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Frequency analysis of rainfall events in Karbala city, Iraq, by creating a proposed formula with eight probability distribution theories

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ABSTRACT

Due to its impact on the derivation of hydrological models and the safe design of sewer and storm networks, the anticipation of rainfall events should be intensively studied. In this regard, studying the rainfall events in Karbala, Iraq, has specific importance after the rapid increase in population in this city and the impact of climate change beyond 2003. Herein, the maximum daily rainfall depth of Karbala city has been analyzed to investigate and extract its probability of future occurrence using frequency analysis. Eight theoretical probability distributions, which are Weibull, Gamma, Gumbel, Log normal, Generalized Extreme Value, Normal, Exponential, and Log-Pearson Type III, were fitted using Hyfran Plus software to simulate the characteristics of the observed probability of rainfall depth. Based on the results of four statistical indicators, the exponential distribution revealed the best performance as compared with other distributions. Accordingly, the synthetic storms of 24 hr were derived for cumulative and incremental distribution of rainfall depth using the Soil Conservation Service method type II for the arid and semiarid region to recurrence periods (T = 2, 5, 10, 15, 25, 50, 100, 200, and 500), also the rainfall intensity duration frequency curves were developed. As an essential finding, new validated empirical formula has been proposed to optimize the coefficients of the location of Karbala city which may fill the gap for predicting the rainfall intensity and improving storm management strategies in Iraq.

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KEYWORDS
Frequency analysis; rainfall intensity; SCS method; empirical formula; Karbala city

1. Introduction

The precise analyzing and good understanding of rainfall events for any specific region catchment area are state of art to face the hazard of these natural events and allow the decision-makers and specialists to ensure safety requirements and alternatives of hydraulic design. Adopting the frequency analysis and selecting the best-fit distribution can reveal the harmonic behavior of rainfall events and extract the probable storm hyetographs and intensity curves.

Numerous studies have concluded the appropriate probability distribution of rainfall in various locations around the world. For example, Chow et al. [1] stated the main steps for developing the Intensity Duration Frequency (IDF) relations by comparing different probability distributions and obtaining the most fitted one that can present the rainfall events. Some studies used monthly data, such as Husak et al. [2], who studied the variation in monthly rainfall in Africa by using Gamma distribution for many specified locations. Their study tested the goodness of fitting by the Kolmogorov–Smirnov test and compared the results with the Weibull distribution. Their results revealed that the Gamma distribution has the dominant representation of the rainfall events for 98% of the study area. However, this study has high limitations by only using two distribution factors, Gamma and Weibull, without mentioning the other formulas. Consequently, Al-Suhili and Khanbilvardi [3] carried out a metrological investigation to fit the best distribution model using frequency analysis for monthly rainfall at three rain gauge stations during the period 1984–2010 in Sulaimania, Iraq. In comparison to other studies, they claimed that the Gamma distribution can perform the best fitting. Using their proposed model, they also extracted three sets of rainfall data for three rain gauge stations.

Other studies refer to the analysis of Intensity Duration Frequency (IDF) by using daily climate data. For example, Becker et al. [4] used daily precipitation data in the United States of America by using frequency distribution models. They discovered that the Gamma distribution can account for the recurrence of daily precipitation. Similarly, applying Soil Conversation Service (SCS) II for cumulative rainfall curves can be used efficiently for deriving the temporal variation of storms in arid and semiarid regions [5]. Kawara and

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Elsebaie [6] derived Intensity Duration Frequency (IDF) relations for the Yalamlam region in the Saudi Arabian Kingdom. The utilized rainfall data was analyzed based on daily measurements for 30 years. Two distribution parameters were adopted, which are Log-Pearson type III and Gumbel, to determine the probable rainfall depth. Referring to their results, no considerable difference can be observed between the two models.

Estimating or predicting rainfall events could be done by creating models or empirical formulas. For example, Al-Awadi [7] assessed the IDF curves for Baghdad, Iraq, and developed a new empirical formula to estimate the rainfall intensity. Shrestha et al. [8] showed the importance of updating the Intensity Duration Frequency relations (IDF) to avoid the effects of climate change and improve the performance of the drainage network. Awadallah and Hamed [9] developed storm hyetographs in Oman based on the SCS method for arid and hyper-arid regions. The rainfall data were gathered from 48 rain gauge stations. According to their main finding, the developed profile by Chin [10] was close to that extracted by SCS. Mahdi and Mohamedmeki [11] investigated three frequency models, the Gumbel distribution, log Pearson Type III, and the log normal distribution to develop empirical formulas for estimating intensity duration curves in Baghdad, Iraq. At a 10% significant level, they found that the three models were close to each other. Shehu B et al. [12] stated the importance of duration frequency curves of rainfall depth for design requirements of water systems according to local and regional analysis in Germany. The local extreme value revealed the best performance according to their obtained results. Majeed [13] assessed the risk of rainfall intensity in the eastern basin of Erbil city, Iraq, and investigated the produced runoff in three zones of the study area and concluded the morphological maps for flood hazard related to the rainfall intensity. Elsebaie et al. [14] developed the IDF curves for different return periods in the Al-Lith region of western Saudi Arabia to evaluate the risk management of flash floods with various distribution models. Based on their study, the Log-Pearson type III produced the best performance for predicting IDF curves for that semi-arid region. Therefore, it is essential to detect the storm distribution characteristics, rainfall depth and rainfall intensity. Although the above studies mentioned empirical formulas or models, they used a limited number of distribution models. Moreover, a lack of findings is noted for extracting and understanding the storm hyetograph in the middle of Iraq. Therefore, the present study covers these points and aims to extract the best probability distribution method of rainfall events for Karbala city in Iraq using Hyfran Plus software by selecting eight distribution models. Also, the storm hyetograph was derived for cumulative and incremental distribution of rainfall depth based on the SCS method for the semi-arid region, as well as the frequency curves of the maximum rainfall depth and rainfall intensity were assessed. This research aims to close the gap by developing a new proposed formula for predicting rainfall intensity based on the specialty of its location, which could aid project planners in Karbala.

