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RESEARCH PAPER

Derivation of the Rainfall Intensity- Duration- Frequency Curve for Erbil city, Using SCS II Method

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A B S T R A C T:

Countries in the Middle East region are classified as arid and semi-arid regions in the world. Because of its geographical location, it is characterized by fluctuating rainfall, which is exposed to frequent floods and causes human and material losses, on the other hand there is a lack of short-duration interval rainfall data. Therefore, to achieve hydrological studies of floods and planning for flood mitigation structure, it is necessary to derive the Rainfall Intensity- Duration- Frequency (IDF) curve, as there is a traditional method for calculating IDF curves, which is based only on two statistical distributions and only one statistical test. In this research, Soil conservation service (SCS) Type II for 24-hour rainfall distribution suitable for the arid and semi-arid regions was adopted to derive the IDF curve for maximum daily rainfall data in Erbil city. The method used has few computational steps than the traditional methods, the number of parameters is less, the number of used statistical distributions is 6, and the number of statistical tests is 4, which increases reliability. The optimal distribution was chosen for Erbil city, and the IDF curves were derived. The maximum daily rainfall was used during a specified return period from 2 to 200 years. The results showed that the maximum difference between the IDF curves obtained from the SCS theory and the traditional method is about 11%. Also, empirical relationships for representation IDF Talbot, Bernard and Ishiguro were applied, and through the test, Bernard was found to be the best.

KEY WORDS: IDF curve; Max. daily rainfall; return period; SCS; Hyfran plus, Design rainfall storm.
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1.INTRODUCTION :

Water is one of the most important natural resources for countries and an essential basis for their growth and development, which necessitates the search for ways to conserve water wealth and optimally utilize all water that the hydrological cycle gives through planning and rational management of the water. Rainfall is one of the most important sources of water for its contribution to agriculture, human and industrial consumption, and groundwater recharge. Recent years have witnessed great interest in rainfall in the design, development and management of rainfall water. The main problem facing the management and planning of rainwater projects is the inadequate observed data on the amount of rain in rainstorms that come within a short time. Rainfall has changed all over the world due to climate change caused by human activities, and this event is necessary to consider by researchers

in preparing the Hydrological Study of Drought and Flood. Rainfall storms are considered critical climatic phenomena, and knowing how they occur, intensity magnitude, duration, and required return periods are necessary for studies of the design of hydraulic structures for flood mitigation and control. Due to the problem, unsuitable hydraulic structure capacity has been built in some spot points in the urban area, this problem needs to provide a suitable model to estimate the design rainfall storm through the return period. Factors such as the type of structure, size, capacity, cost, and level of protection are essential in the selection storm return period for Sewer design considered in the event of a flood with a return period of 10 to 100

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years. Whereas for inner street canals, the return period is 25 to 50 years, and for highway bridge design the return period is 50 to 100 years (A. Osman Akan, 1982)

To prepare IDF curves, researchers proposed different methods, some of which can be used in certain areas and for use in others; they need to be re-calibrated. The Corps of Engineers in the US Department of Agriculture, in cooperation with the Soil Conservation Services (1986), presented four models after dividing the United States into four climatic regions. These models can be used in similar climatic area of the world, and these models are S-Curve maximum accumulated daily rainfall distribution (Rainfall distribution patterns) SCS I, SCS Ia, SCS II, SCS III. (Chow et al., 1988)

In 1932, the first IDF ties were formed, and since then, many relations of IDF curve were developed in many areas in the world (Obeid and El Kholy, 2021) . Hershfield, Bell present one of the models used to estimate the amount of short-term precipitation with different return periods in the United States for return periods from 2 to 100 years, by distributing the maximum daily rainfall over 24-hours using a special ratio named Bell ratio (Hinckley et al., 1991). Hershfield used rainfall contour maps to calculate rainfall design depths for various durations and return times. (Hinckley et al., 1991).

