Intensity-Duration-Frequency (IDF) Modelling for Kurdistan Region Provinces-Iraq

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Abstract:

Intensity-Duration-Frequency (IDF) relationship is essential for water resources planning and management. The present research aimed to collect data from different rain gauge stations, and derive IDF models for Erbil, Sualimani, Duhok, and Halabja Provinces, Kurdistan Region-Iraq. Stations with rainfall records for 15 years and more were considered in this study. Gumbel Distribution and Log Pearson Type-III (LPT-III) techniques were examined for IDF curves establishment. In this study total of 72 empirical rainfall intensity equations were derived for both the Gumbel and LPT-III distribution methods to estimate rainfall intensity from different rainfall durations with required return periods. Although the LPT-III method over-performed the Gamble method in a few stations, the Gambel method was found to be more stable and robust for all types of data with different skewness values. Therefore, the assumption that the LPT-III method is more accurate compared to other methods, for rainfall data with skewness ≤1.44, does not hold in this study.

Keywords: IDF, Gumbel, Log Pearson Type-III, Rainfall Intensity, Kurdistan Region, Duhok.

1. INTRODUCTION

Intensity–duration–frequency (IDF) relationship is the more frequent and essential statistic in water resources planning and management including the hydraulic and hydrologic design and operation of hydraulic structures. IDF curves are prerequisite information for the design of reservoirs, channels, pumping stations, storm sewer systems, and culverts (AlHassoun 2011; Elsebaie 2012). IDF relationships are graphical illustrations of the quantity of water that precipitates within a specified period of time in catchment areas (Dupont and Allen 1999).

According to Chow et al. (1988) and Nhat et al. (2006), the IDF relationships have been established since 1932. Chen (1983) used only three rainfall durations and frequencies to derive a general IDF formula for different regions of USA. Buishand (1993) applied annual maximum rainfall amounts for durations of 1 to 10 days to study the effect of rainfall time correlation on the determination of IDF relationships. Ilona and France´s (2002) implemented the regionalization of IDF relationships for different districts and achieved rainfall analysis. Yu et al. (2004) used 46 recording rain-gauges to create local IDF formulae for non-recording locations based on the scaling theory.

AlHassoun (2011), applied LPT-III and Gumbel distribution methods to develop an empirical formula to evaluate the rainfall intensity. The results showed slight difference in IDF curves between both methods. Elsebaie (2012) analyzed rainfall data to derive depth–duration–frequency relationships and the results indicated that the Gumbel distribution method was better than other methods including LPT-III distribution. Eckersten (2016) indicated that the storms assessed from the non-stationary IDF curves exceeded the storms assessed from the stationary IDF curves.

Hussein (2014) used several methods to derive IDF empirical formula to estimate rainfall intensity in Karbala-Iraq and determined the LPT-III as the best method describing the rainfall data. Al- Awadi (2016) derived IDF curves for Baghdad City-Iraq using rainfall data with 2, 5, 10, 25, 50, and 100 years return periods and different rainfall durations, identical results were found from Gumbel, LPT-III, and Log normal distribution functions for rainfall data analysis. Dakheel (2017) derived IDF curves for Nasiriya-Iraq using rainfall durations of 5, 10, 20, 30, 60, 120, 180, 360, 720, and 1440 minutes with return periods of 2, 5, 10, 25, 50, and 100 years. LPT-III and Gumbel distribution methods were used, and LPT-III was identified as the better distribution method. Hamaamin (2017) derived IDF curves for the city of Sulaimani-Iraq from daily rainfall data with returning frequencies of 2, 5, 10, 25, 50, and 100 years, and for different rainfall durations of 5, 10, 20, 30, 60, 120, 360, 720, 1440 minutes. Moreover, an empirical formula was established to predict the rainfall intensity at any returning period and duration. Kareem et al. (2022) developed empirical IDF formulas and the IDF curves for the city of Erbil-Iraq. The formulae were derived for various return periods (2, 5, 10, 25, 50, and 100 years) and for rainfall durations of 10, 20, 30, 60, 120, 180, 360, 720, and 1440 min. They used Gumbel and LPT-III methods to obtain the curves. Zeri et al. (2023) generated IDF curves for Baghdad, Basrah and Mosul cities in Iraq. The researchers used Global Precipitation Measurement Integrated Multi-Satellite Retrievals for Global Precipitation Measurement, Global Satellite Mapping of Precipitation near real-time , and gauge corrected satellite precipitation datasets. They used Sherman equation to derive IDF curves for rainfall intensities with 2-, 5-, 10-, 25-, 50-, and 100-year return periods. Shamkhi et al. (2022) studied frequency of intensity of rain duration for Al Kut city, Iraq. The authors applied three essential techniques of frequency analysis (i.e. Gumbel distribution, lognormal, and log Pearson Type III) for the rainfall intensity during 1992 and 2019 for the return periods of 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 6, 12, and 24 h with 2, 5, 10, 25, 50, and 100 years. Majeed et al. (2021) investigated maximum daily rainfall data for Al-Najaf City-Iraq during 30 years using the Indian Meteorological Department empirical formula to calculate the short durations rainfall intensity for 5, 10, 20, 30, 60 and 120 minutes, and with return periods of 2, 5, 10 and 25 years. They derived IDF curves for the collected data during 1989 to 2018 using Gumbel, Lognormal and Log Pearson Type III methods. Mahdi and Mohamedmeki (2020) updated previously developed IDF curves for Baghdad city-Iraq. The researchers applied Gumbel Distribution Theory, the Log Pearson Type III and Log Normal Distribution techniques to achieve rainfall intensities for various short durations of 0.25, 0.5, 1, 2, 3, 6, 12 and 24h and return periods of 2, 5, 10, 25, 50 and 100 years.

Water resources planning and management require rainfall intensity estimations and determinations all over the places and locations. However, up to now, these relationships have not been specifically formed for all localities and Provinces of the Kurdistan Region-Iraq. For this reason, mostly, KR water resources planners and managers are forced to assume values of rainfall intensities in their management plans and design. Consequently, the objectives of the current study were to: collect available rainfall data from all KR different weather stations in Erbil, Sulaimani, and Duhok provinces (with rainfall data of 15 years and more) to establish spatial-specific IDF curves for different locations and cities. In this study, empirical formulae were derived to estimate rainfall intensity considering different rainfall duration and returning periods. Gumbel and LPT-III distribution functions were evaluated to find the more suitable function to describe the rainfall probability distribution. This paper is the first effort to develop empirical IDF equations for all the weather stations in the KR-Iraq Provinces.

2. MATERIALS AND METHODS

2.1. Study Area

The study area is located in the KR-Iraq and is limited between 44.3872° E longitudes and 36.4103° N latitudes. The three main cities Sulaimani, Erbil, and Duhok inside and surrounding weather stations were considered in this study. Sulaimani, Erbil, and Duhok cities have an average elevation of 830 m, 406 m, and 585 m above sea level respectively. KR has a population of 6,171,000 according to the 2020 analysis covering (Kurdistan Regions Statistics office 2020), having an area of 40,643 km^2. There are seasonal fluctuations different weather changes in the cities related to the seasons. The study region is enclosed by a Zagros Mountain range from the east and north and the lowlands from the south and the west of Iraq. The region has Mediterranean climate which is characterized by mild wet winters and warm to hot, dry summers (Lionello et al. 2006). There is obvious difference in the amount of precipitation in the region which is differ from mean annual precipitation of 400 mm to 1000 mm spatially across the region from lower places to higher mountainous areas respectively (Al-Timimi et al. 2020).

2.2. Data Collection

The daily meteorological dataset was collected from different government institutions including the directorate of agriculture in Duhok City and the National Center for Environmental Prediction and General Directorate of Meteorology and Seismology in KR-Iraq (GDMS). According to the GDMS database in 2022, there are about 45 rainfall stations in the KR. The stations that have more than 15 years of data collection are 36 stations. The location of these stations is distributed to the different cities which are ten, three, and twenty-three stations located in Sulaimani, Erbil, and Duhok Provinces, respectively (Fig. 1).

The rainfall data were recorded on daily basis and consistently by using conventional rain gauges. The dataset consists of maximum daily 24 h rainfall in mm for each water year. Stations with recorded data of 15 years and more were considered for this study. Maximum daily rainfall for each recorded years are presented in Table 1 for Sulaimani and Erbil provinces. Data for Duhok province precipitation gauge stations are illustrated in Tables 2 and 3.

