University of Thi-Qar Journal Vol.12 No.2 June 2017
Web Site: https://jutq.utq.edu.iq/index.php/main
Email: journal@jutq.utq.edu.iq

"Drawing Curves of The Rainfall Intensity Duration Frequency (IDF) and Assessment equation Intensity Rainfall for Nasiriyah City, Iraq "

https://doi.org/10.32792/utq/utj/vol12/2/6

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Abstract

The rainfall Intensity-Duration-Frequency (IDF) relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resource projects. The purpose of this research is to get curves frequency the intensity of rain duration for Nasiriyah city, Iraq, and finding empirical equations the curves. Where are collected data of the rain 36 years ago from 1980 to 2015. Used Indian Meteorological Department (IMD) empirical reduction formula and methods of distribution: Gumbel and Log Pearson Type III during short periods (10, 20, 30, 60,120,180, 360, 720 and1440) minute with a specified return period (2, 5, 10, 25, 50 and 100) years. The results obtained showed that intensity of rainfall decreases with increase in storm duration and rainfall of any given duration will have a larger intensity if its return period is large. The chi-square goodness of fit test was used to determine the best fit methods of distribution (Easy fit software 5.6) and conclude that the Log Pearson type III was the best method.

"رسم منحنيات تكرار الشدة المطرية وتقدير معادلة الشدة لمدينة الناصرية، العراق"

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جامعة ذي قار

الخلاصة

تعتبر العلاقة بين الشدة المطرية وتكرار استدامة الشدة هي احدى اكثر الادوات المستعملة في هندسة مصادر المياه، سواء في التخطيط والتصميم او في تشغيل مصادر المياه. الغرض من هذا

البحث هو ايجاد منحنيات تكرار شدة الاستدامة المطرية لمدينة الناصرية، العراق وايجاد معادلات المنحنيات. حيث جمعت البيانات المطرية 36 سنة مضت من 1980 الى 2015. استخدمت المعادلة التجريبية لقسم الارصاد الجوية الهندية (IMD) وطرق التوزيع: كامبل وبيرسن لوغارتم النوع III خلال مدد قصيرة (10، 20، 30، 60، 120، 180، 360، 720، 1440) دقيقة وفترات رجوع (2، 5، 10، 25، 50، 100) سنة. النتائج اظهرت ان الشدة المطرية تتناقص بازدياد مدة العاصفة المطرية وكذلك بين ان هطول الامطار يعطي كثافة مطرية خلال فترات رجوع كبيرة. كذلك تم ايجاد افضل طريقة توزيع باستخدام طريقة الكاي تربيع في برنامج (Easy fit software 5.6) واستنتج ان طريقة بيرسن لوغارتم النوع III هي الافضل.

Keywords: IDF curves, daily rainfall, goodness of fit test, return period, Nasiriyah city.

1. Introduction

Statistics and evaluation of extreme rainfall data are important in water resources planning and management for design purposes in construction of sewerage and storm systems, determination of the required discharge capacity of channels, and capacity of pumping stations. So they are important in order to prevent flooding, thereby reducing the loss of life and property, insurance of water damage and evaluation of hazardous weather. Assessment of rainfall Intensity-Duration-Frequency (IDF) relationship is a primary basic input for the design of the storm water drainage system for cities (Chawathe, 1977). The IDF curves allow the engineer to design safe and economical flood control measures.

Studies on the rainfall IDF relationship have received much attention in past few decades. *Matin et al. (1984),* developed the IDF curve for North-East cities Bangladesh and also observed that the rainfall data in this city follow Gumbel's distribution. *Al-Dokhayel (1986),* estimated the rainfall depth duration frequency relationships for Qasim city in Saudi Arabia at various return periods, using two methods distributions (Gumbel and the LPT III). *Koutsoyiannis et al. (1998),* cited that IDF relationship is a mathematical relationship between the rainfall intensity, the duration and the return period, the IDF-curves allow for the estimation of the return period of an observed rainfall event or conversely of the rainfall amount corresponding to a given return period for different aggregation times. *Chowdhury et al. (2007),* developed the short duration rainfall IDF curve for Sylhet with return period of 2, 5, 10, 20, 50 and 100 years. *Marta bara et al. (2009),* elaborated the evaluation of IDF curves of extreme rainfall by simple scaling theory to the IDF characteristics of short duration rainfall in Slovakia. *Khaled et al. (2011),* applied L-moments and generalized least squares regression methods for estimation of design rainfall depths and development of IDF relationships. *Al Hassoun (2011),* developed an empirical formula to estimate the rainfall intensity in Riyadh city and find that there was not much difference in the results of rainfall analysis of IDF curves between Gumbel and LPT III methods. *Ayad Hussain, (2014),* derived IDF empirical formula that used at Karbala city and compared different statistical distributions and conclude that the Log Pearson type III was the best method of other methods.

