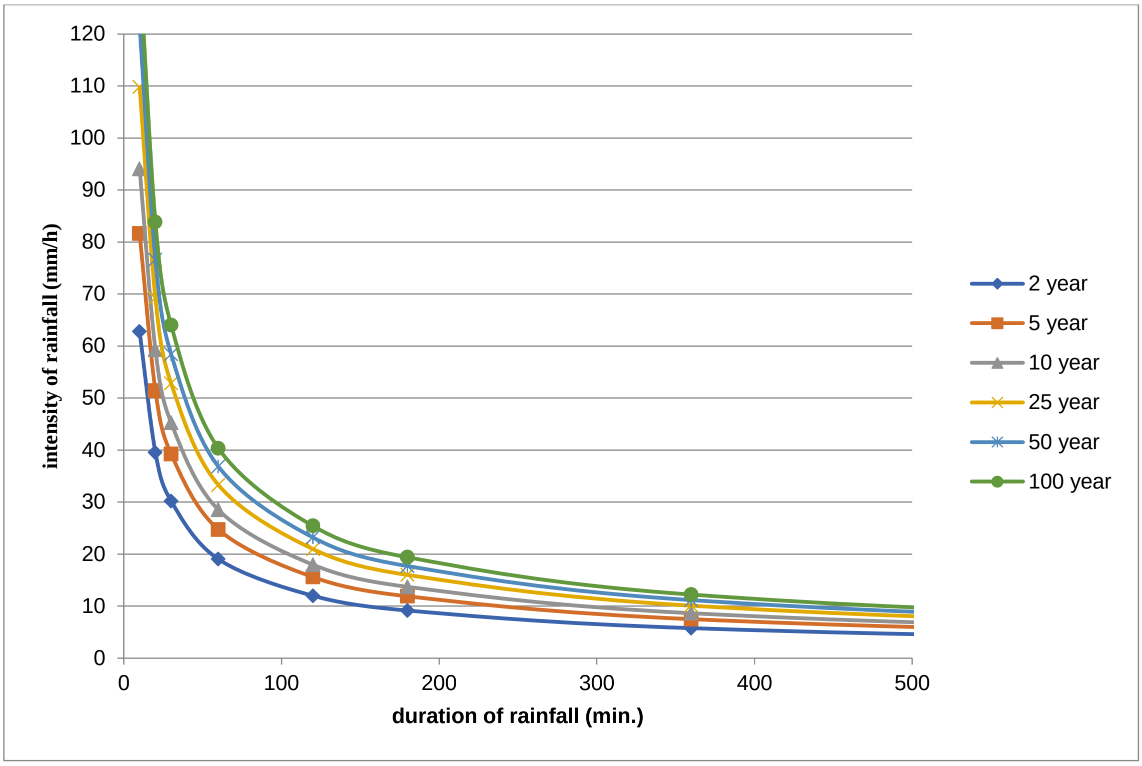

Fig. (2): IDF curves on ordinary scale for various recurrence intervals. (Gumbel Method)