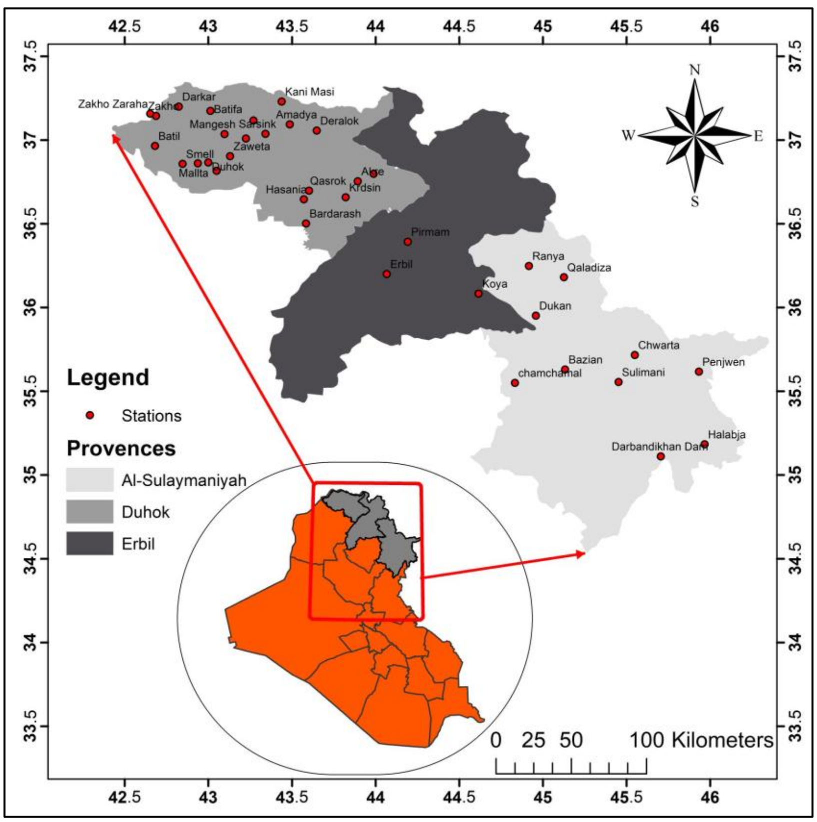

Fig. 1: Location of Gauge Stations

Table 1. Maximum Daily Rainfall of Sulaimani and Erbil Stations (mm)

Year	Sulaimani Stations										Erbil Stations		
	Dukan	Sulaimani	Chamchemal	Darbandikhan	Bazian	Ranya	Qaladiza	Chwarta	Halabja	Penjwen	Erbil	Pirmam	Koya
1984	56												
1985	60												
1986	41												
1987	71												
1988	106.6												
1989	48												
1990	84												
1991	82.5												
1992	73										79	77.8	
1993	100	56									57.9	63	
1994	61.5	56									41.7	62	
1995	64	43.5									75.7	69.6	
1996	64.5	51.1									23.9	38.5	
1997	116	82									35.8	56.6	
1998	33.2	43									36.8	41.6	

1999	41	40.5	25.5								28.3	40.4	
2000	41.2	44.5	50.1	31.2							46.4	41.2	
2001	57	46.3	62.1	40.2	31	39	55				48.3	67.3	35.5
2002	59	73.6	90	80.4	85.5	92.2	133	80.8	63.5	145.5	59.2	68.7	84
2003	52.5	78.5	43.5	43	52.7	87.5	82	57.5	53.4	67	41.4	45	105
2004	67.8	45.3	63.3	49	51	68	54	53.8	46.3	86	40.6	49.8	68
2005	58	71	65	93.1	49.5	108	48.5	68.9	78.4	121.5	34	57.6	47
2006	58.9	130.4	118.6	0	154.5	110	113	130.9	114.5	180	104	122.1	35
2007	41.7	53.9	56	67.5	68	43	87.5	55.5	38.8	88.5	38	41.2	50
2008	41	42.4	26.8	26.8	21.9	55.5	51	43.2	30	57.5	41	48.8	39
2009	46.2	66.7	44.7	89.1	58.5	82.5	52	62.8	55.2	55.5	28.2	41.2	45.5
2010	39.4	72.5	65	91.6	71.5	53.5	40	61.3	96.1	106.5	33.8	48.9	62
2011	57	50.9	61.3	71.6	71.5	60.7	63.5	95.4	29.8	93.5	67	58.4	40.8
2012	60.4	56.2	29.1	51.6	37.1	45	46.5	36.5	71.6	83	29.4	48.6	70
2013	63.7	88.1	80.3	89.6	68.2	79.7	85	75.5	61.2	98	71.8	23.7	78.5
2014	32.7	61.2	33.8	43.2	54.1	50.5	80.5	50	42.3	82.2	51	50.6	48.7
2015	64.8	64.4	60.7	91	52.7	57.8	59.5	40	70.2	70	55.8	68.1	65
2016	85.6	106.2	67.2	47	68	75.4	67	52.5	34.8	90.5	42.4	43.3	54
2017	27.4	37.7	33.2	36.6	41.8	91	74	86.5	33.2	88.5	31.4	35.9	54

2018	70.4	131.8	71	81	102	77.7	75	92	65.4	109	51.1	51.1	66.6
2019	24.6	51.8	48.5	103.4	59.5	86	75.5	54	60.2	121.5	59.5	69	46
2020	24.6	60.3	37.1	46.2	87	74.3	32.5	82.5	29.8	29.8	36.8	41.4	30.5
2021	36.2	35.8									15.3		23.6

Table 2. Maximum Daily Rainfall of Duhok Stations (mm)

Years	Duhok Stations													
	Duhok	Akra	Sarsink	Semell	Batil	Malta	Zaweta	Amadia	Mangesh	Zakho	Bamarny	Zakho Ziraha	Batifa	Kani Masi
1976	32.5													
1977	44.7													
1978	40													
1979	35													
1980	59													
1981	58													
1982	51													
1983	34.2													
1984	39.5													
1985	36.4													
1986	42.2													
1987	46.9													
1988	48													
1989	23.3													

1990	46													
1991	24.4			28.7	30.8	25	45	45	40					
1992	70	62.3	130	60	52	102	101	70	80					
1993	150	69	56	44	27	51.5	70	60	58					
1994	120.9	71	50.5	65.4	82.1	60	78	80	70					
1995	40	60	19	45.3	17.8	35	67	34	29					
1996	47	44	40	35.3	33.5	39.5	60	86.5	31					
1997	60	56.5	50	50	42	47	50	60	35					
1998	52	58.4	40	26.7	37	36	36.5	52	33					
1999	37	49	21	26.2	22	35	53	44	29					
2000	67.4	56	62.5	45.3	51.5	49	79	51.5	40	53.7	46.7	45.5	49.7	39
2001	31.8	65	120	35.5	43.3	23.2	46	60	52	27.6	56	42	51.5	51
2002	60	70	91	47.5	51	52.04	82.5	58	47	70.8	58	63	54.4	42
2003	41	66.5	64	38.1	47	44	73.5	61	55	82	54	35.8	50.1	63
2004	65	62	81.5	42	52.3	45.8	76.5	44	52	33.5	59	32.5	51.1	52.5
2005	64	54	73	40	44.2	59.5	69	40	36.5	41.1	57	45	49.9	85
2006	71.6	90	82	51	48.3	54	96	69	70	53	90	56	67	58
2007	38.5	42.5	46	26.7	20.4	32	70	47.5	40	34	42	24.2	44	45
2008	38.5	48	86	45.5	47	40	74	55	45	32.6	47.5	32	45	45

2009	31	92.2	64	45	58	42.5	66	52	53	48.8	72	45.5	72	54
2010	32.7	46.8	92	31	27	33	54	48	40	39.1	43	40	40	43
2011	62.7	101.8	128	96	62	70	95	125	71	105.7	132	103.5	60	105
2012	42.4	51.8	70	35.2	32	43	77	67	68	53.6	71	56	65	48
2013	101.5	86.5	120	65	65	72	133	78	115	87.8	77.5	61.2	77	86
2014	94	84.8	137	78	74	93	149	70	154.5	93.4	88	98	103	78
2015	44.1	80.5	55	34	42	36	79	36	105	58.4	123.5	70.5	66	72
2016	37.4	70	84	27	36	31	88	57	78	38.3	90	63	59	59
2017	39.3	28.5	66	37	31	41	56	59	52	29.6	58	23	50	84
2018	65.2	84	79	85	65	86	111	63	88	61.5	71	60.7	73	59
2019	75.4	68	149	52	47	62	95.4	77	78	43.1	71	42.2	63	68
2020	81.7	64	116	119	82	78.5	88.5	105	103	66	98	69.5	80	83
2021	28.3	47	62	26.5	27	26.2	55	47	42.5	34.1	42	32.4	40	52
2022	26.9	25.8	37	39.5	15.5	23.5	24.5	35	25	30.7	36	29	31	38