The study objective to collect rainfall data for Nasiriyah city to get IDF curves and derive empirical equation of IDF for various return period where used two different statistical distributions, investigate probability distribution function for the maximum daily rainfall data by Chi-square test using Easy fit software 5.6.These curves and equations are useful in the design of urban drainage works, e.g. storm sewers, culverts and other hydraulic structures.

2. Description of Study Area

The study area is Nasiriyah, a city in southeastern Iraq on the Euphrates river, which is capital of Thi Qar. Its position is between latitude 30° 30′ - 32° 00′ N, longitude 45° 00′ - 47° 00′ E(Al ziady, 2017).

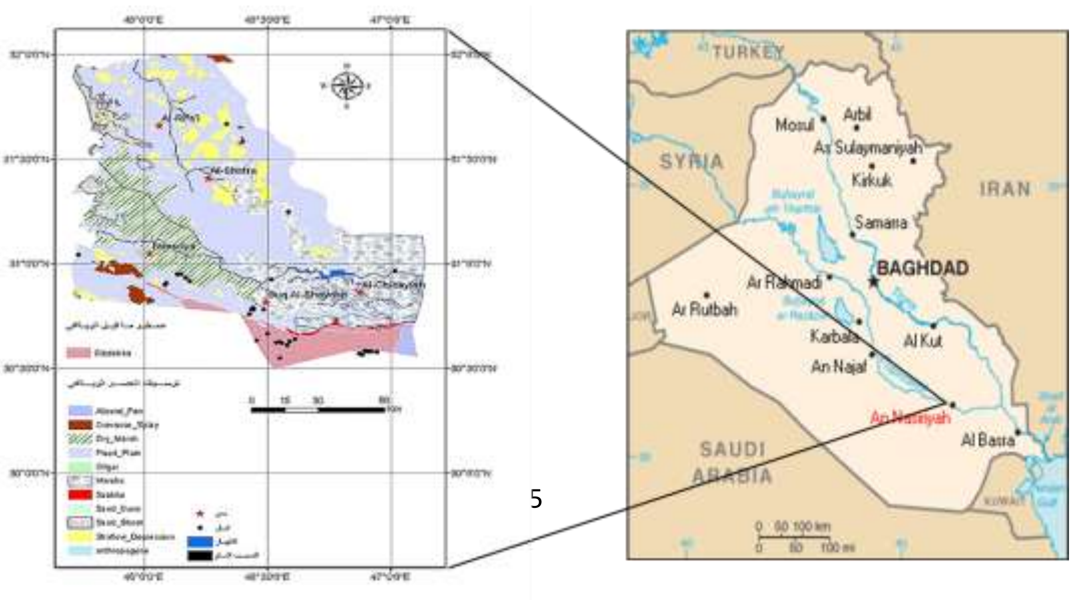

Figure 1: Location map of Nasiriyah city, Iraq.

3. Collected Data

To draw IDF curve and estimate the formula for intensity duration frequency relationship for Nasiriyah city, the available data are acquired from Republic of Iraq, Ministry of Transportation, Iraqi Meteorological Organization and Seismology, (Unpublished data) includes 24 hour rainfall data basis from 1980-2015 for Nasiriyah city were considered as presented in Table 1.

Table (1) Maximum Daily Rainfall Recorded in Nasiriyah City During 1980-2015 (Iraqi Meteorological Organization and Seismology).

NO	year	Maximum daily Rainfall during year in 'mm'	NO	year	Maximum daily Rainfall during year in 'mm'
1	1980	29.3	19	1998	51.5
2	1981	20.6	20	1999	36.1
3	1982	26.2	21	2000	47.8
4	1983	18.0	22	2001	17.0
5	1984	30.9	23	2002	85.9
6	1985	17.2	24	2003	M*
7	1986	39.1	25	2004	21.0
8	1987	12.0	26	2005	27.0
9	1988	M*	27	2006	28.3
10	1989	11.6	28	2007	73.8
11	1990	14.8	29	2008	10.8
12	1991	48.3	30	2009	12.1
13	1992	21.9	31	2010	10.8
14	1993	10.7	32	2011	10.4
15	1994	22.8	33	2012	31.4
16	1995	27.3	34	2013	50.9
17	1996	44.9	35	2014	33.4
18	1997	22.0	36	2015	18.0

M*: Missing data.