A study in South Africa was carried out using the traditional method and simple measurement techniques to obtain the relationships between the rain intensities of different durations and frequencies with the reference intensity for 24-hours (Smithers, 1998)

Minh Nhat in 2008 studied seven stations in Vietnam and five stations in Japan in which data are available for durations of 10min, 30min, 1h, 2h, 4h, 9h, 12h, 24h and for a period of 30 years. The traditional method and the measurement were used to find equations that relate the maximum rain intensity in terms of the reference intensity, which is the intensity within h 24 and the frequency of the year 10, and use the GIS program to obtain the equations in places where measurements are not available (ungagged station) (NHAT, L, 2008).

Mauro Naghettini in brazil applied the characteristics of correlation of four neighboring stations for drawing intensity curves in ungagged station. (Naghettini, 2013).

Elsebaie (2012) used two distribution approaches, the Gumbel and Log-Pearson type III distributions, to develop IDF equations in both the Najran and Hafr-Albatin regions, with durations ranging from 10 to 1440 minutes and return periods ranging from 2 to 100 years. In terms of the Gumbel distribution method, the results were marginally better than those produced from the Log-Pearson III distribution. (Jaleel, r.Lamia Abdul, 2013)has used Gumbel in developing IDF curve for Basrah city, Iraq. Paola et al. (2014) presented a study to evaluate the IDF curves and analyzed the rainfall pattern for three cities: Addis Ababa (Ethiopia), Dar es Salaam (Tanzania) and Douala (Cameroon) in order to verify the changes in rainfall patterns.

Cheng and Aghakouchak (2014) used a specific IDF model based on three variables, 1 h duration, 10-year return period ; 24 hour duration , 10-year return period ; 1 h duration , 100-year return period, for 5 selected station in USA for studying the climate change impacts.

In 2016, a study carried out by a group of researchers, including Medard Noukpo Agbazo in West Africa, on thirty stations and they applied the measurement method. It was found that the measurement is simple and takes the form of two straight lines and then a mathematical relationship was established depending on the coefficients of location and scale (Agbazo et al., 2016)

To estimate precipitation IDF curve for the city of Sulaymaniyah, Iraq using daily precipitation data and empirical formula and compared the data with IDF curve

For Sulaymaniyah city, Iraq, (Hamaamin, 2017). The study showed that the IDF curves computed with the coefficient of determination (R2 = 1) fitted with the expected values of rainfall intensities.

Ahmed Awda Dakheel (2017) used Indian Meteorological Department formula and Gumbel, Log Pearson Type III distribution to derive IDF curve for Naseriayah city in the south of Iraq, he found the best distribution for case study is log Pearson.

Abdulrazzak et al. (2018) have used a new Temporal Rainfall distribution patterns (RDP) that depend on actual measured sub-daily rainfall data applied in Medina, Saudi Arabia and compared with the SCS type II. They found that the difference between the two method IS about 18%.

Mohammed et al. (2018) used a new methodology to develop IDF curves in ungagged area in USA. This paradigm is built on considering the peculiarities of satellite-based precipitation products, such as bias adjustment and areal to point rainfall transformation.

Jalut (2018) constructed IDF curves for Kirkuk station, Iraq using a new classification method to estimate rainfall intensity for different return periods.

Abdullah et al. (2019) studied the efficiency of the SCS type II method in the distribution of the daily rain storm and compared it with real data with short duration to derive the rainfall IDF curve in Jeddah, Saudi Arabia. They found that there is a slight difference, and this method can be used safely in rainstorms when the duration is less than 3 hours.

There are many studies that rely only on the traditional method, such as that done in Saudi Arabia (Ewea et al., 2017), Iraq (Hasan, 2020), (Basim K. Nile2, 2021), India (Dar et al., 2016), Rwanda (Wagesho and Claire, 2016), Egypt (Awadallah et al., 2017), Bangladesh (Rasel and Islam, 2015), Turkey (Dergi, 2022), Iran(Adib et al., 2019) and other countries, as in all these studies the most appropriate empirical equation constants were determined based on the least squares method.

According to the study of (Obeid & El Kholy, 2021) carried out in lebanon, SCS-Type II Distribution is more suitable to obtain sub-hourly rainfall data from the given daily records.