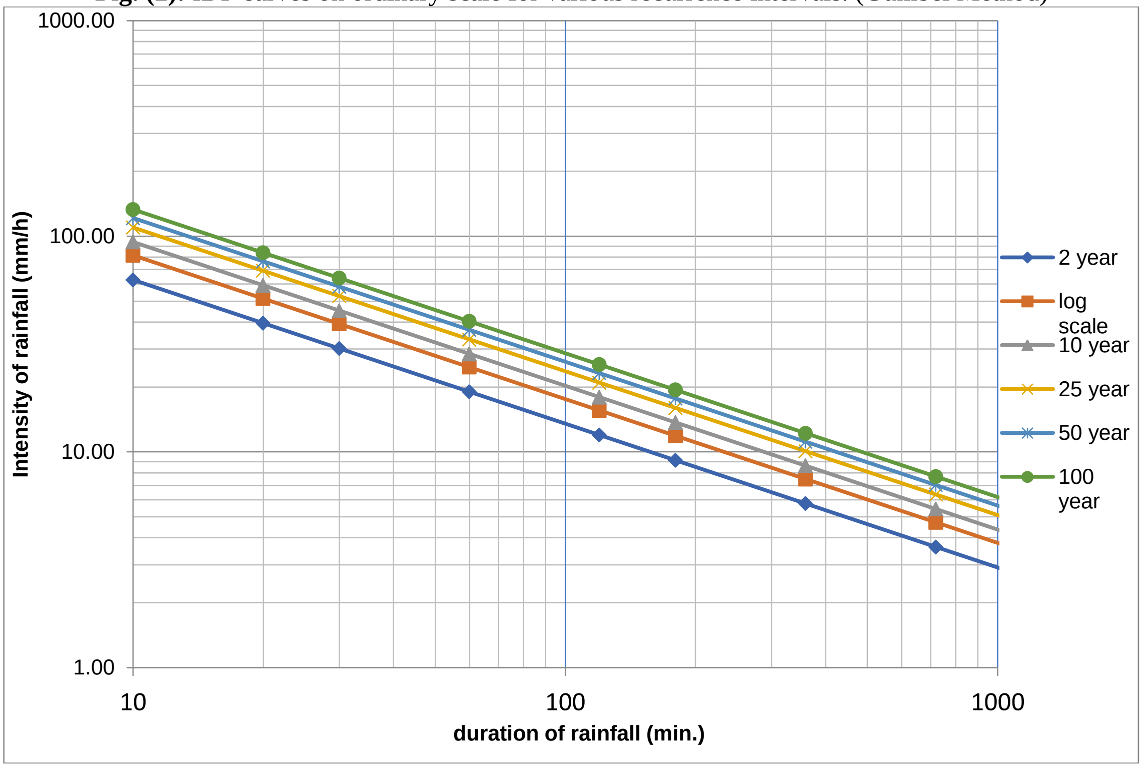

Fig. (3): IDF curves on log-log scale for various recurrence intervals. (Gumbel Method)

Table (3): Obtained rainfall intensities through using LPT III distribution for different recurrence intervals Computed precipitation *(P_T)* and intensity *(I_T)*

	10 min				20 min				30 min			
	P_{ave} = 11.04			S=3.55	P_{ave} = 13.91			S=4.47	P_{ave} = 15.93			S=5.12
Tr	K	P^*_T	P_T	I_T	K	P^*_T	P_T	I_T	K	P^*_T	P_T	I_T
2	0.42	1.08	12.08	72.48	0.42	1.18	15.22	45.66	0.42	1.18	15.33	30.67
5	0.85	1.14	13.97	83.81	0.85	1.24	17.6	52.8	0.85	1.3	20.14	40.29
10	1.25	1.2	15.98	95.89	1.25	1.3	20.13	60.41	1.25	1.36	23.05	46.1
25	1.66	1.26	18.34	110.08	1.66	1.36	23.11	69.35	1.66	1.42	26.46	52.92
50	1.91	1.3	20.0	119.96	1.91	1.4	25.19	75.57	1.91	1.46	28.83	57.67
100	2.13	1.33	21.55	129.31	2.13	1.43	27.15	81.46	2.13	1.49	31.08	62.17
	60 min				120 min				180 min			
	P_{ave} = 20.07			S=6.45	P_{ave} = 25.28			S=8.13	P_{ave} = 28.94			S=9.3
	K	P^*_T	P_T	I_T	K	P^*_T	P_T	I_T	K	P^*_T	P_T	I_T
2	0.42	1.28	19.31	19.31	0.42	1.38	24.34	12.17	0.42	1.44	27.86	9.28
5	0.85	1.4	25.38	25.38	0.85	1.50	31.98	15.99	0.85	1.56	36.61	12.2
10	1.25	1.42	26.69	26.69	1.25	1.56	36.59	18.29	1.25	1.62	41.88	13.96
25	1.66	1.52	33.34	33.34	1.66	1.62	42.0	21.0	1.66	1.68	48.08	16.02
50	1.91	11.56	36.33	36.33	1.91	1.66	45.77	22.88	1.91	1.72	52.4	17.46
100	2.13	1.59	39.16	39.16	2.13	1.69	49.34	24.67	2.13	1.75	56.48	18.82
	360 min				720 min				1440 min			
	P_{ave} = 36.47			S=11.73	P_{ave} = 45.94			S=14.77	P_{ave} =57.89			S=18.61
	K	P^*_T	P_T	I_T	K	P^*_T	P_T	I_T	K	P^*_T	P_T	I_T
2	0.42	1.54	35.1	5.85	0.42	1.64	44.22	3.68	0.42	1.74	55.72	2.32
5	0.85	1.66	46.12	7.68	0.85	1.76	58.11	4.84	0.85	1.86	73.22	3.05
10	1.25	1.72	52.77	8.8	1.25	1.82	66.49	5.54	1.25	11.92	83.77	3.49
25	1.66	1.78	60.58	10.09	1.66	1.88	76.32	6.36	1.66	1.98	96.16	4.0
50	1.91	1.82	66.02	11.0	1.91	1.92	83.18	6.93	1.91	2.02	104.8	4.36
100	2.13	1.85	71.16	11.86	2.13	1.95	89.66	7.47	2.13	2.05	112.96	4.7