2. Study area and climatic parameters

Karbala city is located in the middle of Iraq. The estimated area covers 5034 km^2, and it extends between latitudes 32° 36‘31‟N and longitudes 44° 01’ 32” E (Figure 1). According to the Karbala city local authority, the estimated population in 2021 is 1500 000 per capita. The city of Karbala has significantly suffered from some problems, such as climate change impacts [15], particularly increasing temperatures [16], and rainfall issues [17]. The study area has an arid to semi-arid climate, with hot and dry summers and cold winters and an average annual gained rainfall depth of 107 mm. The monthly maximum and minimum temperatures averaged 45 degree Celsius in July and August, and 6 degree Celsius in January. The mean value of monthly maximum evaporation is 445 mm. As a result, the mean monthly maximum and minimum relative humidity can be specified as 73% in January and 29% in July. In the present study, the available data on the daily rainfall depth for the period from 2004 to 2019 have been analyzed to specify the maximum annual rainfall depth in mm. Then, the recurrence of the rainfall events is observed. Finally, a rainfall frequency analysis is performed.

3. Methodology of frequency analysis

3.1. Probability of rainfall event

To visualize the maximum rainfall event data and perform the frequency analysis, the relationship between the observed value of the rainfall event and the probability should be specified. In this study, the plotting position or probability of rainfall events has been obtained according to Weibull's formula. Accordingly, the return period for the observed magnitude of the rainfall event was calculated as follows [1]:

$$P = (m/n + 1) \tag{1}$$

$$T = 1/P \tag{2}$$

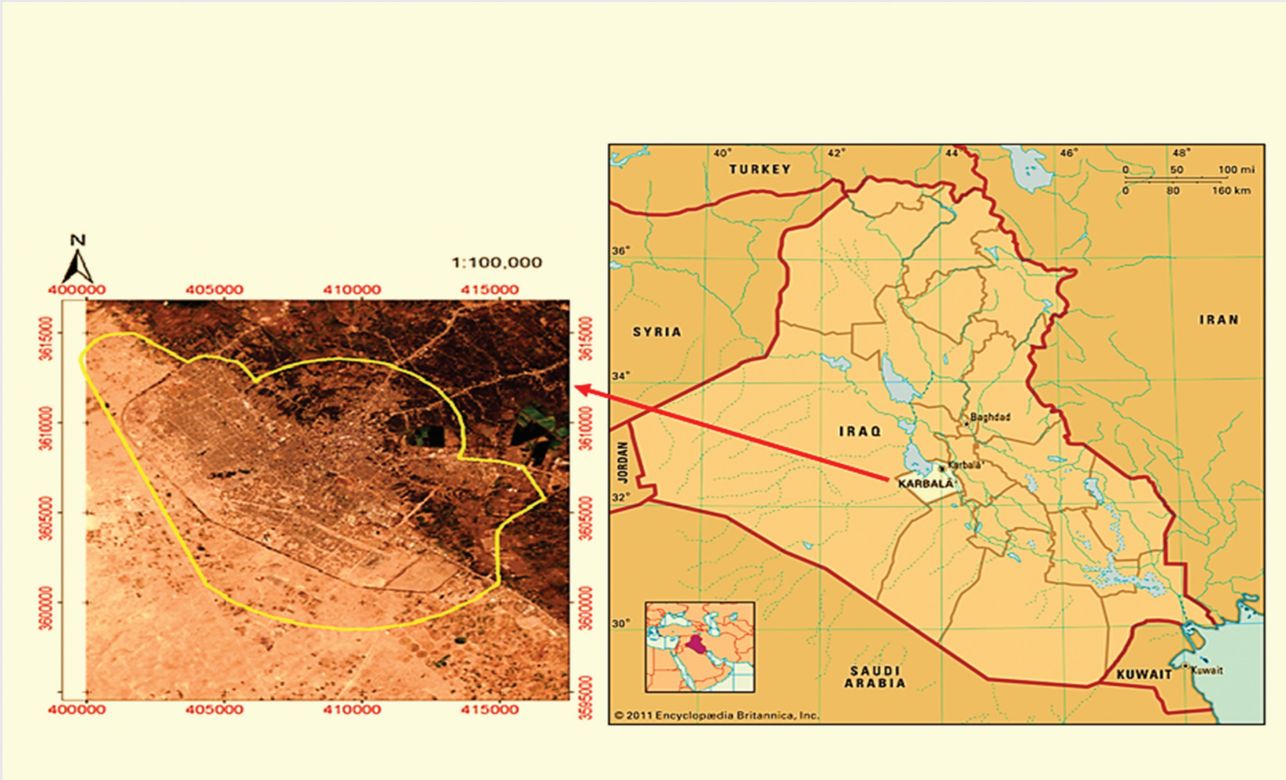

Figure 1. Study area – Karbala city in Iraq.

where P is the probability, m is the rank by considering the descending order, n is the total number of the observed value of rainfall event, and T is the return period of the event.