Table 3. Maximum Daily Rainfall of Duhok Stations

Years	Duhok Stations								
	Dyara luk	Qasrwk	Duhok Dam	Bardarash	Drkaw	Swara Tuka	Hisnia	Dinarta	Krdsin
2000	99	52.7		37.1		62			
2001	108	53.2	38.4	44.3	23.5	40	26		
2002	72	53	49	38.4	67	62.5	54		
2003	89	62	48	50	110	63	72.5	70	
2004	86	65	44.6	61	32.2	62.4	55	80	
2005	39	51.5	54.5	40	37.3	50	83	67	
2006	115	69	74	75	44.5	84	77	120	
2007	45	52	35.7	48	34.8	46	60.4	47.5	
2008	95	34	44	40	53	74	42.2	68	44
2009	47	71	70	45	47.1	68	73.5	110	64
2010	75	38.2	36	50	40.2	44	54	51.7	50
2011	117	132	62	78	89.4	102	138.6	155	108
2012	68	48.5	50.6	32	63.3	71	45	85	32
2013	124	53	89	54	74	95	63.5	125	56
2014	100	69	121	50.3	105.6	158	61.2	102.5	68.5
2015	56	54	49.2	42.8	34.9	60	66.2	126.7	30.7
2016	78	38	47.4	31.9	25.1	79	47.2	150	46
2017	77	30	39.6	29.8	26.2	51	39	50	24
2018	102	67	59.4	56.5	45.8		70	130.4	75
2019	122	62	73.8	51.5	44.9		71	126.3	44
2020	120	86	85.2		72		60	67.5	47
2021	60	37	26.8		41.2		41	65	35
2022	36	22.7	30.4		21		20	41.5	32

2.3. Precipitation Duration Reduction Formula

The presented maximum rainfall data for all the 36 selected stations in the KR are on the daily basis for all different years. To generate IDF curves for typical periods, there are two methods: either by using the data from classic rain gauges and downscaling annual maximum rainfall to shorter durations or by obtaining comprehensive rainfall data from meteorological stations on short timescales (only automatic rain gauges can generate such data). Usually, maximum rainfall intensity is required for typical rainfall periods of 5, 10, 20, 30, 60, 120, 180, 360, 720, and 1440 to draw IDF curves for the study areas.

The Indian Meteorological Department (IMD) Equation (1) was applied to determine the rainfall data for times smaller than 24 hours because of the absence of these typical times (Ramaseshan 1996). The IMD technique is the application of an empirical equation for downscaling the amount of precipitation falling on a 24 h duration basis into shorter-duration precipitations. The IMD technique can be implemented for rainfall analysis in stations where there are rain gauges that can record data of cumulated 24 h rainfall amounts, but where there are no automated rain gauges that can record both rainfall amount and duration data at the same time.

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

Where t is the required duration time in hours, P_{24} is the daily precipitation depth in mm, and P_t is the required precipitation depth for a duration less than 24 h in mm.

2.4. IDF Curves and Frequency Distribution

The historical rainfall data were used to derive the IDF relationships with the assistance of statistical tools to define rainfall data distribution. The IDF relationships were constructed by using estimates of rainfall intensities over various recurrence intervals and timescales. To define the distribution of rainfall data, different statistical distribution methods were used worldwide, to define the rainfall data distribution. For example, the lognormal, normal, LPT-III, the Generalized Extreme Value (GEV), and Gumbel distributions are commonly used. In this study two methods were selected depending on recommendation from previous researches (Acar and Senocak,2008; AlHassoun 2011; Dupont and Allen 1999; Elsebaie 2012; Hamaamin 2017; Nhat et al. 2006; Oyebande 1982).

2.4.1. Gumbel Distribution

The German mathematician Emil Gumbel established the Gumbel data distribution method, and it has been generally utilized for modeling extraordinary occasions in hydrology and other study areas (Gumbel 1958; Gumbel,1941).

The most broadly used distribution for IDF analysis is the Gumbel method of distribution because of its appropriateness for modeling maxima. It is quite straightforward and uses only extraordinary events (peak rainfalls or maximum values) (Nadarajah, 2006; Yong et al., 2021). The Gumbel methodology can be used to compute the 2, 5, 10, 25, 50, and 100- years return intervals for each rainfall duration period. The frequency of precipitation P_T (in mm) for each duration with a specified return period *T* (in years) is given by the following equation:

$$P_T = P_{ave} + KS \qquad (2)$$

Where P_T is the frequency of precipitation (mm) for a specific duration (*t*) in a minute with any returning period of *T* years, P_{ave} is the average of the maximum precipitation data points (*n*) as in Equation (3).

$$P_{ave} = \frac{1}{n}\sum_{i=1}^{n} P_i \qquad (3)$$

The number of events or years of record is *n*, and the individual extreme value of rainfall is P_i, The *K* is the Gumbel frequency factor, which can be found by Equation (4):

$$K = -\frac{\sqrt{6}}{\pi}\left[0.5772 + ln\left[ln\left[\frac{T}{T-1}\right]\right]\right] \qquad (4)$$

To calculate the standard deviation, the following Equation (5) is used:

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

where *S* is the standard deviation of P_T data. The frequency factor (*K*), which is a function of the sample size and return period, when multiplied by the standard deviation gives the departure from the average rainfall of the desired return period. The rainfall intensity I_T (mm/h) for the return period T_d is then calculated as follows Equation (6):

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

The frequency of the rainfall is generally defined as the largest value observed in each year, by reference to the annual maximum series. An alternate data format for rainfall frequency studies is based on the peak-over threshold concept, which consists of all precipitation amounts above certain thresholds carefully chosen for distinctive different durations. The annual-maximum-series method is more well known in practice due to its less difficult structure (Borga et al. 2005). From the raw data, the statistical variables (standard deviation and average) and the maximum precipitation (*P*) for each the durations of 5, 10, 20, 30, 60, 120, 180, 360, 720, and 1440 min were calculated.

2.4.2. Log-Pearson Type III (LPT-III)

LPT-III is one of the widely used distribution methods in hydrology for determining the intensity–duration relationships. LPT-III contains a logarithm of the measured values. The standard deviation and the mean are determined utilizing the logarithmically transformed data. A simplified expression for LPT-III distribution as following:

$$P^* = \log(P_i) \quad (7)$$

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

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

$$S = \left[\frac{1}{n-1}\sum_{i=1}^{n}[P^* - P_{ave}^*]^2\right]^{1/2} \quad (10)$$

The Pearson frequency factor K_T is determined by the skewness coefficient (C_s) and the Return period (T). The P_T^*, P_{ave}^*, and S^* are the same as previously described in Gambel method but based on logarithmically transformed P_i values.

The frequency factor for this distribution must be computed utilizing the skewness coefficient $C_{s.}$ Equation (11) calculates the skewness coefficient:

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

K_T values can be obtained from tables in numerous sources of hydrologic data, such as Chow et al. (1988). By knowing the recurrence interval and the skewness coefficient, the frequency factor K_T for the LPT-III distribution can be extracted. The antilog of the solution in Equation (8) represents the estimated extreme value for the given return period. LPT-III distribution works good for data with skewness ≤ 1.44, however if the data has skewness more than that range, perhaps another distribution would give more realistic results (Griffis and Stedinger 2007).

2.5. Derivation of IDF Empirical Formula

The relationship between the return period (T), rainfall duration (t), and rainfall intensity (I) is described by the IDF empirical equation based on each of the of LPT III and Gumbel distribution methods. To derive a formula for calculating the rainfall intensity (I) for the study region, there are a number of steps that must be accomplished so as to establish a formula that is appropriate for the calculation of rainfall intensity for a particular rainfall period and particular recurrence interval, which is reliant mainly on the results obtained from the IDF curves. The following steps are used to derive the equation:

$$I = \frac{CT^m}{t^a} \tag{12}$$

where t is the duration of rainfall (minutes), T is the return period (years), I is the intensity of rainfall (mm/h), and the constants (a, m, and C) are empirical parameters that are dependent on precipitation data, location, size, and shape of the study region. The parameters can be obtained by logarithmic transformation of Equation (12), to obtain Equation (13):

$$log\ I = log(CT^m) - a\ log\ t \tag{13}$$

Assuming ($CT^m = K$), Equation (13) can be rewritten as Equation (14):

$$log\ I = log(k) - a\ log\ t \tag{14}$$

Plotting the logarithm of time (*log t*) value against the logarithm of precipitation intensity (*log I*) value will present a linear relationship. To find the average value of the constant for all return periods (the linear relationship's slope), solve Equation (13), which represents the constant a, and *log(K)* in Equation (14) represents the intercept from each return period's plot. The linear relationship's slope will be presented.