Kareem et al. (2022) used traditional method for deriving IDF curve in Erbil city, they use Indian Meteorological Department (IMD) method of rainfall distribution with Gumbel and LPT III Log Pearson type III statistical Distribution, they discovered that the outcomes of the Gumbel and LPT III procedures do not differ noticeably.

The lack of metrological data like sub-daily rainfall data, i.e. hourly and minutely data which are needed in the comparison and verification of IDF curve. For this reason, it is necessary to study the characteristics of rainfall Intensity-Duration-Frequency at different return periods.

The Aims of the study are to develop IDF curve based on SCS II 24-hour rainfall distribution method at various return periods of (2, 5, 10, 15, 25, 50, 100 and 200) years, to improve the reliability of heavy rainfall estimates by fitting the statistical distributions to max daily rainfall data for Erbil station, where rainfall data are available for the periods from 1980 to 2021, and to compare the study with previous one generated by traditional method Indian Meteorological Department (IMD, LPT III and Gumbel.

Moreover, to apply empirical formulas for IDF curve for implementation the best model in Erbil city.

The importance of the research is summarized in the possibility of benefiting from the relationship that we obtained in calculating the design rain intensity of the water facilities to be constructed and the protection of the existing facilities. It is also possible to complete the missing data in the partially measured and unmeasured sites.

1.1 Study area

Erbil City the capital of Kurdistan region-Iraq, is located in the center of Erbil Governorate in the north of Iraq. The governorate is bordered by Turkey in the north and in the northeast by Iran. The coverage area is 15074 km², the city is located in a plain area. The meteorology station is located in Latitude 36◦ 12', Longitude 44◦ 04', and altitude of 470 m (a.sl.) (Figure 1). Erbil has a transitional climate between the Mediterranean climate and the desert climate (arid and semi-arid region) (Chow et al., 1988), and is characterized by low humidity and temperatures in the winter; while the weather is mild in the summer. The city is in a plain area surrounded by hills in the north and east. Therefore, the city is subjected to many floods during heavy rain storm.

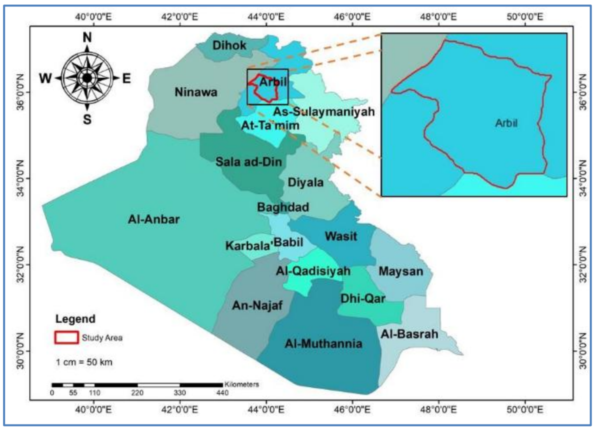

Figure 1. The location of the study area and coordinates

2. MATERIALS AND METHODS

The applied methodology summarized in the following points.

2.1 Fitting statistical distribution to rainfall data

Daily rainfall data are collected from the Erbil meteorology station, the data are shown in table 1 (Kurdistan Regional Government, 2021). The data were statistically analyzed with six statistical distributions (Exponential, Generalized extreme value GEV, Gumbel, Lognormal, Inverse Gamma and Log person 3) using the model suggested by Hyfran Plus software. Four statistical tests (CHI Test, Root Mean Square Error RMSE, Index of Agreement IOA, Nash) were conducted to select the best statistical distribution and to extend the data set for seven return period (2, 5, 10, 25, 50, 100, 200) years.

2.2 Rainfall estimation with short duration for IDF curve

According to United States Department of Agriculture (1986), the intensity of rainfall varies during 24-hour storm into four types as shown in Figure 2, with respect to geographic regions. The type SCS II is used for arid and semi-arid area which is used in the current research.

For Derivation Sub-Daily (short duration) Rainfall Data according to type SCS II used bell ratio (Awadallah and Younan, 2012), (Chow et al., 1988). Based on multiplying the rainfall depths of selected best statistical distribution by Bell ratio to obtain short duration rainfall depth at (5, 10, 20, 30, 60, 120, 180, 360, 720, 1440) minutes. Afterwards were used in derive rainfall intensity frequency curves. (Chow et al., 1988).