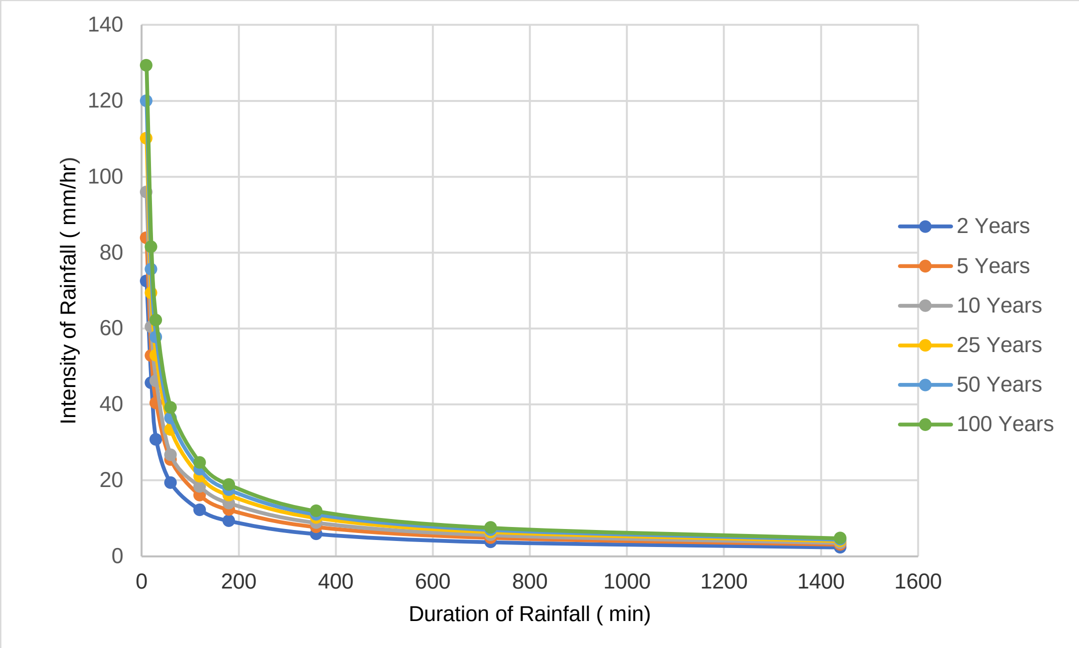

Fig. (4): IDF curves on ordinary scale for various recurrence intervals. (LPT III Method)