Finding m and C is as simple as plotting the logarithmic return period (*logT*) against the logarithmic intercept (*log* CT^m) in a different graph as in Equation (16). Assuming that:

$$K = CT^m \tag{15}$$

Equation (16) can be achieved by taking log of both sides of Equation (15):

$$log\ k = log\ C + m\ \ log\ T \tag{16}$$

a linear equation of the plot can be obtained by plotting *log T* and *log k* in Equation (16), then we can find m which is the slope of the linear relationship. The value of the anti-log of the intercept from the plotted curve is the C coefficient for Equation (12).

2.5.1. Goodness of Fit

The Goodness of Fit is a test that can determine how well the observed frequency of occurrence in a sample agrees with the predicted frequencies obtained from the assumed distributions in a sample. By using the chi-square quantity, it is likely to complete a goodness-of-fit test between observed and predicted values for different frequencies, which is expressed as:

$$X^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i \qquad (17)$$

where X^2 is a random variable with a Chi-square sampling distribution. The observed and predicted frequencies of class intervals are shown in the histogram by O_i and E_i. The k is the number of class intervals. The X^2 value is small if the predicted frequencies match the observed frequencies; apart from that, it is large. A bad fit rejects the null hypothesis, whereas a good fit accepts it. The critical region will thus be in the chi-square distribution's right tail (Al-Shaikh 1985; Elsebaie, 2012; Oyebande 1982).

3. RESULTS AND DISCUSSIONS

3.1 Rainfall Intensities Scale-down and Calculations

In this study IDF curves and empirical equations were acquired to estimate the rainfall intensity in the Kurdistan Regions of Iraq. Therefore, total of 36-gauge stations were selected depending on data availability for more than 15 years. LPT-III and Gumbel distribution methods were evaluated to estimate intensities of rainfall for different rainfall durations and return periods. Due to the large amounts of data and statistics for all the selected 36 stations, it was not possible to demonstrate all stations statistics and curves, for this reason, the authors only included certain tables and figures and samples of calculations for certain stations in each province. As a sample of calculations results, results of the rainfall intensities calculated by Gumbel and LPT-III techniques for Duhok station shown in Tables 4 and 5.

In the Gumbel distribution method in Table 4 the return period of 2, 5, 10, 25, 50, and 100 years were considered for each duration (5, 10, 20, 30, 60, 120, 180, 360, 720, and 1440 min). For each duration, the data of average maximum precipitation (P_{avg}), standard deviation (S), Gumbel frequency factor (K), the frequency of precipitation (P_T), and rainfall intensity (I_T) were calculated. According to the IDF curves, the more the return period the more the rainfall intensity. In addition, the more the rainfall duration at the same return period, the less the rainfall intensity will be expected. The results of the LPT-III technique are illustrated in Table 5. Results illustrate slight differences in the results obtained using the two techniques.

Gambel method found to be more suitable than the LPT-III to estimate vales at lower frequencies up to 10 years, while the LPT-III method predicts intensity better in higher frequencies from 10 years and above (Izinyon and Igbinoba, 2010).

Results of this study illustrated that the LPT-III technique produces to some extent lower results than the Gumbel technique for short return periods, for instance, 2, 5, and 10 years. Whereas the results show contrary when the return period increased to 25, 50, or 100 years, as the Gumbel technique produces to some extent lower results than the LPT-III technique (Table 4 and 5). While The LPT-III technique is thought to be more precise for this station as it accounts for the skewness of the data distribution more than the Gambel method.

Table 4. Rainfall intensities calculated using the Gumbel method for Duhok station with various standard time scales and return periods.

Computed precipitation (P_T) and intensity (I_T) Gumbel method									
T_r	10 min			20 min			30 min		
(year)	P_{ave} = 10.06		S=4.7817	P_{ave} = 12.675		S=6.0245	P_{ave} =14.51		S=6.896
	K	P_T	I_T	K	P_T	I_T	K	P_T	I_T
2	-0.1641	9.2757	55.654	-0.1641	11.687	35.06	-0.1641	13.378	26.755
5	0.7196	13.501	81.009	0.7196	17.011	51.032	0.7196	19.472	38.945
10	1.3047	16.299	97.795	1.3047	20.536	61.607	1.3047	23.508	47.015
25	2.0440	19.834	119.01	2.0440	24.99	74.969	2.0440	28.606	57.212
50	2.5924	22.457	134.74	2.5924	28.294	84.881	2.5924	32.388	64.776
100	3.1368	25.06	150.359	3.1368	31.573	94.720	3.1368	36.143	72.285
	60 min			120 min			180 min		
	P_{ave} = 18.281		S=8.689	P_{ave} = 23.033		S=10.947	P_{ave} = 26.366		S=12.532
2	-0.1641	16.855	16.855	-0.1641	21.236	10.618	-0.1641	24.309	8.103
5	0.7196	24.534	24.534	0.7196	30.911	15.455	0.7196	35.384	11.795
10	1.3047	29.618	29.618	1.3047	37.316	18.658	1.3047	42.716	14.239
25	2.0440	36.041	36.041	2.0440	45.409	22.705	2.0440	51.98	17.327
50	2.5924	40.807	40.807	2.5924	1.413	25.707	2.5924	58.853	19.618

100	3.1368	45.537	45.537	3.1368	57.373	28.686	3.1368	65.675	21.892
	360 min			720 min			1440 min		
	P_{ave} = 33.219		S=15.789	P_{ave} = 41.853		S=19.893	P_{ave} = 52.731		S=25.063
2	-0.1641	30.6258	5.104	-0.1641	38.589	3.216	-0.1641	48.619	2.026
5	0.7196	44.581	7.430	0.7196	56.168	4.681	0.7196	70.768	2.949
10	1.3047	53.819	8.969	1.3047	67.808	5.651	1.3047	85.432	3.560
25	2.0440	65.491	10.915	2.0440	82.514	6.876	2.0440	103.96	4.331
50	2.5924	74.15	12358	2.5924	93.424	7.785	2.5924	117.71	4.904
100	3.1368	82.746	13.79	3.1368	104.25	8.687	3.1368	131.35	5.473

Table 5. Rainfall intensities calculated using the LPT-III method for Duhok station with various standard time scales and return periods.

Computed precipitation (P_T) and intensity (I_T) PT- III method												
T_r	10 min				20 min				30 min			
(year)	P_{ave} = 10.06			S=4.7817	P_{ave} = 12.675			S=6.0245	P_{ave} =14.51			S=6.896
	K	P_T^*	P_T	I_T	K	P_T^*	P_T	I_T	K	P_T^*	P_T	I_T
2	-0.1065	0.946	8.828	52.97	-0.1065	1.046	11.122	33.37	-0.1065	1.105	12.731	25.46
5	0.7956	1.105	12.732	76.39	0.7956	1.205	16.042	48.13	0.7956	1.264	18.363	36.73
10	1.3302	1.20	15.82	94.92	1.3302	1.30	19.93	59.79	1.3302	1.36	22.82	45.63
25	1.9514	1.31	20.36	122.14	1.9514	1.41	25.65	76.95	1.9514	1.47	29.36	58.72
50	2.3802	1.38	24.23	145.38	2.3802	1.48	30.53	91.58	2.3802	1.54	34.94	69.89
100	2.7855	1.46	28.56	171.38	2.7855	1.56	35.99	107.96	2.7855	1.61	41.20	82.39
	60 min				120 min				180 min			
	P_{ave} = 18.281			S=8.689	P_{ave} = 23.033			S=10.947	P_{ave} = 26.366			S=12.532
2	-0.1065	1.205	16.041	16.04	-0.1065	1.306	20.210	10.10	-0.1065	1.364	23.135	7.71
5	0.7956	1.364	23.136	23.14	0.7956	1.465	29.150	14.58	0.7956	1.523	33.368	11.12
10	1.3302	1.46	28.75	28.75	1.3302	1.56	36.22	18.11	1.3302	1.62	41.46	13.82
25	1.9514	1.57	36.99	36.99	1.9514	1.67	4.61	23.30	1.9514	1.73	53.35	17.78