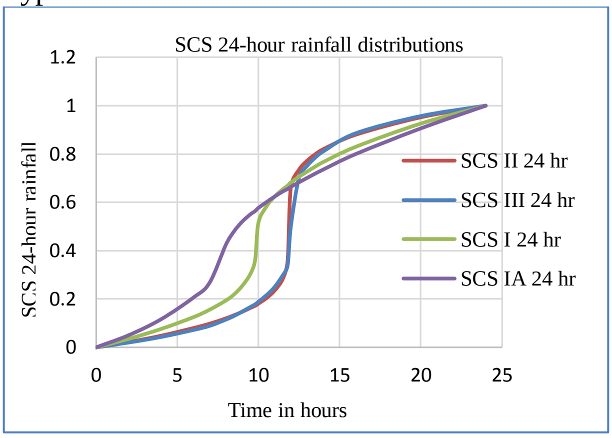

Figure 2. SCS 24-hour rainfall distributions (United States Department of Agriculture, 1986)

2.3 IDF Curve by Empirical Formulas

The empirical equation in the IDF relationship is one of the most widely used tools in water resource engineering, whether in the planning, design and operation of water projects, or to protect them from floods. There are many formulas, which express the relationship between the maximum rainfall intensity (as an independent component) and other parameters; such as the duration and frequency of rainfall (independent parameters). (Obeid & El Kholy, 2021), (Khansa et al., 2020). The formulas used in the current research are:

1- Talbot relationship $I = \frac{a}{t+b}$ ....(1)

2- Bernard relationship $I = \frac{a}{t^c}$ ....(2)

3- Ishiguro relationship $I = \frac{a}{\sqrt{t}+b}$ ....(3)

Where

I: intensity of rain mm/h

T: duration in minutes

a,b,c Constants fitting parameters determined by the least squares method. (Obeid & El Kholy, 2021),(Khansa et al., 2020)

Table 1. Daily rainfall data for Erbil station

Year	Max daily rainfall (mm)	Year	Max daily Rainfall (mm)	Year	Max daily rainfall (mm)	Year	Max daily rainfall (mm)
1980	57.6	1991	62.4	2002	32.3	2013	71.8
1981	40.9	1992	15.7	2003	59.2	2014	51
1982	38.1	1993	79	2004	41.4	2015	37.6
1983	32.9	1994	41.7	2005	34	2016	55.8
1984	42.7	1995	75.7	2006	103.9	2017	36.4
1985	72.7	1996	22.3	2007	38	2018	51.1
1986	73.6	1997	35.8	2008	37.8	2019	59.5
1987	31.8	1998	36.8	2009	41	2020	36.8
1988	37.2	1999	25.8	2010	33.8	2021	57.7
1989	48.4	2000	46.4	2011	67		
1990	35.8	2001	48.3	2012	21		

3. RESULTS

3.1 Frequency Analysis of the Maximum Daily Rainfall

The record period for Erbil Station spans is 42 years; from 1980 to 2021. Table 1 shows the maximum annual rainfall values.

The data were analyzed by Hyfran plus software and processed to choose the most suitable distribution function. The software allows to draw probability plots for a group of probability distributions (Exponential, GEV Generalized extreme value distribution, Gumbel, Lognormal, inverse Gamma, Log person type 3). The prediction of the data by the statistical distribution is presented in Table (2).

Figures (3) shows actual data extension by equation y = 20.034ln(x) +27.699 and correlation coefficient R^2 = 0.9583.