3.2. Method of estimating distribution parameters

Several methods are used for estimating the parameters of hydrologic frequency models. These methods include the method of moments, the probability method of weighted moments, mixed moments, the least squares method, and the maximum likelihood method [18]. The most dominant methods for estimating the parameters of the distribution are moments and the maximum likelihood [19]. In general, the maximum likelihood method can provide the optimal solution of estimated parameters with the least mean square error for a wide range of applied sciences, making it the most efficient technique for performing frequency analysis [20]. Thus, for the current study, the method of maximum likelihood has been adopted to estimate the parameters.

3.3. Probability distribution and the utilized numerical tools

Among many probability distributions, eight methods have been used to relate the rainfall depth events with their recurrence periods ($T = 2$, 5, 10, 15, 25, 50, 100, 200, and 500 years). These distribution methods are Weibull, Gamma, Gumbel, Log normal, Generalized Extreme Value (GEV), Normal, Exponential, and Log-Pearson Type III. These methods can be considered as the most extensively used distributions to estimate and model the extreme

Table 1. Probability distribution functions (PDF) [21].

Distribution methods	Probability distribution functions (PDF)	
Weibull	F (x\a, b) =ab−a xa−1 e−(xb)a	(3)
Gamma	F (x\a, b) = 1ba (1Γ(a))xa−1 e(xb)	(4)
Gumbel	F(x)= σμσμσe−1−(x−μ)/σexp(−e−(x−μ)/σ)	(5)
Log normal	F (x\σμσ,μ) =σπμσ1xσ2πe−(logx−μ)22σ2	(6)
(GEV)	F(x) =μσe((−1−kx−μσ)1k)	(7)
Normal	F (x\σμσ,μ) =σπμσ1σ2πe−(x−μ)22σ2	(8)
Exponential	F (x\μμ) = μμ1μexμ	(9)
Log-Pearson Type III	F(x)=1axΓ(b)[ln(x−c)a]b−1 exp[−ln(x−c)a]	(10)

events for any hydrological system [1,21]. Table 1 shows the mathematical representation of the probability distribution functions (PDF) that have been utilized for the current work. It can be clearly seen from these distributions that the mathematical parameters are complex, so using numerical tools (a software package) can simplify the frequency analysis. The hydrologic frequency analysis by HYFRAN software version 2.2 was used in this study to extract statistical distributions. This software provides many distributions to analyze the hydrological events and supports the decision-making process for selecting the proper distribution.

a and K are the shape parameters, b and σ (standard deviation) are the scale parameters, Γ(a) and Γ(b) are the Gamma function, μ is the mean value, and c is the location parameter.

3.4. Testing the goodness of fit

Four statistical indicators, which are the root mean square errors (RMSE), Chi square test (x^2), index of agreement (IOA), and model efficiency (Nash–Sutcliffe efficiency) [22], were applied to assess the performance of probability distribution methods. These indicators give a better understanding for comparison of the results according to each return period for the specified distribution previously mentioned to conclude the best match between the observed and simulated rainfall depth, which can be elaborated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (S_i - O_i)^2}{N}} \tag{3}$$

$$\frac{\sum_{i=0}^{N} (O_i - Si)^2}{S_i} \tag{4}$$

$$\frac{\sum_{i=1}^{N} (S_i - O_i)^2}{\sum_{i=1}^{N} (|O_i - O^-| + |S_i - O^-|)^2} \tag{5}$$

$$\frac{\sum_{i=1}^{N} (S_i - O_i)^2}{\sum_{i=1}^{N} (O_i - O^-)^2} \tag{6}$$

where S_i and O_i are the simulated and observed values, O^- represents the mean value for the observed results. Generally, the best agreement can be achieved according to the obtained least error from Equations (11) and (12), while the efficiency of the extracted model can be specified with respect to Equations (13) and (14); the values of one for IOA and NE indicate the best performance for the model.

3.5. Synthetic storm distribution, IDF relation, and modeling

By analyzing the observed rainfall events according to the best-fitting probability distribution, the temporal distribution of storms can be implemented. The synthetic storm of 24 hr was derived by considering the expected depth for each return period for both cumulative and incremental distribution time during 24 hr based on the proposed method by the U.S. Department of Agriculture of Agriculture Soil Conservation Service, 1986, SCS method type II for arid and semiarid regions [23], and the methodology of the Alternating Block Method (ABM) presented by Chow et al. [1]. By multiplying the rainfall depth by its ratio over 24 hr, the rainfall depth can be converted to storm rainfall distribution. A Microsoft Excel work sheet has been created to investigate the maximum depth of rainfall at an accumulated time step of 0.5 hr by using the logic function in the work sheet to obtain the maximum cumulative ratio for each 0.5 hr. As a result, the maximum depth of rainfall can be estimated by multiplying the produced maximum ratio by the rainfall depth for each return period over a single day at a time step of 0.5 hr. The IDF curves can be developed by applying Equation 11 as follows:

$$I = R_{max}/D \tag{7}$$

where R_{max} is the maximum rainfall depth for the specified return period and D is the duration of rainfall [1]. To simplify the concluded IDF curves, a proposed form of the empirical formula presented by Wenzel [24] (1982) and Chow et al. [1] has been adopted to assess the coefficients of location of Karbala city and predict the rainfall intensity, which can be written as follows:

$$I = a \times T^b/D^{b1} + a1 \tag{8}$$

whereas a, a1, b, and b1 are the coefficients of location for Karbala city for a given return period (T) and duration (D). To optimize the coefficient values of the new proposed formula, the computer program package IBM SPSS 24 (Statistical Package for the Social Sciences) has been utilized. Two sets of data were used to perform the nonlinear regression; the first set was for the training stage and contained around 80% of the data, while the second stage (testing stage) included 20% of the data. The performance of the new predicted formula was investigated during the testing stage using two statistical indicators, which are the correlation coefficient (R) and mean absolute error (MAE), as represented below:

$$R = \frac{\sum_{i=1}^{N}(M_i - M^-)*(P_i - P^-)}{\sqrt{\sum_{i=1}^{N}(M_i - M^-)^2 * \sum_{i=1}^{N}(P_i - P^-)^2}} \quad (9)$$

$$= \frac{\sum_{i=1}^{N}|P_i - M_i|}{N} \quad (10)$$

where M_i and M^- are the extracted and the mean values, respectively, for the most agreement distribution method, while P_i and P^- are the predicted and the mean value for the obtained results of the proposed formulas respectively, and N is the total amount of data.

4. Results and discussion

4.1. Probability distribution and model fitting

Figure 2 shows the probability plots (plotting positions) of the maximum value of the observed rainfall events according to Equation 1. It is clear that the magnitude of the observed rainfall decreases as the probability of occurrence increases. The graphical representation of the probability distribution demonstrates that the maximum value of the observed rainfall depth is 68 mm, which may occur with a plotting position of approximately 6%, while the minimum rainfall depth of 6.1 mm is obviously seen with a plotting position of 94%. Generally, the observed rainfall depth can be ranged from 20 to 30 mm with a plotting position of 30–70%. Also, it is noted that the rainfall depth of 7–18 mm occurs with a probability domain of 70–90%. Table 2 compares the extracted results of rainfall depth by HYFRAN plus software version 2.2 for different probability models with their recurrence periods ($T = 2$, 5, 10, 15, 25, 50, 100, 200, and 500 years). Based on the results of the statistical indices shown in Table 3 for evaluating the performance of each model used in this study, it is noted that the exponential distribution reveals the best agreement with observed data, whereas NE, IOA, CHI, and RMSE were equal to 0.95, 0.99, 2.21, and 3.35, respectively.

4.2. Storms distribution and IDF

Figure 3 shows the developed accumulative storm distribution during the 24 hr for each return period using SCS II based on the exponential model. Generally, the design of the storm patterns of Karbala city illustrates

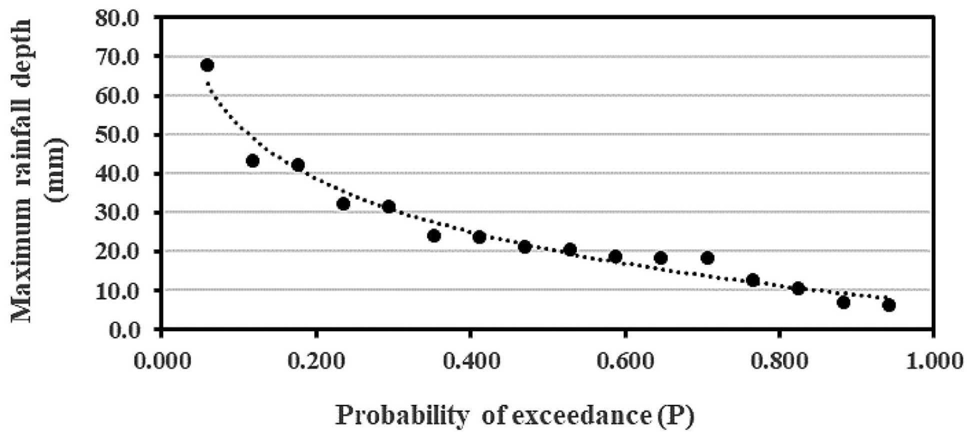

Figure 2. Probability distribution of the maximum rainfall depth in Karbala city.

Table 2. Extracted rainfall depth using HYFRAN plus software according to different probability distribution.

T, years	Rainfall depth, mm							
	Weibull	Gamma	Gumbel	Log normal	GEV	Norm	Exp	Log-Pearson Type III
2	22.8	22	22.2	20.7	21.3	24.9	18.8	21.2
5	37	35.8	35.2	35.8	34.6	38.3	37.2	35.2
10	45.5	44.8	43.9	47.6	44.6	45.3	51.1	45.3
15	50	49.7	48.8	54.9	50.8	48.8	59.2	51.3
20	53	53.2	52.2	60.3	55.3	51.1	65	55.5
25	55.2	55.8	54.9	64.6	58.9	52.8	69.5	58.9
50	61.8	63.7	63	78.8	70.8	57.6	83.4	69.3
100	67.9	71.5	71	94	83.8	61.9	97.3	79.9
200	73.7	79	79.1	111	98.1	65.9	111	90.7
500	80.8	88.7	89.7	135	119	70.7	130	105

Table 3. The values of statistical indicators for assessing goodness of fit for different probability distribution.