4. Estimation of Short Duration Rainfall

The rainfall data consists of the maximum daily rainfall values from 1980 to 2015. From maximum daily rainfall corresponding values of 0.166 hr, 0.33 hr, 0.5 hr,1 hr, 2 hr, 3 hr,6 hr,12 hr and 24 hr, rainfall values can be obtained using Indian Meteorological Department(IMD) empirical reduction formula (Ramaseshan,1996) which is;

$$P_{(t)}=P_{(24)}\,(t/24)^{(1/3)} \qquad (1)$$

Where; $P_{(t)}$ is the required rainfall depth in mm at t-hr duration, $P_{(24)}$ is the daily rainfall in mm and t is the duration of rainfall for which the rainfall depth is required in hr. Table 2 explains derived shorter duration rainfalls from maximum daily rainfall during year.

Table (2) The required precipitation $P_{(t)}$ depth for the duration t-hour in mm.

Year	0.166 hr.	0.33 hr.	0.5 hr.	1 hr.	2hr.	3hr.	6hr.	12hr.	24hr.
1980	5.675	7.12	8.166	10.265	12.904	14.751	18.543	23.309	29.3
1981	3.990	5.006	5.741	7.217	9.072	10.371	13.037	16.388	20.6
1982	5.075	6.367	7.302	9.179	11.539	13.191	16.581	20.843	26.2
1983	3.486	4.374	5.017	6.306	7.927	9.062	11.391	14.319	18
1984	5.985	7.509	8.612	10.826	13.609	15.557	19.555	24.582	30.9
1985	3.331	4.179	4.794	6.026	7.575	8.659	10.885	13.683	17.2
1986	7.574	9.502	10.898	13.699	17.22	19.685	24.745	31.105	39.1
1987	2.324	2.916	3.344	4.204	5.285	6.041	7.594	9.546	12
1988	M*	M	M	M	M	M	M	M	M
1989	2.247	2.819	3.233	4.064	5.108	5.84	7.341	9.228	11.6
1990	2.866	3.596	4.125	5.185	6.518	7.451	9.366	11.773	14.8
1991	9.356	11.737	13.462	16.923	21.272	24.317	30.568	38.424	48.3
1992	4.242	5.322	6.104	7.673	9.645	11.026	13.86	17.422	21.9
1993	2.072	2.6	2.982	3.748	4.712	5.387	6.771	8.512	10.7
1994	4.416	5.54	6.355	7.988	10.041	11.479	14.429	18.138	22.8
1995	5.288	6.634	7.609	9.565	12.023	13.744	17.277	21.718	27.3
1996	8.697	10.911	12.515	15.731	19.775	22.606	28.416	35.719	44.9
1997	4.261	5.346	6.132	7.708	9.689	11.076	13.923	17.501	22
1998	9.976	12.515	14.354	18.044	22.681	25.929	32.593	40.97	51.5
1999	6.993	8.772	10.062	12.648	15.899	18.175	22.846	28.718	36.1

2000	9.259	11.616	13.323	16.747	21.052	24.066	30.251	38.026	47.8
2001	3.293	4.131	4.738	5.956	7.487	8.559	10.758	13.524	17
2002	16.64	20.875	23.943	30.097	37.832	43.248	54.364	68.336	85.9
2003	M*	M	M	M	M	M	M	M	M
2004	4.068	5.103	5.853	7.357	9.248	10.573	13.29	16.706	21
2005	5.230	6.561	7.525	9.46	11.891	13.593	17.087	21.479	27
2006	5.482	6.877	7.888	9.915	12.463	14.248	17.91	22.513	28.3
2007	14.296	17.934	20.57	25.857	32.503	37.156	46.706	58.71	73.8
2008	2.092	2.624	3.01	3.784	4.756	5.437	6.835	8.591	10.8
2009	2.343	2.94	3.372	4.239	5.329	6.092	7.657	9.625	12.1
2010	2.092	2.624	3.01	3.784	4.756	5.437	6.835	8.591	10.8
2011	2.014	2.527	2.898	3.643	4.58	5.236	6.581	8.273	10.4
2012	6.082	7.63	8.752	11.001	13.829	15.809	19.872	24.979	31.4
2013	9.86	12.369	14.187	17.833	22.417	25.627	32.213	40.492	50.9
2014	6.47	8.116	9.309	11.702	14.71	16.816	21.138	26.57	33.4
2015	3.486	4.374	5.017	6.306	7.927	9.062	11.391	14.319	18

M*: Missing data.