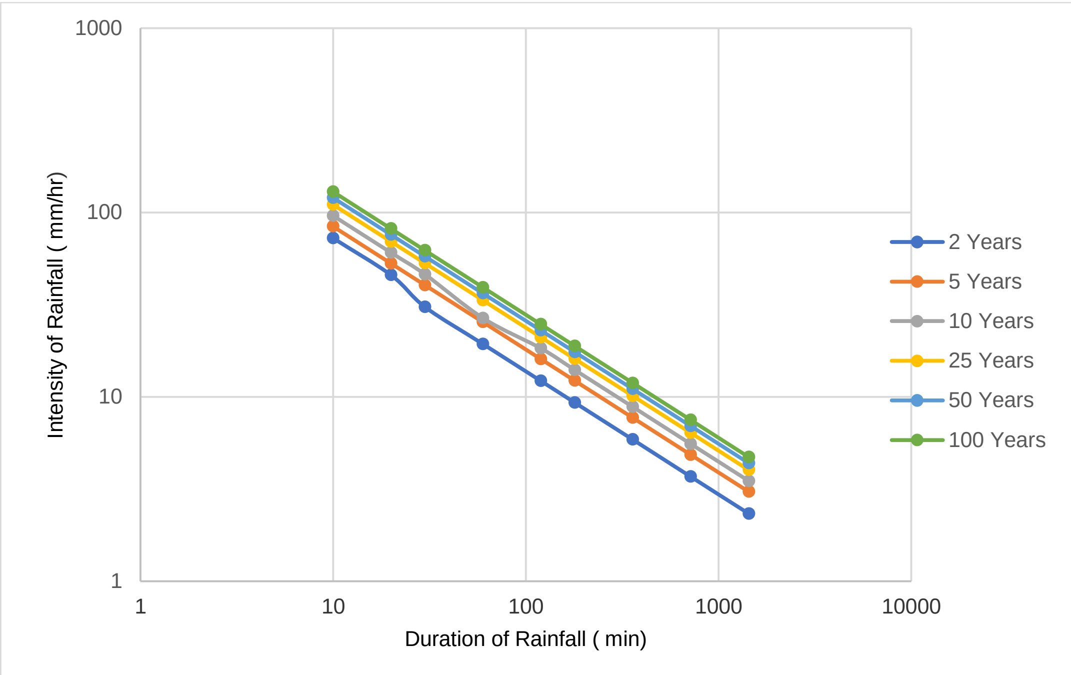

Fig. (5): IDF curves on log-log scale for various recurrence intervals. (LPT III Method)

3.2 Generating Empirical IDF Formula

The IDF empirical formulas were obtained using Gumbel and LPT III methods for comparing the result obtained from IDF curves for estimation of the precipitation in Duhok city. Hence, the rainfall intensity duration curve with all six return periods (2,5,10,25,50 and 100 years) were used in Gumbel and LPT III Distribution methods. To change the equation into a linear form, antilog of the data was taken as illustrated in section 2.3. Equations (17 and 18) show a slight difference in result for IDF empirical formula of Gumbel and LPT III respectively for all return periods. Table 4 demonstrates the values of parameters computed by analyzing the IDF data using both Gumbel and LPT III distribution methods.

Table (4): Empirical parameters for derived equations

Constant values used in emprical formula			
Region	Parameter	Gumbel	Log Pearson III
Duhok City	C	271.6988	308.771
	M	0.187	0.149
	A	0.667	0.67

$$I = \frac{271.6988T^{0.187}}{t^{0.667}} \quad (17)$$

$$I = \frac{308.771T^{0.149}}{t^{0.670}} \quad (18)$$

Where (I) represent the rainfall intensity in (mm/h) for any specific time (t in minutes) with recurrence interval of (T in years). The above empirical formulas correlated intensity (I) as an autonomous variable as opposed to time (t) and recurrence interval (T) as dependent variables. The above formulas might be considered as a common formula for anticipating rainfall intensities for any desired time and recurrence interval for Dohuk city.

Following the derivation of IDF formulas, the accuracy of values should be examined with the same values obtained from IDF curve for all return periods and durations. (Table 5) Illustrates the value of coefficient of determination***** R2=1 for all return periods in Gumbel method while (Table 6) shows the

value of coefficient of determination in LPT III method which means that the driven formulas could be successfully used with high performance for estimation of rainfall intensity calculations. (Fig 6 and 7) show the plot of selected frequency values (2, 5,10,25,50 and 100) in Gumbel and LPT III methods respectively from (table 5and 6).

Table 5. Comparing the intensity values obtained from empirical formula (17) and IDF curves (Gumbel Method) for various recurrence intervals of (2, 5,10,25,50 and 100 years).