50	2.3802	1.64	44.03	44.03	2.3802	1.74	55.47	27.74	2.3802	1.80	35.50	21.17
100	2.7855	1.72	51.90	51.90	2.7855	1.82	65.39	32.70	2.7855	1.87	74.86	24.95
	360 min				720 min				1440 min			
	P_{ave} = 33.219			S=15.789	P_{ave} = 41.853			S=19.893	P_{ave} = 52.731			S=25.063
2	-0.1065	1.465	29.148	4.86	-0.1065	1.565	36.724	3.06	-0.1065	1.665	46.269	1.93
5	0.7956	1.624	42.042	7.01	0.7956	1.724	52.969	4.41	0.7956	1.824	66.737	2.78
10	1.3302	1.72	52.23	8.71	1.3302	1.82	65.81	5.48	1.3302	1.92	82.92	3.45
25	1.9514	1.83	67.22	11.20	1.9514	1.93	84.69	7.06	1.9514	2.03	106.70	4.45
50	2.3802	1.90	80.00	13.33	2.3802	2.00	100.80	8.40	2.3802	2.10	127.00	5.29
100	2.7855	1.97	94.31	15.72	2.7855	2.07	118.83	9.90	2.7855	2.18	149.71	6.24

3.2 IDF Curve Calculations

Due to the abundance of collected data from 36 stations, resulted plots will be 72 curves for both Gumbel, and LPT-III methods. Therefore, for each city only two main stations had been chosen to show their IDF plots. Figures 2 to 4 show selected IDF curves using Gumbel and LPT-III methods on the log-log scale for T = 2, 5, 10, 25, 50, and 100 years for Sulaimani, Erbil and Duhok cities.

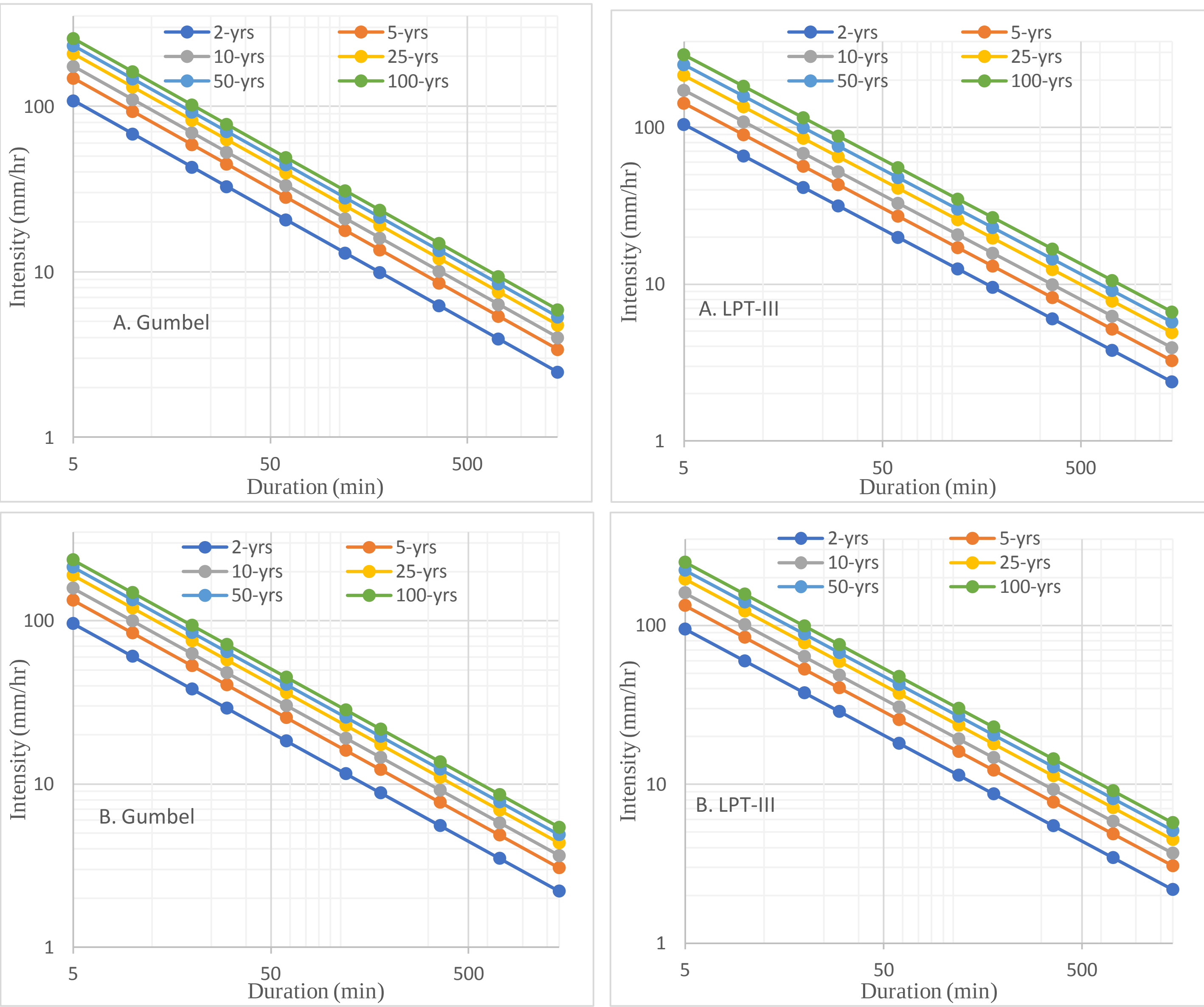

Fig. 2. IDF curves using Gumbel and LPT-III methods for A) Sulaimani, and B) Halabja stations.

The results from Tables 4 and 5 demonstrated that using the Gumbel technique, the intensity of rainfall for different return periods is higher than that determined in Sulaimani by (Hamaamin, 2017; Hasan and Saeed, 2020). This is due to adding more data in the current study compared to the previous studies. Also, for Erbil city, the intensity of rainfall determined using the Gumbel and LPT-III methods for different return periods in this study higher than that determined by Kareem et al. (2022). Likewise, Duhok station results has a higher intensity of rainfall by using the Gumbel technique for different return periods compared to the findings by (Hasan and Saeed, 2020)