Where:

Y=maximum daily rainfall data in mm

X= return period in year

R= correlation coefficient

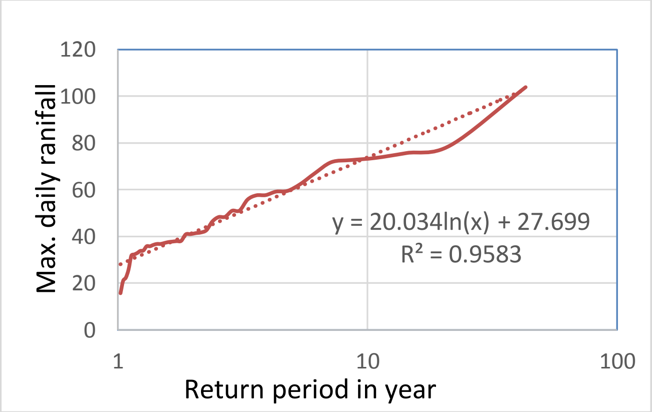

Figure 3. The general trend observed rainfall data

The values of the reliability tests, Chi Square, RMSE Root Mean Square Error, IOA Index of Agreement and Nash are presented in Table 3. The criteria of choosing the most suitable probability distribution function are presented in Table (3), which shows that the inverse gamma distribution is the best criterion for data representation.

Table 2. Daily rainfall data for Erbil station with statistical prediction

Return period	Observed daily rainfall (mm)	Exp.	GEV	Gumbel	Lognormal	Inverse Gamma	Log person 3
43.00	103.9	129.84	89.468	92.66	95.08	106.352	88.864
21.50	79	107.5133	79.71333	81.81	83.27667	89.66333	79.70667
14.33	75.7	94.23111	73.59778	75.07333	76.06222	79.96444	73.78222
10.75	73.6	87.59	70.54	71.705	72.455	75.115	70.82
8.60	72.7	80.18	66.96	67.864	68.368	70.096	67.316

7.17	71.8	74.01667	63.95	64.65333	64.95667	65.99667	64.36333
6.14	67	69.61429	61.8	62.36	62.52	63.06857	62.25429
5.38	62.4	66.3125	60.1875	60.64	60.6925	60.8725	60.6725
4.78	59.5	62.6037	58.19259	58.54815	58.51111	58.42222	58.67037
4.30	59.2	58.09667	55.59667	55.85667	55.74	55.46	56.02667
3.91	57.6	54.40909	53.47273	53.65455	53.47273	53.03636	53.86364
3.58	55.8	51.33611	51.70278	51.81944	51.58333	51.01667	52.06111
3.31	51.1	48.7359	50.20513	50.26667	49.98462	49.30769	50.5359
3.07	51	46.50714	48.92143	48.93571	48.61429	47.84286	49.22857
2.87	48.4	44.57556	47.80889	47.78222	47.42667	46.57333	48.09556
2.69	48.3	42.88542	46.83542	46.77292	46.3875	45.4625	47.10417
2.53	46.4	41.39412	45.97647	45.88235	45.47059	44.48235	46.22941
2.39	42.7	40.06852	45.21296	45.09074	44.65556	43.61111	45.45185
2.26	41.7	38.88246	44.52982	44.38246	43.92632	42.83158	44.75614
2.15	41.4	37.815	43.915	43.745	43.27	42.13	44.13
2.05	41	36.84921	43.35873	43.16825	42.67619	41.49524	43.56349

Table 3. statistical reliability tests for extension data

Test name	Exp.	GEV	Gumbel	Lognormal	Inverse Gamma	Log person3	Criteria	Optimum value	Best distribution
CHI Test	23.8	6.1	4.5	3.9	2.2	5.91	Choose min value	0.85	inverse Gamma
RMSE	10.4	4.5	4.3	5.1	3.7	4.40	Choose min value	4.1	inverse Gamma
IOA	0.93	0.97	0.98	0.98	0.99	0.97	Choose max value	0.99	inverse Gamma
Nash	0.82	0.87	0.91	0.93	0.95	0.87	Choose max value	0.97	inverse Gamma

Where
CHI Test: Chai-Square test
$\chi 2 = \sum((Oi - Ei)2/Ei)$
Oi = observed value (actual value)
Ei = expected value.