5. Frequency Distribution Methods

The first step in the construction of IDF curves is fitting some theoretical frequency distribution to the extreme rainfall amounts for a number of fixed durations. A logical step to proceed then is to describe the change of the parameters of the distribution with duration by a functional relation. From the fitted relationships the rainfall intensity for any duration and return period can be derived (Nguyen et al., 1998). In this study, annual maximum values for all the available durations have been statistically analyzed using two different distributions, namely: Gumbel distribution and Log Pearson III distribution.

5.1 Gumbel Theory of Distribution

Gumbel distribution methodology was selected to perform the flood probability analysis. The Gumbel distribution is the most widely used distribution for IDF analysis owing to its suitability for modeling maximum. It is relatively simple and uses only extreme events (maximum values or peak rainfalls). The Gumbel distribution calculates the 2, 5, 10, 25, 50 and 100 years return intervals for each duration period and requires several calculations. Frequency precipitation P_T (in mm) for each duration with a specified return period Tr (in year) is given by (Borga, 2005):

$$P_T = P_{ave} + K_T \times S \qquad (2)$$

Where K_T is Gumbel frequency factor given by:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{Tr}{Tr-1}\right)\right]\right\} \qquad (3)$$

And P_{ave} is the average of the maximum precipitation corresponding to a specific duration. In utilizing Gumbel's distribution the arithmetic average in EQ. (2) is used:

$$P_{ave} = 1/n \sum_{i=1}^{n} P_{(t)} \qquad (4)$$

Where; n is the number of events or years of record and the standard deviation S is calculated by:

$$S = \sqrt{\frac{(\bar{P} - P_{ave})^2}{n-1}} \qquad (5)$$

Where; $\bar{P}$ Maximum precipitation depth corresponding to a specific duration. Then the rainfall intensity I_T (mm/h) for return period T_r is obtained from:

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

Where; T_d is duration in hours.

Table (3) The values of standard deviation (S) and the average of precipitation (Pave).

Duration	**S**	**P_{ave}**
0.166 hr.	3.553	5.445
0.33 hr.	4.457	6.83
0.5 hr.	5.112	7.834
1 hr.	6.426	9.848

2 hr.	8.078	12.379
3 hr.	9.234	14.152
6 hr.	11.608	17.789
12 hr.	14.591	22.361
24 hr.	18.342	28.108

Table (4) The values of Gumbel frequency factor in order to a specified return period.

Tr years	K_T
2	-0.164
5	0.719
10	1.305
25	2.044
50	2.592
100	3.137

Table (5) Computed precipitation (P_T) in (mm) and intensity (I_T) in (mm/h)

Tr / t min	2		5		10		25		50		100	
	P_T	I_T	P_T	I_T	P_T	I_T	P_T	I_T	P_T	I_T	P_T	I_T
10	4.862	30.389	7.999	49.998	10.082	63.012	12.707	79.423	14.654	91.593	16.591	103.697
20	6.099	18.484	10.035	30.411	12.647	38.327	15.942	48.309	18.384	55.711	20.814	63.073
30	6.996	13.992	11.51	23.021	14.506	29.013	18.285	36.57	21.086	42.173	23.873	47.746
60	8.794	8.794	14.469	14.469	18.235	18.235	22.984	22.984	26.506	26.506	30.008	30.008
120	11.054	5.527	18.188	9.094	22.921	11.461	28.891	14.445	33.318	16.659	37.721	18.86
180	12.637	4.212	20.791	6.93	26.203	8.734	33.028	11.009	38.088	12.696	43.121	14.374
360	15.885	2.647	26.135	4.355	32.938	5.489	41.516	6.919	47.878	7.979	54.204	9.034

(Gumbel distribution).