t(min)	2 Year (R^2=1)		5 Year (R^2=1)		10 Year (R^2=1)		25 Year (R^2=1)		50 Year (R^2=1)		100 Year (R^2=1)	
	IDF curve	Eq17	IDF curve	Eq17	IDF curve	Eq17	IDF curve	Eq17	IDF curve	Eq17	IDF curve	Eq17
	I	I	I	I	I	I	I	I	I	I	I	I
10	62.77	66.62	81.59	79.04	94.06	90	109.81	106.8	121.50	121.58	133.09	138.41
20	39.54	41.95	51.40	49.79	59.25	56.68	69.18	67.28	76.54	76.60	83.84	87.19
30	30.17	32.02	39.22	38	45.22	43.25	52.79	51.34	58.41	58.44	63.98	66.53
60	19.01	20.17	24.71	23.93	28.49	27.25	33.26	32.34	36.80	36.82	40.31	41.90
120	11.97	12.70	15.57	15.08	17.95	17.16	20.95	20.37	23.18	23.19	25.39	26.40
180	9.14	9.69	11.88	11.5	13.69	13.1	15.99	15.54	17.69	17.70	19.38	20.15
360	5.76	6.10	7.48	7.25	8.63	8.25	10.07	9.8	11.14	11.15	12.21	12.69
720	3.63	3.84	4.71	4.56	5.43	5.2	6.34	6.17	7.02	7.02	7.69	8.00
1440	2.28	2.42	2.97	2.87	3.42	3.27	4.00	3.88	4.42	4.42	4.84	5.03

*****Coefficient of determination (R^2) is a number between 0 and 1. The higher and closer number to 1 means the observations are close to the model's prediction. The coefficients of determination use simple linear regression analysis to show how an independent variable is changing with respect to an independent variable. A general formula for (R^2) could be written as

$$R^2 = 1 - \frac{\text{Total Variation}}{\text{Unexplained Variation}}$$

(For more information see: Turney, S. (2022). "Coefficient of Determination (R²) | Calculation &

Table (6): Comparing the intensity values obtained from empirical formula (18) and IDF curves (LPT III Method) for various recurrence intervals of (2, 5,10,25,50 and 100 years).

t(min)	2 Year (R2=1)		5 Year (R2=1)		10 Year (R2=1)		25 Year (R2=1)		50 Year (R2=1)		100 Year (R2=1)	
	IDF curve	Eq18	IDF curve	Eq18	IDF curve	Eq18	IDF curve	Eq18	IDF curve	Eq18	IDF curve	Eq18
	I	I	I	I	I)	I	I	I	I	I	I	I
10	72.48	73.14	83.81	83.84	95.89	92.97	110.08	106.57	119.96	118.17	129.31	131.03
20	45.66	45.96	52.80	52.68	60.41	58.41	69.35	66.96	75.57	74.25	81.46	82.33
30	30.67	35.02	40.29	40.14	46.10	44.51	52.92	51.03	57.67	56.58	62.17	62.74
60	19.31	22.00	25.38	25.22	26.69	27.97	33.34	32.06	36.33	35.55	39.16	39.42
120	12.17	13.83	15.99	15.85	18.29	17.57	21.00	20.15	22.88	22.34	24.67	24.77
180	9.28	10.54	12.20	12.08	13.96	13.39	16.02	15.35	17.46	17.02	18.82	18.87
360	5.85	6.62	7.68	7.59	8.80	8.41	10.09	9.65	11.00	10.70	11.86	11.86
720	3.68	4.16	4.84	4.77	5.54	5.29	6.36	6.06	6.93	6.72	7.47	7.45
1440	2.32	2.61	3.05	3.00	3.49	3.32	4.00	3.81	4.36	4.22	4.70	4.68