RMSE: Root Mean Square Error = √[Σ(Pi – Oi)2 / n], where:
Σ is a fancy symbol that means "sum"
Pi is the predicted value for the ith observation
Oi is the observed value for the ith observation
n is the sample size

IOA: Index of Agreement = d

$$d = 1 - \frac{\sum_{i=1}^{n}(\mathrm{Oi}-\mathrm{Pi})^2}{\sum_{i=1}^{n}(|Pi-\bar{O}|+|Oi-\bar{O}|)^2} \quad , 0 \le d \le 1$$

Oi is the observation value
Pi is the forecast value
Obar is the average observation values
Pbar is the average forecast values.

Nash $NSE = 1 - \frac{\sum_{T=1}^{T}(Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_o^t - \overline{Q_m})^2}$

where Q_o^t is the mean of observed discharges,
Q_m^t is modeled discharge.
Q_o^t is observed discharge at time t

(Chi-Square Goodness of Fit Test Calculator (2020)), (Zach, V. (2020)), (Index of Agreement (2022)), (Web-based Hydrograph Analysis Tool (2022)).

The extension maximum daily rainfall depth to return period (2, 5, 15, 25, 50, 100, 200 Year) is presented in table 4, using Inverse gamma distribution.

Table 4. maximum daily rainfall data with return period according to inverse gamma distribution

RP	2	5	10	25	50	100	200
Depth (mm)	41.2	59.8	74.1	94.4	111	130	151

3.2 Using SCS II method for arid and semi-arid area

The pattern of the 24-hour rainfall distribution rate in Bell ratio embedded the SCS type II storm distribution is shown in Table 5 (Awadallah & Younan, 2012 and Chow et al., 1988).

Based on multiplying the rainfall depths (Table 4) by Bell ratio (Table 5) to obtain sub-daily (short duration) rainfall depth for return periods of (2, 5, 10, 25, 50, 100, 200) years are shown in Table 6.

Table 5. Bell Ratios between 24-hr duration and other storm duration ratio

Time (min)	5	10	20	30	60	120	180	360	720	1440
Bell Ratio	0.13	0.2	0.28	0.34	0.44	0.57	0.63	0.75	0.88	1

Table 6. Sub-daily depth of rainfall for short duration according to SCS II

D RP	5	10	20	30	60	120	180	360	720	1440
2	5.36	8.24	11.54	14.01	18.13	23.48	25.96	30.90	36.26	41.20
5	7.77	11.96	16.74	20.33	26.31	34.09	37.67	44.85	52.62	59.80
10	9.63	14.82	20.75	25.19	32.60	42.24	46.68	55.58	65.21	74.10
25	12.27	18.88	26.43	32.10	41.54	53.81	59.47	70.80	83.07	94.40
50	14.43	22.20	31.08	37.74	48.84	63.27	69.93	83.25	97.68	111.00
100	16.90	26.00	36.40	44.20	57.20	74.10	81.90	97.50	114.40	130.00
200	19.63	30.20	42.28	51.34	66.44	86.07	95.13	113.25	132.88	151.00

D= Duration (min.), RP= Return period (Yr.)

The IDF cure values are calculated for return periods based on multiplying each rainfall depth at short duration (Table 6) by factor of one hour duration (Figure 4 and 5) (Chow et al., 1988).