Statistical indicators	Weibull	Gamma	Gumbel	Log normal	GEV	Norm	Exp	Log-Pearson Type III
NE	0.81	0.80	0.78	0.90	0.82	0.76	.95	.83
MAX							.95	
IOA	0.93	0.93	0.92	0.97	0.94	0.90	.99	.94
MAX							.99	
Chi	6.61	6.86	7.95	3.28	6.33	8.88	2.21	5.73
MIN							2.21	
RMSE	6.29	6.40	6.82	4.46	6.10	7.04	3.35	5.86
MIN							3.35	

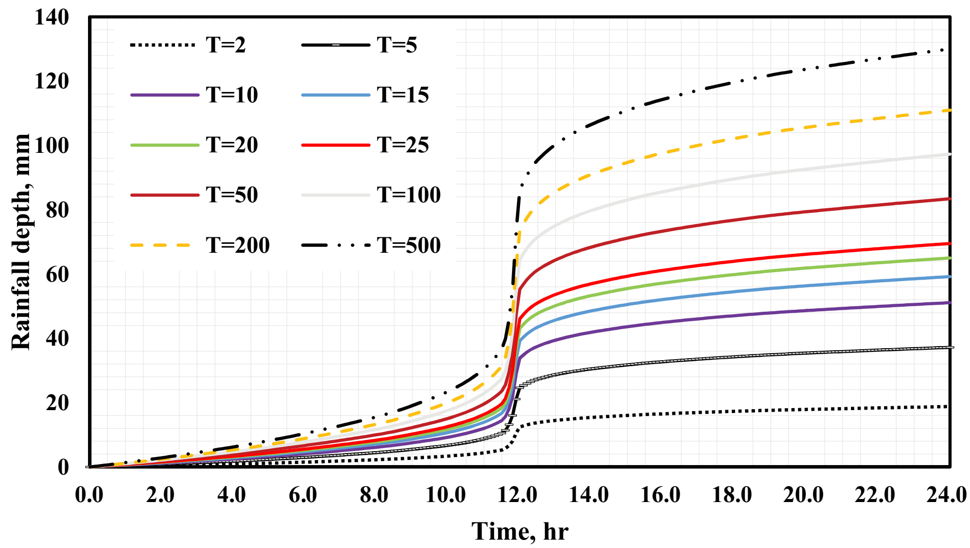

Figure 3. Accumulative storm distribution of Karbala city for each return period using SCS II.

the increasing rainfall depth during the day, whereas three portions identify the curves (S curves). The accumulative rainfall depth is directly proportional to each return period. However, the accumulative rainfall depth reaches its maximum value (130 mm) at $T = 500$, while at $T = 2$, the rainfall depth equals approximately 20 mm. For $T = 200$, 100, 50, 25, 20, 15, 10, and 5, the accumulative rainfall depths are 111, 97, 83, 70, 65, 59, 51, and 37 mm, respectively. Figure 3 depicts the incremental storm distribution over the course of 24 hr.

The derived storms reveal the variation in the maximum value of rainfall. It can be shown that the maximum value of rainfall increases with increasing the return periods, whereas the proposed peak of incremental rainfall depth occurs at the midpoint duration (12 hr), and the others are positioned before and after the peak alternately in descending order (ABM). Accordingly, the maximum incremental rainfall depth is 2.6, 5.1, 7, 8.15, 9.53, 11.43, 13.34, 15.21, and 17.82 mm for $T = 2$, 5, 10, 15, 25, 50, 100, 200, and 500 years, respectively (Figure 4).

Figure 5 shows the maximum accumulative rainfall depth distribution during 24 hr for each 0.5 hr, which has been used for deriving the IDF curves. Rainfall depth is observed to increase with duration and return period in general. Figure 6 depicts the derived IDF curves of Karbala city based on Equation 11, where rainfall intensity is inversely proportional to increasing duration and directly proportional to return periods.

The maximum rainfall intensity in mm/hr can be specified at 0.5 hr with 14.3, 28.3, 38.8, 45.0, 52.8, 63.4, 74.0, 84.4, and 98.8 for $T = 2$, 5, 10, 15, 25, 50, 100, 200, and 500, respectively. It is clear that the intensity of the rainfall increased as the return period increased during the 24-hr period.

4.3. IDF new proposed formula with comparisons

Based on the derived results of IDF relations and the proposed empirical form mentioned previously in Equation 11, the program package IBM SPSS 24 adjusted the coefficient of location of Karbala city for the training stage using nonlinear regression to obtain the optimal value of the coefficient of determination (R^2). Accordingly, the new proposed formula can be presented as follows:

$$I = 13.384 \times T^{0.249}/D^{0.729} - 0.491 \qquad (11)$$

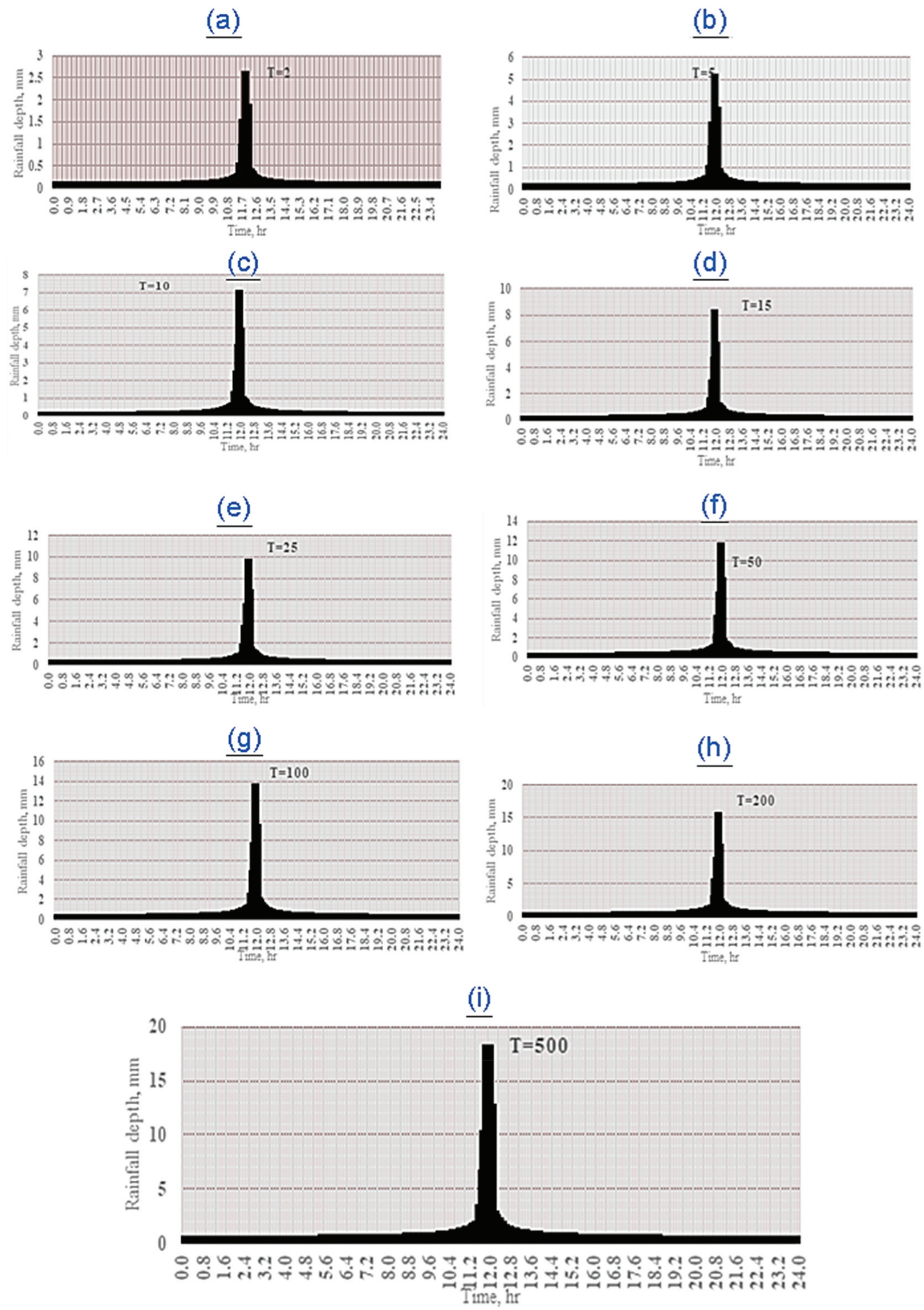

Figure 4. Incremental storm hyetograph during 24 hr for different return periods using SCSII.

where $R^2 = 0.987$. To ensure the performance of Equation 11, 20% of the data series of IDF relations were evaluated with respect to the new proposed formula as shown in Figure 7, where $R = 0.997$ and MAE = 0.58.

Table 4 demonstrates a comparison between the rainfall intensity obtained from the exponential distribution in the present study and the rainfall intensity derived from the Gumbel distribution by Omran

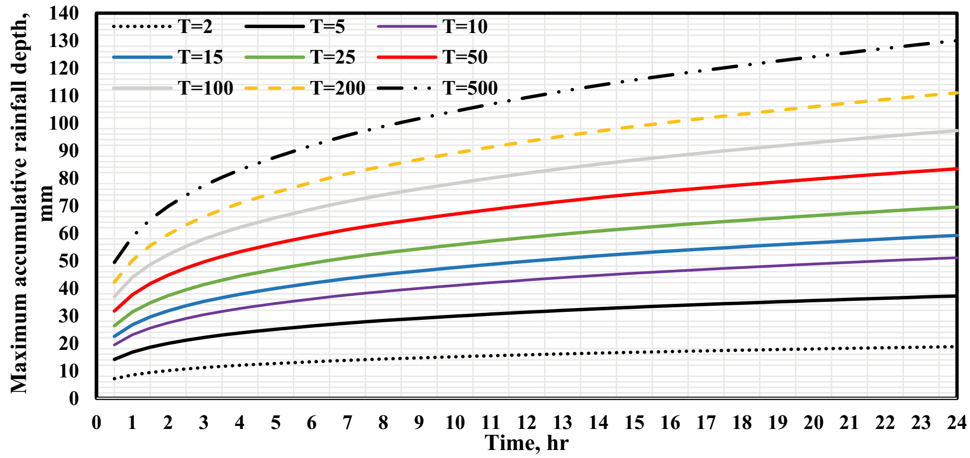

Figure 5. Maximum accumulative rainfall depth distribution.