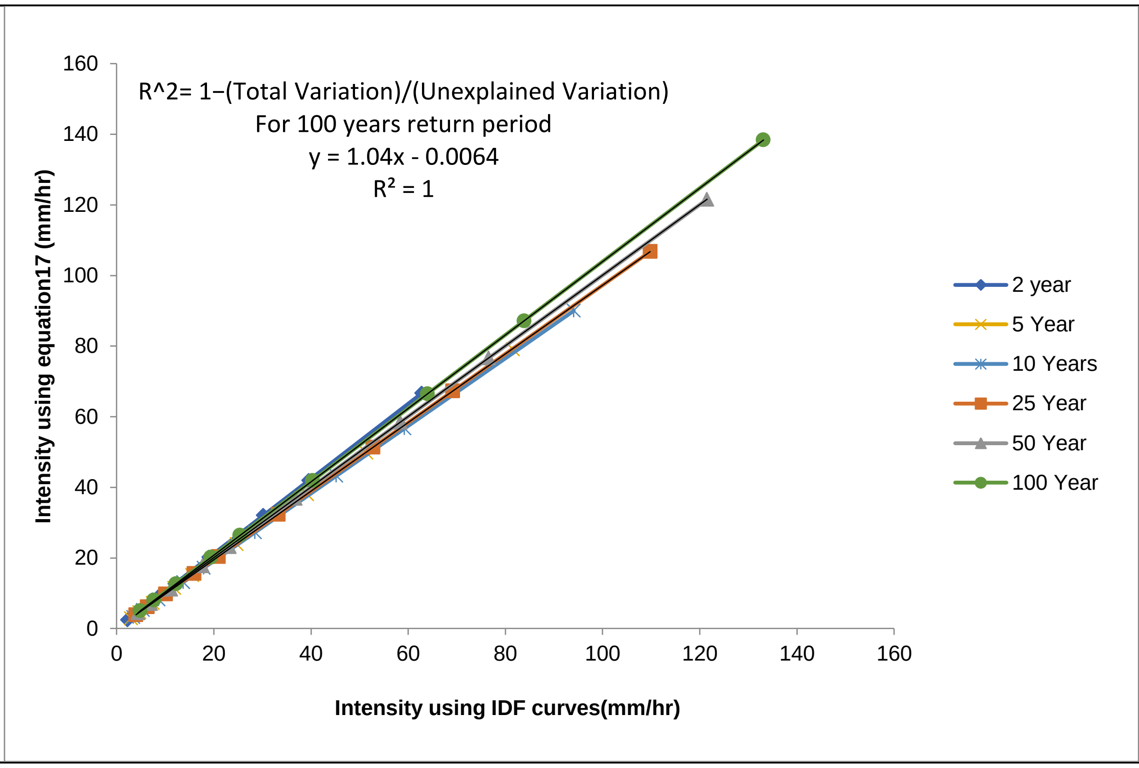

Fig. (6): Rainfall intensities obtained from empirical formula (17) versus IDF curves for recurrence intervals of (2, 5,10,25,50 and 100) years (Gumbel method).