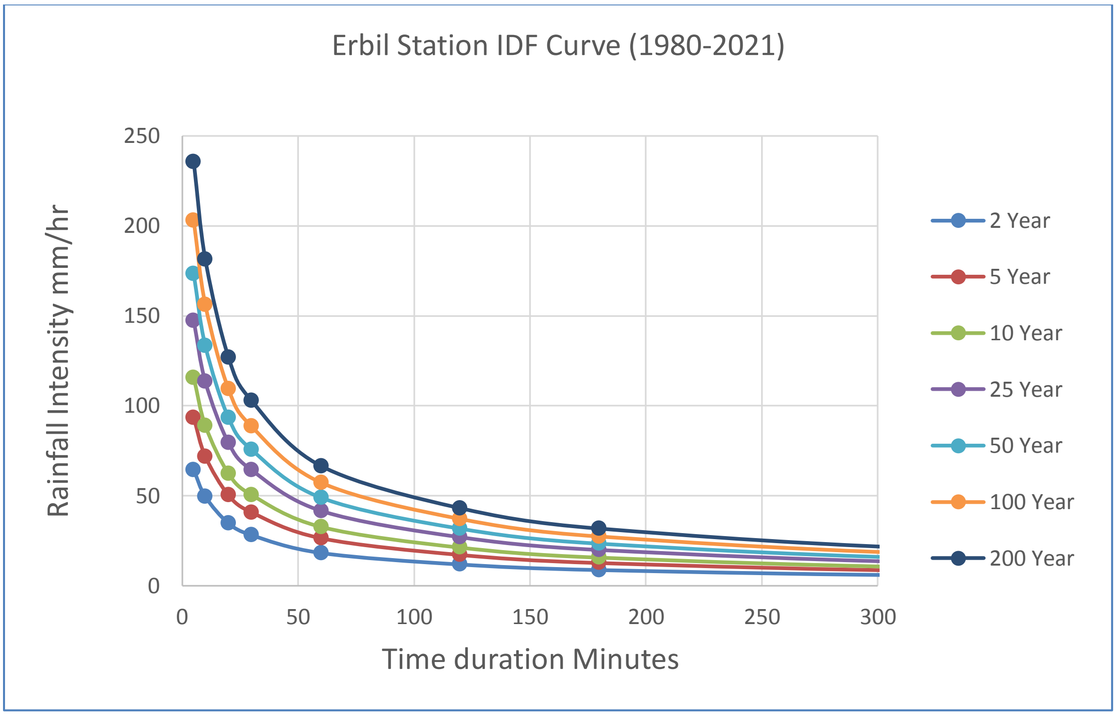

Figure 4. Intensity-duration-frequency curves For Erbil station (normal scale)

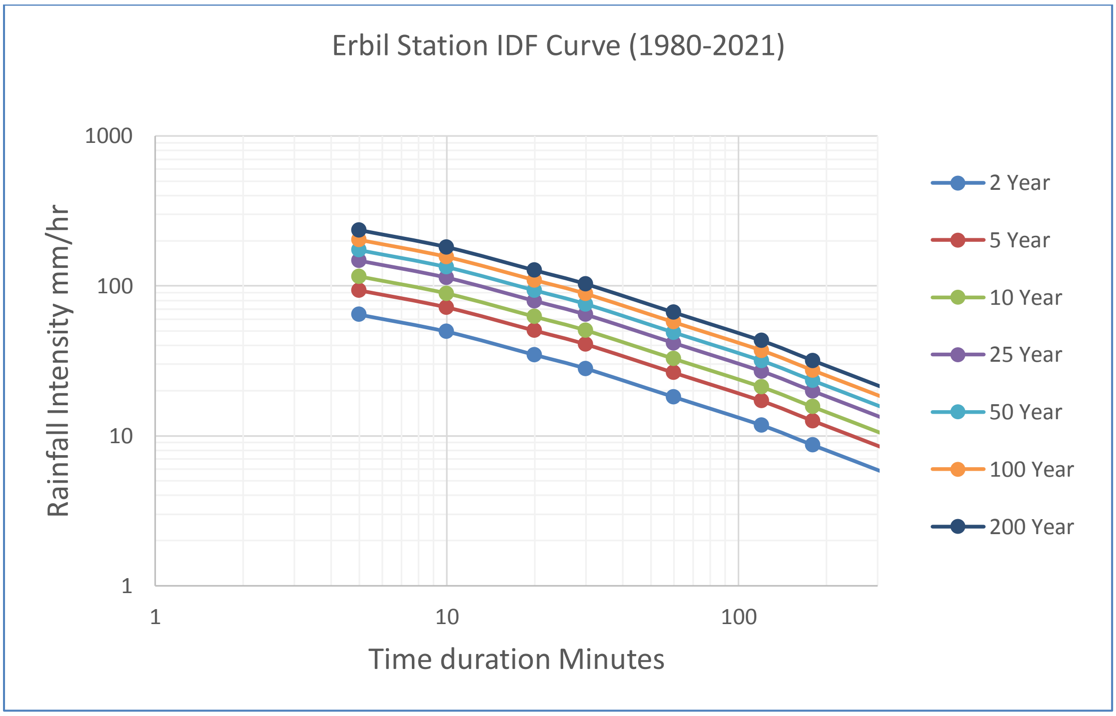

Figure 5. Intensity-duration-frequency curves For Erbil station (Log-Log scale)

After finding out the values of intensities at short duration with return period IDF Curve, the data simulated with empirical formulas by using Bernard, Talbot, and Ishiguro equations (Obeid & El Kholy, 2021),(Khansa et al., 2020), Table 7. shows the values of the different parameters.