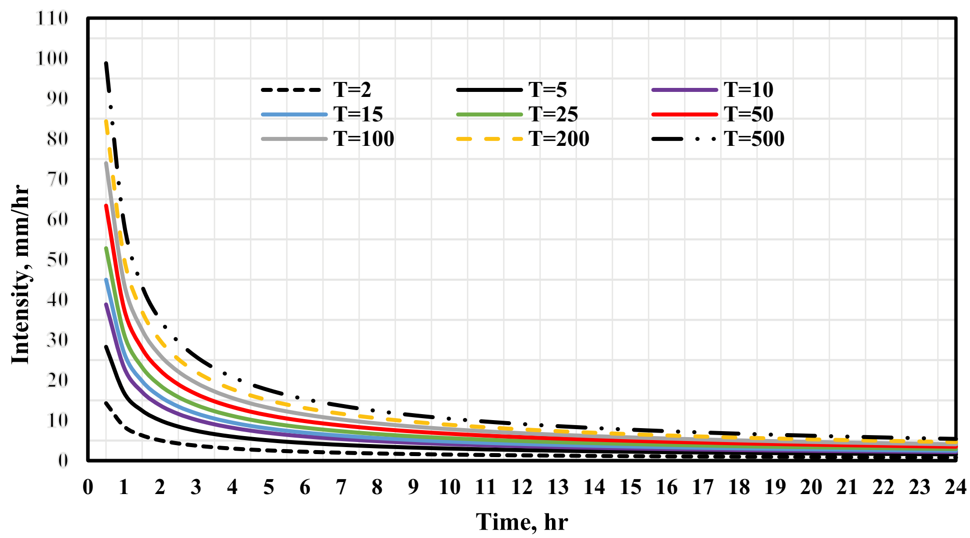

Figure 6. The derived IDF curves of Karbala city.

et al. [25]. It can be concluded that the rainfall intensity estimated by this study is greater than that predicted by Omran et al. [25] for all return periods. The mentioned values of rainfall intensity for $T = 5$ to 50 in Table 4 are considered necessary because specialists in water resources engineering can depend on them to assess the effect of rainfall intensity on urban drainage design and water control structures according to the risk and the cost (optimal design). Furthermore, it can be noted that extracted results of IDF for the current study by Exp distribution are utmost than the produced results of Log-Pearson type III that obtained by Hussein [26]. Accordingly, the results of this work may reveal the conservative limits of IDF which can be used to evaluate the worst-case scenario to evaluate the performance of storm networks in Karbala city.

5. Conclusion

The current study presents a frequency analysis of rainfall events in Karbala, Iraq, according to different probability distributions by utilizing HYFRAN Plus software version 2.2 and the SCS methodology to conduct cumulative and incremental synthetic storms over the course of 24 hr. Furthermore, the IDF curves were derived and modeled. Accordingly, the main conclusions can be summarized as follows:

(1) The plotting position analysis of rainfall events reveals that around 20–30 mm of rainfall depth can be specified with a probability range of 30–70%. Also, it is noted that rainfall depths of 7–18 mm occur with a probability domain of 70–90%.

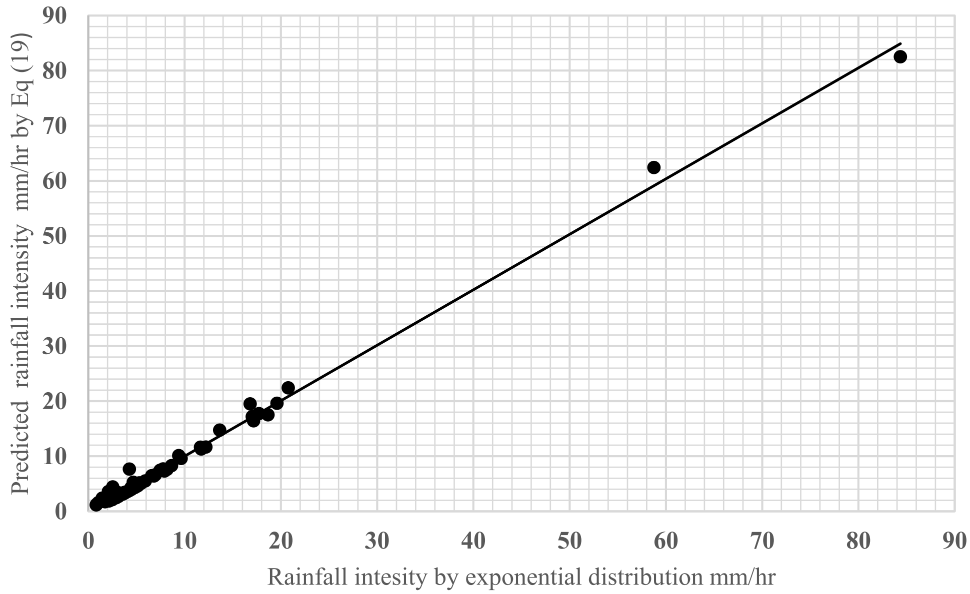

Figure 7. Evaluation the performance of Equation (19).

Table 4. Comparisons of the results of rainfall intensity.

			Intensity of rainfall in mm/hr			
			Return period (*T*)			
Authors	Probability distribution	Duration	5 years	10 years	15 years	50 years
Omran et al. [22]	Gumbel	0.5 hr	22.3	28.7	32.1	42.1
		1 hr	13.9	17.5	19.5	25.3
Present study	Exp	0.5 hr	28.272	38.836	44.992	63.384
		1 hr	16.814	23.1	26.758	37.697

(2) The exponential model was found to be the best fitted model among the eight theoretical probability distributions used to fit the observed data.

(3) The developed synthetic storms for cumulative and incremental distribution during 24 hr using SCS method type II for arid and semiarid can be considered a very important approach to understanding and comparing storm variation with return periods. Furthermore, the performance of storm network in Karbala city could be evaluated and modeled based on the different scenarios of synthetic storm profile and the extracted IDF curves of the current work to ensure the optimal operation management and specify the alternatives and avoid the failure mode.