720	19.968	1.664	32.852	2.737	41.403	3.45	52.187	4.348	60.183	5.015	68.136	5.678
1440	25.1	1.045	41.296	1.72	52.045	2.168	65.6	2.733	75.651	3.152	85.648	3.568

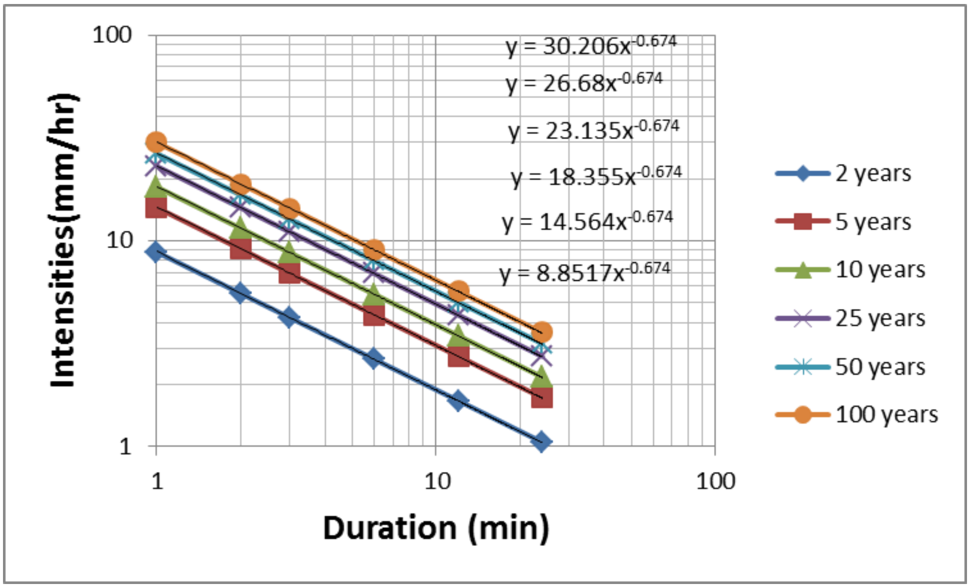

Figure 2: IDF curves by Gumbel distribution at Nasiriyah City.

5.2 Log Pearson Type III Distribution (LPT III).

The LPT III distribution model is used to calculate the rainfall intensity at different rainfall durations and return periods to form the historical IDF curves for each station. LPT III distribution involves logarithms of the measured values. The mean and the standard deviation are determined using the logarithmically transformed data. In the same manner as with Gumbel method, the frequency precipitation is obtained using LPT III method. The simplified expression for this latter distribution is given as follows:

$$P_{(t)}^{*} = \log P_{(t)} \quad (7)$$

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

$$Pave^{*} = 1/n \sum_{i=0}^{n} P_{(t)}^{*} \quad (9)$$

$$S^{*} = \sqrt{\frac{(\overline{P}^{*} - P_{ave}^{*})^2}{n-1}} \quad (10)$$

Where; P_T*, P_{ave}* and S* are as defined previously in Section 5.1 but based on the logarithmically transformed $P_{(t)}$ values; i.e. $P_{(t)}$* of Eq. (7). K_T is the Pearson frequency factor which depends on return period (Tr) and skewness coefficient (Cs).

The skewness coefficient Cs is required to compute the frequency factor for this distribution. The skewness coefficient is computed by Eq.(11) (Chow, 1988):

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

K_T values can be obtained from tables in many hydrology references; for example (reference Chow, 1988). By knowing the skewness coefficient and the recurrence interval, the frequency factor, K_T for the LPT III distribution can be extracted. The antilog of the solution in Eq. (8) will provide the estimated extreme value for the given return period. Table 6 shows the computed frequency precipitation P_T* values and intensities (I_T) for nine different durations and six return periods using LPT III methodology.

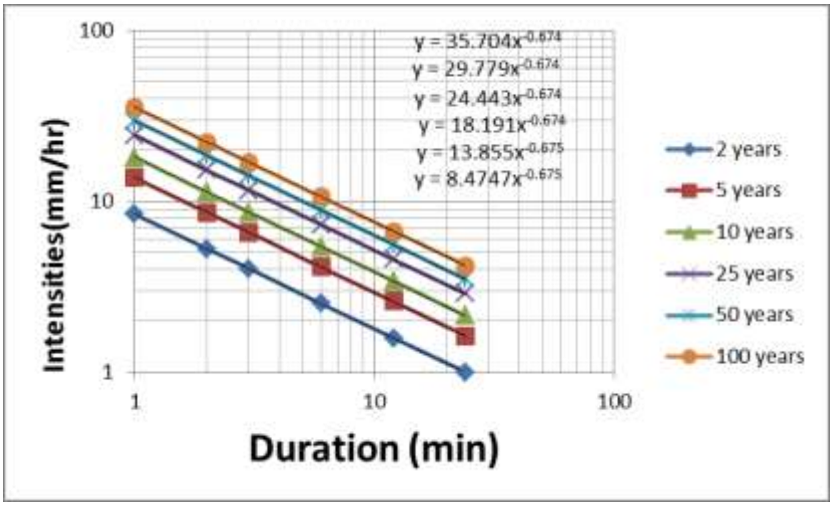

Figure 3: IDF curves by Log Pearson III distribution at Nasiriyah City.