Table 7. The Parameters of the Empirical Equations

Return Period	Talbot			Bernard			Ishiguro		
	a	b	R^2	a	c	R^2	a	b	R^2
2.00	1990.52	31.15	0.991	228.94	0.65	0.974	97.70	-1.16	0.964
5.00	2889.15	31.15	0.991	332.29	0.65	0.974	141.81	-1.16	0.964
10.00	3580.03	31.15	0.991	411.75	0.65	0.974	175.72	-1.16	0.964
25.00	4560.79	31.15	0.991	524.55	0.65	0.974	223.86	-1.16	0.964
50.00	5362.80	31.15	0.991	616.79	0.65	0.974	263.23	-1.16	0.964
100.00	6280.75	31.15	0.991	722.37	0.65	0.974	308.28	-1.16	0.964
200.00	7295.33	31.15	0.991	839.06	0.65	0.974	358.08	-1.16	0.964

4. DISCUSSION

According to the probability the most suitable one is inverse gamma. The adequacy of the inverse gamma fit is checked using visual inspection because of minimum deviation of data, as well as, the four statistical test criteria (Chi-Square Goodness of Fit Test Calculator (2020)), (Zach, V. (2020)), (Index of Agreement (2022), (Web-based Hydrograph Analysis Tool (2022) show that the best one is inverse gamma. Therefore, the rainfall depths prediction by Inverse Gamma distributed with Bell ratio pattern are shown in Table (5) the design depth of rainfall was calculated through the short time distribution of Bell ratio for all return period the result (Table 6), and then the maximum intensity for different rainfall depth in mm/hr were calculated the intensity-duration- frequency IDF curves for return periods of 200, 100, 50, 25, 10, 5 and 2-year are shown in Figures (4 and 5). For empirical formulas a,b, and c Constants fitting parameters determined by the least squares method (Obeid & El Kholy, 2021), (Khansa et al., 2020), and the results of IDF curve test by correlation coefficient (Index of Agreement Calculator 2022).

5. CONCLUSIONS

The rainfall intensity duration frequency curves were established for Erbil city using comparison among the six probability distributions (Exponential, GEV, Gumbel, Lognormal, Inverse Gamma and Log person 3 distribution) for (2-200) year return period with observed Maximum daily rainfall for 42 years of record data in Erbil station and through testing by 4 statistical tests. The results showed acceptable fitting with Inverse Gamma distribution at confidence level of 95%, and by using pattern SCS II with Bell ratio, which is suitable for arid and semi-arid regions. Although the average precipitation is decreased due to the phenomenon of climate change, the intensity of short-term precipitation is increased for a specific continuity in the city of Erbil. In other words, the short-term duration of precipitation increased for the duration of a specific intensity.

When comparing SCS II for derivation IDF Curve used in arid and semi-arid regions, with the previous studies, which have used traditional method based on the Gumbel and Log person 3, the difference was 11%.

The parameters of the IDF empirical formula are determined by the least square method. Comparison between the three empirical equations showed that the results applied to empirical IDF equations can be implemented in Erbil city.

Regarding the last two storms that had happened in Erbil on 30 October 2021 with depth of rainfall 52 mm through 52 minutes, and on 17 December 2021 with 57.6 mm through 1 hour, from the results obtained in IDF curve, it is clear that for these two storms the probability of occurrence is 2% and return period is 50 years.

Finally, it could be stated that the acquired results from this study can be adapted for design of Hydraulic structure and infrastructure in Erbil city.

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Conflict of Interest

The authors declare no conflict of interest.

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