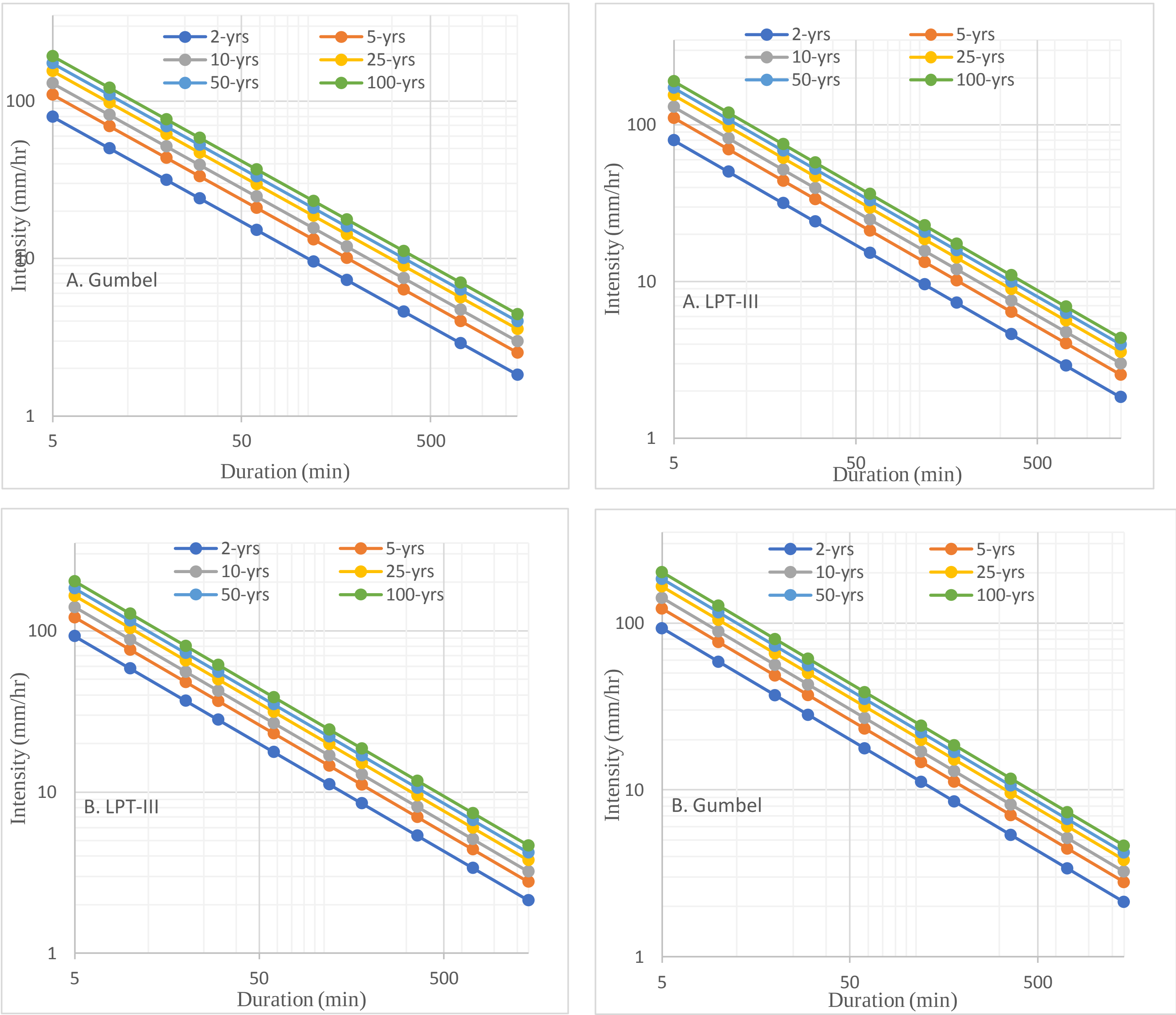

Fig. 3. IDF curves using Gumbel and LPT-III methods for A) Erbil, and B) Permam stations.

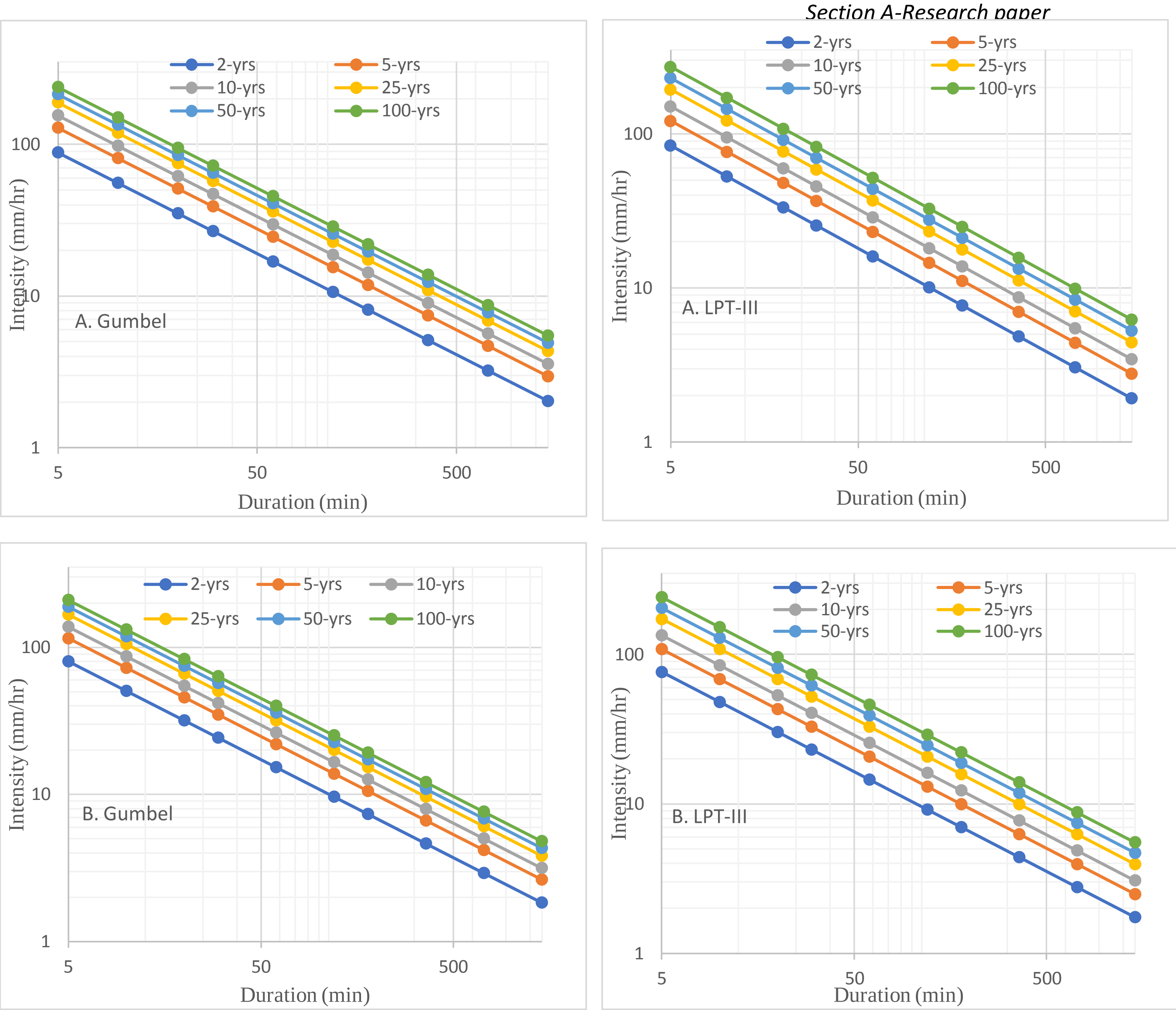

Fig. 4. IDF curves using Gumbel and LPT-III methods. A) Duhok, and B) Semell stations.

3.4. General Empirical IDF Formula

The rainfall intensity data for different return periods of 2, 5, 10, 25, 50, and 100 years with different duration were utilized to derive an empirical equation to estimate the precipitation data for 36 stations in Kurdistan Region by using Gumbel distribution frequency and LPT-III techniques. A logarithmic conversion was performed to the precipitation parameters for both techniques during the development of the IDF empirical formulas, which permitted the relationship to be converted into a linear equation, which in turn permitted the formula to be used to calculate all of the parameters associated with it. The calculation procedure of the linear equation parameters leads to the empirical formula (12). The empirical formulae derived from the generated IDF curve for each station are presented in Tables 6 to 8. For each station, the derived empirical equation which relates returning period (T_r) in years and rainfall duration (t) in minutes as independent variables to rainfall intensity (I) in mm/hour as a dependent variable can be utilized as a common formula to estimate or predict rainfall intensity with every returning frequency and for any duration more accurately compared to the IDF curves.

Table 6: The Empirical Equation of Sulaimani and Halabja city Stations. $\boldsymbol{I_T}$ in (mm/h), $\boldsymbol{T_r}$ in (years) and $\boldsymbol{t}$ in (minutes)

Stations	**Dukan**	**Sulaimani**	**Chamchamal**	**Darbandikhan**	**Bazian**
Gumbel Method	$I_T = \frac{270.208\, T_r^{0.208}}{t_d^{0.667}}$	$I_T = \frac{293.327\, T_r^{0.216}}{t_d^{0.667}}$	$I_T = \frac{258.404\, T_r^{0.219}}{t_d^{0.667}}$	$I_T = \frac{294.391\, T_r^{0.213}}{t_d^{0.667}}$	$I_T = \frac{294.302\, T_r^{0.236}}{t_d^{0.667}}$
LPT-III Method	$I_T = \frac{278.053\, T_r^{0.197}}{t_d^{0.667}}$	$I_T = \frac{267.089\, T_r^{0.258}}{t_d^{0.667}}$	$I_T = \frac{259.482\, T_r^{0.222}}{t_d^{0.667}}$	$I_T = \frac{299.043\, T_r^{0.217}}{t_d^{0.667}}$	$I_T = \frac{294.173\, T_r^{0.234}}{t_d^{0.667}}$
Stations	**Ranya**	**Qaladiza**	**Chwarta**	**Halabja**	**Penjwen**
Gumbel Method	$I_T = \frac{339.46\, T_r^{0.174}}{t_d^{0.667}}$	$I_T = \frac{319.966\, T_r^{0.201}}{t_d^{0.667}}$	$I_T = \frac{314.055\, T_r^{0.197}}{t_d^{0.667}}$	$I_T = \frac{260.271\, T_r^{0.223}}{t_d^{0.667}}$	$I_T = \frac{433.845\, T_r^{0.204}}{t_d^{0.667}}$
LPT-III Method	$I_T = \frac{355.267\, T_r^{0.157}}{t_d^{0.667}}$	$I_T = \frac{319.16\, T_r^{0.204}}{t_d^{0.667}}$	$I_T = \frac{309.155\, T_r^{0.207}}{t_d^{0.667}}$	$I_T = \frac{253.245\, T_r^{0.241}}{t_d^{0.667}}$	$I_T = \frac{472802\, T_r^{0.166}}{t_d^{0.667}}$

Table 7: The Empirical Equation of Erbil City Stations. $\boldsymbol{I_T}$ in (mm/h), $\boldsymbol{T_r}$ in (years) and $\boldsymbol{t}$ in (minutes).