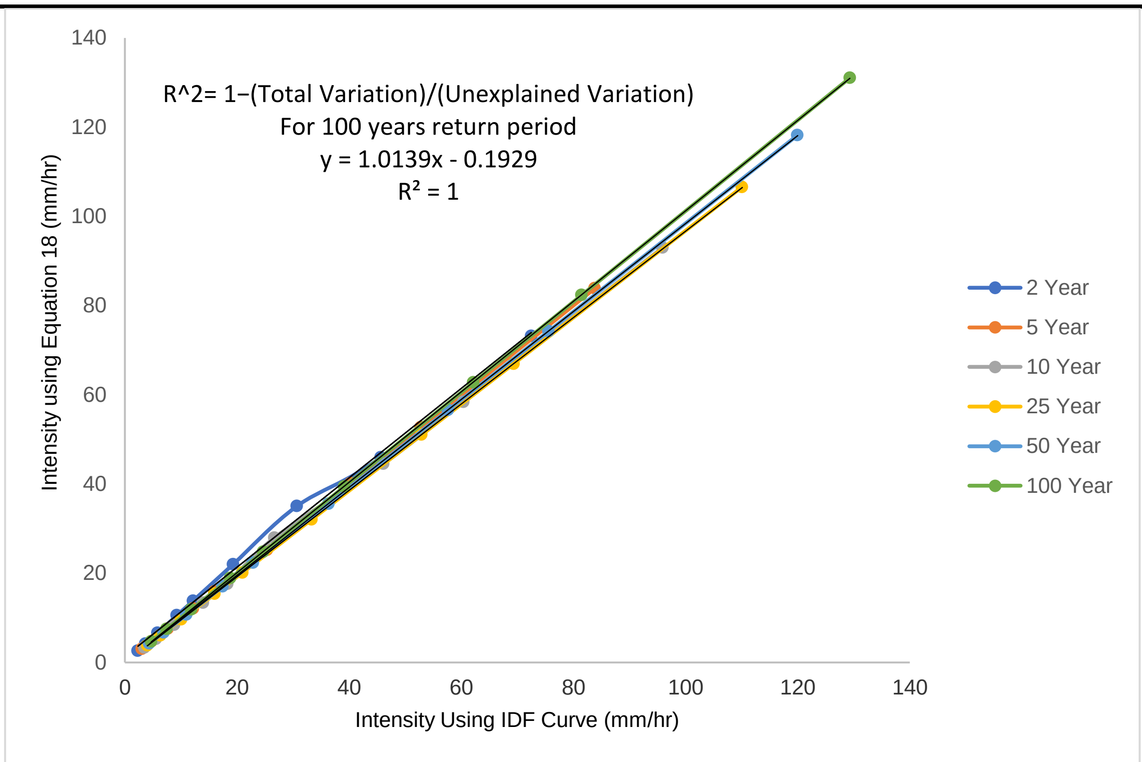

Fig. (7): Rainfall intensities obtained from empirical formula (18) versus IDF curves for recurrence intervals of (2, 5,10,25,50 and 100) years (LPT III method).

3.3 Goodness of fit test

The aim of performing Goodness-of-fit test is to show how the observed frequency of occurrences in a concerned sample and the expected frequencies obtained from a hypothesized distributions are in fit or conformity. A goodness-of-fit test of observed and expected frequencies is depending on chi-square quantity, which is shown in (Eq.19).

$$x^2 = \sum_{i=1}^{k} (O_i - E_{i)})^2 / E_i \quad \text{(19)}$$

Where (x2) is a random variable of sampling distribution closely approximated by the chi-square distribution. The symbols (Oi) and (Ei) are the observed and expected frequencies respectively for the i-th interval in the histogram. A confidence degree of 95% has been achieved when Chi-square has been applied to both intensity empirical formulas (17 and 18) for rainfall intensity values from both IDF curve and intensity empirical equation for all recurrence intervals by applying both Gumbel and LPT III methods.

The critical value of chi square with degree of freedom 8 is 15.51 obtained from chi square distribution table******. The values obtained from table 7 should be less than the critical value provided by chi square distribution table. It can be seen from table 7 shown below, that the values obtained from both Gumble and LPT III methods are close to zero and less than the critical values from chi square distribution table. This indicates that the obtained results are well and no substantial statistical variation has been found between the rainfall intensity values in all recurrence intervals. Consequently, the derived formulas are reliable to be used for estimating of any rainfall frequency and design storm value in Duhok city in lieu of developing IDF curves with acceptable values.

****** The Chi-square (X^2) distribution table is a standard table used as reference which contains the chi-square critical or threshold values. (See: Turney, 2022).

Table (7): Chi-square test for all return periods (2, 5,10,25,50 and 100 years).

Chi square (X^2)		
Return periods (year)	Gumbel method	LPT III method
2	0.137	0.149
5	0.047	0.000457
10	0.106	0.065
25	0.045	0.079
50	0.001	0.021
100	0.141	0.011

4. CONCLUSION

The derived IDF curves and intensity empirical formulas are reliable and highly useful in anticipating rainfall intensities and design storms required for the design of urban flood control hydraulic structures in Dohuk City. The IDF curves and empirical formulas were developed using both Gumbel and LPT III statistical distribution methods for sub daily rainfall durations (10,20,30,60,120,180,360,720 and 1440 min) and recurrence intervals of (2,5,10,25,50 and 100 years). Results suggest that obtained IDF curves are reliable and suitable for predicting rainfall intensities after verifying results by Goodness of fit test with the coefficient of determination (R^2=1) and acceptable values of chi-square with the degree of confidence of 95%. However, practically speaking, using empirical equations for calculating intensity values is more convenient than using IDF graphs/curves. The researchers have also concluded that the results of this study are different than the results of their own previous study performed in other Iraqi urban areas. Subsequently, the researchers suggest that similar analysis must be carried out for obtaining IDF curves and empirical equations for each and every city of Iraq as the climates and topographies are different in each region. It is worth mentioning, despite of the promising results, there are still some limitations require to be acknowledged; the validity of the study cannot be confirmed as there were no observed data available for shorter-durations (minutes) for rainfall storms and the analysis performed only examines the statistical connection between the variables which had been computed by employing a specific empirical equation rather than actual data. Finally, researches are highly recommending KRG and Iraqi governments in collaboration with the concerned entities and institutions to work on establishing automatic rain gauges across the country for each and every city in order to facilitate researches in taking informed decisions on the country's water resource management.

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