(4) The new proposed formula for predicting the intensity of rainfall can be utilized as a new design scale for the planning and management of water resources in Karbala city. It can be recommended to conduct further studies to compare the storm profile during durations shorter than 24 hr (6, 12, and 18 hr).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

[1] Chow VT, Maidment DR, Mays LW. Applied hydrology. New York: McGraw-Hill Book Company; 1988.

[2] Husak GJ, Michaelsen J, Funk C. Use of the gamma distribution to represent monthly rainfall in Africa for drought monitoring applications. International Journal Of Climatology: A Journal Of The Royal Meteorological Society. 2007;27(7):935–944.

[3] Al-Suhili RH, Khanbilvardi R. Frequency analysis of the monthly rainfall data at Sulaimania region, Iraq. Am J Eng Res. 2014;3(5):212–222.

[4] Becker EJ, Berbery EH, Higgins RW. Understanding the characteristics of daily precipitation over the United States using the North American Regional Reanalysis. J Clim. 2009;22(23):6268–6286.

[5] Elfeki AM, Ewea HA, Al-Amri NS. Development of storm hyetographs for flood forecasting in the Kingdom of Saudi Arabia. Arabian J Geosci. 2014;7(10):4387–4398.
[6] Kawara AQ, Elsebaie IH. Development of rainfall intensity, duration and frequency relationship on a daily and sub-daily basis (Case Study: yalamlam Area, Saudi Arabia). Water. 2022;14(6):897.
[7] Al-Awadi AT. Assessment of intensity duration frequency (IDF) models for Baghdad city, Iraq. Journal Of Applied Sciences Research. 2016;12(2):7–11.
[8] Shrestha A, Babel MS, Weesakul S, et al. Developing Intensity–Duration–Frequency (IDF) curves under climate change uncertainty: the case of Bangkok, Thailand. Water. 2017;9(2):145.
[9] Awadallah AG, Hamed KH. Suitability of commonly used design storm profiles for oman. In Towards a Sustainable Water Future: Proceedings of Oman's International Conference on Water Engineering and Management of Water Resources; Bengaluru, India. ICE Publishing; 2021. p. 325–336.
[10] Chin DA. Updated canonical rainfall distributions in the United States. Journal Of Irrigation And Drainage Engineering. 2020;146(12):06020012.
[11] Mahdi ES, Mohamedmeki MZ. Analysis of rainfall intensity-duration-frequency (IDF) curves of Baghdad city. In IOP Conference Series: Materials Science and Engineering; Chennai, India. IOP Publishing; 2020. Vol. 888, No. 1, p. 012066.
[12] Shehu B, Willems W, Stockel H, et al. Regionalisation of rainfall depth–duration–frequency curves with different data types in Germany. Hydrology and Earth System Sciences. 2023;27(5):1109–1132.
[13] Majeed HMS. Risks of rainfall intensity in Erbil's Eastern Basins. Journal Of Basic Sciences. 2023;9(14):413–431.
[14] Elsebaie IH, El Alfy M, Kawara AQ. Spatiotemporal Variability of Intensity–Duration–Frequency (IDF) curves in arid areas: wadi AL-Lith, Saudi Arabia as a case Study. Hydrology. 2022;9(1):6.
[15] Al-Saadi RJM, Algretawee H. Impact of measuring times on Urban Heat Island (UHl) magnitudes between Urban and Suburban areas in Karbala City. Advanced Engineering Science. 2022;54(6):2067–2080.
[16] Algretawee H, Al-Saadi RJM, Al Juboury MF, et al. Determination of difference amount in reference evapotranspiration between urban and suburban quarters in Karbala City. J Ecol Eng. 2022;23(7):180–191.
[17] Alisawi HAO. A sewer overflow mitigation during festival and rainfall periods: case study of Karbala. Appl Water Sci. 2020;10(12):241.
[18] Rao AR, Hamed KH. The logistic distribution. Flood frequency analysis. Boca Raton, FL, USA: CRC Press; 2000. p. 291–321.
[19] Kite GW. Frequency and risk analyses in hydrology, water resources publications. Colorado: United States of America; 1977.
[20] Miura K. An introduction to maximum likelihood estimation and information geometry. Interdisciplinary Information Sciences. 2011;17(3):155–174.
[21] GHORBANI MA, RUSKEEP H. Flood frequency analysis using Mathematica. Turkish Journal Of Engineering And Environmental Sciences. 2010;34(3):171–188.
[22] Phogat V, Skewes MA, Cox JW, et al. Statistical assessment of a numerical model simulating agro hydro-chemical processes in soil under drip fertigated mandarin tree. Irrig Drain Syst Eng. 2016;5(2). DOI:10.4172/2168-9768.1000155
[23] U.S. Soil Conservation Service. Engineering Division. Urban hydrology for small watersheds (No. 55). Engineering division, soil conservation service. USA: US Department of Agriculture; 1986.
[24] Wenzel HG, Hydrology USW, Kibler DF, editors. Rainfall for urban stormwater design. Water resources monograph 7. Washington D.C: AGU; 1982. p. 35–67.
[25] Omran ZA, Al-Bazzaz ST, Ruddock F. Statistical analysis of rainfall records of some iraqi meteorological stations. Journal Of Babylon University Engineering Sciences. 2014;22(1):67–77.
[26] Hussein AK. Deriving rainfall intensity-duration-frequency relationships for Kerbala city. Al Muthana Journal For Engineering Sciences. 2014;3(1):25–37.