Stations	**Erbil**	**Pirmam**	**Koya**
Gumbel Method	$I_T = \frac{215.91\, T_r^{0.22}}{t_d^{0.667}}$	$I_T = \frac{253.247\, T_r^{0.193}}{t_d^{0.667}}$	$I_T = \frac{254.362\, T_r^{0.203}}{t_d^{0.667}}$
LPT-III Method	$I_T = \frac{218.783\, T_r^{0.215}}{t_d^{0.667}}$	$I_T = \frac{250.522\, T_r^{0.195}}{t_d^{0.667}}$	$I_T = \frac{259.123\, T_r^{0.198}}{t_d^{0.667}}$

Table 8: The Empirical Equation of Duhok City Stations. $\boldsymbol{I_T}$ in (mm/h), $\boldsymbol{T_r}$ in (years) and $\boldsymbol{t}$ in (minutes).

Stations	**Duhok**	**Akra**	**Sarsink**	**Semell**	**Batil**
Gumbel Method	$I_T = \frac{239.949\, T_r^{0.246}}{t_d^{0.667}}$	$I_T = \frac{298.361\, T_r^{0.172}}{t_d^{0.667}}$	$I_T = \frac{349.19\, T_r^{0.234}}{t_d^{0.667}}$	$I_T = \frac{217.431\, T_r^{0.238}}{t_d^{0.667}}$	$I_T = \frac{203.64\, T_r^{0.218}}{t_d^{0.667}}$
LPT-III Method	$I_T = \frac{213.226\, T_r^{0.295}}{t_d^{0.667}}$	$I_T = \frac{330.322\, T_r^{0.123}}{t_d^{0.667}}$	$I_T = \frac{376.555\, T_r^{0.203}}{t_d^{0.667}}$	$I_T = \frac{192.753\, T_r^{0.29}}{t_d^{0.667}}$	$I_T = \frac{212.233\, T_r^{0.205}}{t_d^{0.667}}$
Stations	**Malta**	**Zaweta**	**Amadia**	**Mangesh**	**Zakho**
Gumbel Method	$I_T = \frac{225.412\, T_r^{0.224}}{t_d^{0.667}}$	$I_T = \frac{349.325\, T_r^{0.198}}{t_d^{0.667}}$	$I_T = \frac{283.452\, T_r^{0.189}}{t_d^{0.667}}$	$I_T = \frac{271.793\, T_r^{0.251}}{t_d^{0.667}}$	$I_T = \frac{237.812\, T_r^{0.212}}{t_d^{0.667}}$
LPT-III Method	$I_T = \frac{215.12\, T_r^{0.249}}{t_d^{0.667}}$	$I_T = \frac{377.18\, T_r^{0.161}}{t_d^{0.667}}$	$I_T = \frac{275.934\, T_r^{0.202}}{t_d^{0.667}}$	$I_T = \frac{246.866\, T_r^{0.295}}{t_d^{0.667}}$	$I_T = \frac{226.494\, T_r^{0.237}}{t_d^{0.667}}$
Stations	**Bamarny**	**Zakho Ziraha**	**Batifa**	**Kani Masi**	**Dyara luk**

Gumbel Method	$I_T = \frac{319.413\, T_r^{0.207}}{t_d^{0.667}}$	$I_T = \frac{233.982\, T_r^{0.225}}{t_d^{0.667}}$	$I_T = \frac{276.663\, T_r^{0.167}}{t_d^{0.667}}$	$I_T = \frac{288.935\, T_r^{0.177}}{t_d^{0.667}}$	$I_T = \frac{392.467\, T_r^{0.192}}{t_d^{0.667}}$
LPT-III Method	$I_T = \frac{311.625\, T_r^{0.220}}{t_d^{0.667}}$	$I_T = \frac{228.105\, T_r^{0.240}}{t_d^{0.667}}$	$I_T = \frac{283.404\, T_r^{0.156}}{t_d^{0.667}}$	$I_T = \frac{288.865\, T_r^{0.179}}{t_d^{0.667}}$	$I_T = \frac{416.423\, T_r^{0.175}}{t_d^{0.667}}$
Stations	**Qasrok**	**Duhok Dam**	**Bardarash**	**Darkar**	**Swara Tuka**
Gumbel Method	$I_T = \frac{261.135\, T_r^{0.217}}{t_d^{0.667}}$	$I_T = \frac{257.533\, T_r^{0.219}}{t_d^{0.667}}$	$I_T = \frac{226.827\, T_r^{0.165}}{t_d^{0.667}}$	$I_T = \frac{233.592\, T_r^{0.253}}{t_d^{0.667}}$	$I_T = \frac{326.486\, T_r^{0.215}}{t_d^{0.667}}$
LPT-III Method	$I_T = \frac{261.836\, T_r^{0.213}}{t_d^{0.667}}$	$I_T = \frac{248.788\, T_r^{0.235}}{t_d^{0.667}}$	$I_T = \frac{228.099\, T_r^{0.164}}{t_d^{0.667}}$	$I_T = \frac{217.433\, T_r^{0.290}}{t_d^{0.667}}$	$I_T = \frac{313.434\, T_r^{0.226}}{t_d^{0.667}}$
Stations	**Hasania**	**Dinarta**	**Kirdsin**		
Gumbel Method	$I_T = \frac{276.881\, T_r^{0.218}}{t_d^{0.667}}$	$I_T = \frac{424.766\, T_r^{0.216}}{t_d^{0.667}}$	$I_T = \frac{231.197\, T_r^{0.230}}{t_d^{0.667}}$		
LPT-III Method	$I_T = \frac{288.922\, T_r^{0.199}}{t_d^{0.667}}$	$I_T = \frac{422.877\, T_r^{0.229}}{t_d^{0.667}}$	$I_T = \frac{223.906\, T_r^{0.244}}{t_d^{0.667}}$		

The performance and accuracy of the derived empirical formula alongside the measured values of rainfall intensities were verified for all retuning periods and durations using chi-square, goodness-of-fit tests. Table 9 and 10 present values of coefficient of determination (R^2) and the results of the chi-square goodness-of-fit test applied on an annual series of all the data from all the 36 rainfall recording stations located in Sulaimani, Erbil, and Duhok stations respectively considering returning periods of 2, 5, 10, 25, 50 and 100 years.

The chi-square test was applied to test the goodness of the fit of the empirical formula (12), to rainfall intensity values from IDF curves from both Gambel and LPT-III methods.

The maximum R^2 amount for all stations in both methods is shown in Table 9 and 10. According to the available calculated data for the LPT-III method, the Sulaimani station has a higher rate of R^2 = 99.16 while the lowest rate of

R^2 = 92.37 was recorded for the Akre station. Whenever, for the Gumbel method the Brdarash station has the highest R^2 = 98.12, and a minimum rate of R^2 = 96.12 was recorded for the Darkar station.

For a good fitting function, the critical value of 16.92 should not be exceed by the chi-square test values results for a degree of freedom of 9. The lesser the values of chi-square the good the fit will be, the closest value to zero of the chi-square tests results, the better the fit will be. It can be can concluded that there is no statistically significant difference between the rainfall intensity values for all returning periods as shown in the values of the chi-square test in Tables 9 and 10. Consequently, Tables 6 to 8 indicated that the empirical equations can expect the rainfall intensity for thirty-six stations in main three cities for different returning periods and durations with a high level of accuracy. Skewness equation is given below:

$$Skewness = \left[\frac{n}{(n-1).(n-2}\right].\frac{\sum(x_i-\bar{x})^3}{\sigma^3} \quad (18)$$

n: number of variables in the distribution, X_i: random variable, $\bar{x}$=mean of the distribution

σ=standard deviation

Results of Tables 9 and 10 explained that the performance of both methods (LPT-III and Gambel) method fluctuates from one station to another. Although the performance of LPT-III method better than the Gamble method for some station, like Sulaimani station, but its performance worse than the Gambel method for most of the other stations. This show that the Gambel method more robust and stable compared to the LPT-III method most of the time. In other words, the fluctuation of predicting rainfall intensity (I) for LPT-III method higher than the Gambel method, which means that the Gamble method more robust than the LPT-III method. To test this assumption skewness test performed on the data for each station and the results presented in Table 9 and 10 by using equation (18) for Sulaimani and Erbil Province and Duhok Province respectively. It is known that the LPT-III method has a good performance for data sets with skewness≤1.44, it can be observed that the data for Sulaimani City has skewness of 0.93 whch is less than the given limit and this can be the reason of better performance of the LPT-III method with R^2 value of 99.16% compared to the Gambel method with R^2 value of 97.19%. However this assumption was not true for most of the other stations as well with skewness values≤ 1.44, such as Dukan, Chemchemal, Ranya and other sations.

Table 9: Empirical equations performance (R^2, skewness and chi-square test) results for Sulaimani and Erbil Provinces Stations

		Gumbel Distribution							LPT-III Distribution						
		T_r:	2	5	10	25	50	100	T_r:	2	5	10	25	50	100
Sulaimani Stations	**skewness**	**R^2 (%)**	**Chi-square**						**R^2 (%)**	**Chi-square**					
Dukan	0.73	97.35	1.24	0.56	1.23	0.53	0	1.55	96.13	1.63	0.79	1.66	0.67	0.01	1.95
Sulimani	0.93	97.19	1.51	0.71	1.56	0.68	0.01	1.98	99.16	0.66	0.28	0.65	0.3	0	0.94
chamchamal	0.92	97.12	1.41	0.67	1.47	0.63	0.01	1.87	96.77	1.61	0.8	1.72	0.73	0.01	2.16
Darbandikhan	-0.24	97.24	1.46	0.68	1.5	0.65	0.01	1.9	96.23	2.03	1.04	2.21	0.92	0.01	2.7
Bazian	1.62	96.77	2.04	1.06	2.29	0.98	0.01	2.94	96.72	2.03	1.05	2.28	0.97	0.01	2.92
Ranya	0.15	97.97	0.85	0.34	0.75	0.33	0	0.92	96.08	1.34	0.6	1.22	0.48	0.01	1.34
Qaladiza	1.05	97.47	1.29	0.58	1.28	0.56	0	1.6	97.52	1.32	0.6	1.31	0.55	0.01	1.61
Chwarta	1.12	97.54	1.2	0.53	1.16	0.51	0	1.45	98	1.07	0.48	1.04	0.44	0	1.3
Halabja	0.90	97.03	1.52	0.73	1.6	0.69	0.01	2.04	97.55	1.45	0.7	1.58	0.68	0.01	2.07
Penjwen	0.72	97.41	1.8	0.84	1.84	0.8	0.01	2.31	93.5	3.11	1.63	3.22	1.22	0.02	3.4
Erbil Stations															
Erbil	1.09	97.1	1.22	0.57	1.25	0.54	0.01	1.59	96.55	1.38	0.67	1.43	0.6	0.01	1.76
Pirmam	1.85	97.62	0.92	0.39	0.86	0.37	0	1.07	98.1	0.76	0.32	0.69	0.29	0	0.85
Koya	0.79	97.44	1.08	0.48	1.05	0.46	0	1.32	96.73	1.31	0.61	1.3	0.54	0.01	1.56

Table 10: Empirical equations performance (R^2, skewness, and chi-square test) results for Duhok Provinces Stations

		Gumbel Distribution							LPT- III Distribution						
		T_r	2	5	10	25	50	100	T_r:	2	5	10	25	50	100
Stations	**skewness**	**R^2 (%)**	**Chi-square**						**R^2 (%)**	**Chi-square**					
Duhok	1.91	96.54	2.0	1.0	2.2	0.9	0.0	2.9	99.0	0.8	0.4	0.9	0.4	0.0	1.4

Akre	0.09	98	0.7	0.3	0.6	0.3	0.0	0.8	92.4	1.5	0.7	1.3	0.5	0.0	1.3
Sarsink	0.48	96.8	2.3	1.2	2.6	1.1	0.0	3.4	93.1	3.9	2.3	4.6	1.8	0.0	5.1
Semell	1.72	96.71	1.6	0.8	1.8	0.8	0.0	2.3	99.1	0.6	0.3	0.7	0.3	0.0	1.0
Batil	0.47	97.13	1.1	0.5	1.1	0.5	0.0	1.5	95.2	1.7	0.8	1.8	0.7	0.0	2.1
Malta	1.03	97.02	1.3	0.6	1.4	0.6	0.0	1.8	98.0	1.1	0.5	1.2	0.5	0.0	1.6
Zaweta	0.79	97.53	1.3	0.6	1.3	0.6	0.0	1.6	94.2	2.2	1.1	2.1	0.8	0.0	2.3
Amadia	1.41	97.7	0.9	0.4	0.9	0.4	0.0	1.1	98.5	0.7	0.3	0.7	0.3	0.0	0.8
Mangesh	1.40	96.44	2.3	1.3	2.7	1.2	0.0	3.6	98.4	1.5	0.7	1.7	0.8	0.0	2.6
Zakho	0.94	97.27	1.2	0.5	1.2	0.5	0.0	1.5	98.4	0.9	0.4	0.9	0.4	0.0	1.2
Bamarny	1.05	97.36	1.4	0.6	1.4	0.6	0.0	1.8	98.0	1.2	0.6	1.2	0.5	0.0	1.6
Zakho Ziraha	1.01	97	1.4	0.7	1.5	0.6	0.0	1.9	97.5	1.3	0.6	1.4	0.6	0.0	1.9
Batifa	0.88	98.09	0.6	0.2	0.5	0.2	0.0	0.6	97.3	0.8	0.3	0.7	0.3	0.0	0.7
Kani Masi	0.73	97.91	0.8	0.3	0.7	0.3	0.0	0.8	97.9	0.8	0.3	0.7	0.3	0.0	0.9
Dyara luk	-0.21	97.65	1.3	0.6	1.3	0.6	0.0	1.6	94.8	2.5	1.2	2.5	1.0	0.0	2.8
Qasrok	1.69	97.17	1.4	0.6	1.4	0.6	0.0	1.8	97.2	1.3	0.6	1.4	0.6	0.0	1.7
Duhok dam	1.32	97.12	1.4	0.7	1.5	0.6	0.0	1.9	98.0	1.1	0.5	1.1	0.5	0.0	1.5
Bardarash	0.93	98.12	0.5	0.2	0.4	0.2	0.0	0.5	98.0	0.5	0.2	0.4	0.2	0.0	0.5
Darkar	1.05	96.39	2.1	1.1	2.4	1.0	0.0	3.2	97.8	1.6	0.9	2.0	0.9	0.0	2.9
Swara Tuka	1.99	97.2	1.6	0.8	1.7	0.7	0.0	2.2	98.5	1.0	0.4	1.0	0.4	0.0	1.3
Hasania	1.46	97.14	1.5	0.7	1.5	0.7	0.0	2.0	95.6	2.0	1.0	2.1	0.8	0.0	2.4
Dinarta	0.27	97.19	2.1	1.0	2.3	1.0	0.0	2.9	96.9	2.6	1.3	2.9	1.2	0.0	3.7
Kirdsin	1.39	96.89	1.5	0.7	1.6	0.7	0.0	2.1	97.8	1.2	0.6	1.3	0.6	0.0	1.7

4. CONCLUSIONS

In this study IDF curves were derived for a total of 36 rain-gauge stations in KR of Iraq to estimate the intensity of rainfall in the region which are essential for water resources planning and management. Also, a total of 72 empirical equations were derived to estimate the amount of rainfall for any required rainfall periods with different return years. Results of the study showed that Gambel and LPT-III methods can be used successfully to estimate rainfall intensity with reasonable performances. Although the LPT-III method estimated rainfall intensity with higher R2 and chi-square values for a few stations but in general its performance is lower than the Gambel method for most of the other stations. Therefore, this study concluded that the performance of the Gambel method was more stable than the LPT-III method which perform almost the same performance for all stations, while the LPT-III method had a fluctuated performance. This study recommends that the LPT-III method may achieve better for rainfall data with a skewness less than 1.44, however, data with a skewness higher than 1.44 Gambel method is recommended.

Competing interests

The authors confirm that they have no competing interests.

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