Table (6) Computed precipitation (PT) in (mm) and intensity (IT) in

Tr / t min	2		5		10		25		50		100	
	PT	IT	PT	IT	PT	IT	PT	IT	PT	IT	PT	IT
10	4.673	29.211	7.641	47.761	10.010	62.562	13.468	84.180	16.392	102.456	19.6346	122.716
20	5.835	17.682	9.538	28.905	12.533	37.979	16.831	51.004	20.510	62.152	24.596	74.534
30	6.692	13.385	10.940	21.881	14.375	28.750	19.305	38.610	23.524	47.049	28.211	56.423
60	8.413	8.413	13.752	13.752	18.069	18.069	24.267	24.267	29.570	29.570	35.461	35.461
120	10.575	5.287	17.287	8.643	22.714	11.357	30.504	15.252	37.171	18.585	44.576	22.288
180	12.089	4.029	19.762	6.587	25.966	8.655	34.871	11.623	42.492	14.164	50.957	16.985

(mm/h) (Log Pearson III distribution)

360	15.196	2.532	24.842	4.14	32.640	5.440	43.834	7.305	53.414	8.902	64.055	10.675
720	19.102	1.591	31.227	2.602	41.029	3.419	55.100	4.591	67.142	5.595	80.518	6.709
1440	24.013	1	39.253	1.635	51.574	2.148	69.261	2.885	84.398	3.516	101.211	4.217

6. Gneralized IDF Formula

The IDF formulas are the empirical equations representing a relationship among maximum rainfall intensity (as dependent variable) and other

Parameter	Gumbel	Log Pearson III

parameters of interest such as rainfall duration and frequency (as independent variables). There are several commonly used functions found in the literature of hydrology applications (Chow, 1988). In this research ***Bernard equation*** was used to estimate equation rainfall intensity (Rathnam, 2000) which is:

$$I_T = \frac{cTr^m}{d^{\,e}} = \frac{a}{d^{\,e}} \qquad (12)$$

Where I_T intensity in mm/hr, Tr return period in years, d duration in hours and c, m, e are regional coefficients.

6.1 Find constants a and e

In order to find the constants (a) and (e) of EQ. (12), A log-log graph was plotted between the duration and rainfall intensity for each return period to find the constant (e) by nonlinear regression analysis. From graphs the average value of exponents for all recurrence intervals equations was used to establish (e) coefficient. To obtain the values of (c) and (m) derived values of (a) are plotted on log-log scale against corresponding recurrence intervals (Gringorten, 1963) the resulting shown in Table (7).

Table (7). The parameters values used in deriving formulas.

c	8.283	7.565
m	0.301	0.350
e	0.674	0.674
Equation	$I_T = \frac{8.283Tr^{0.301}}{d^{\,0.674}}$	$I_T = \frac{7.565Tr^{0.350}}{d^{\,0.674}}$

7. Goodness of Fit Test

The aim of the test is to decide how good is a fit between the observed frequency of occurrence in a sample and the expected frequencies obtained from the hypothesised distributions. A goodness of fit test between observed and expected frequencies is based on the chi-square quantity, which is expressed as;

$$X^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i \qquad (13)$$

Where; X^2 is a random variable whose sampling distribution is approximated very closely by the chi-square distribution. The symbols O_i and E_i represent the observed and expected frequencies respectively, for the *i-th* class interval in the histogram. The symbol *k* represents the number of class intervals. If the observed frequencies are close to the corresponding expected frequencies, the X^2 value will be small, indicating a good fit; otherwise, it is a poor fit. A good fit leads to the acceptance of null hypothesis, whereas a poor fit leads to its rejection. The critical region will, therefore, fall in the right tail of the chi-square distribution. For a level of significance equal to α, the critical value is found from readily available chi-square tables and X^2 > constitutes the critical region (Al-Shaikh, 1985).

The software (Easy Fit 5.6) was used to conduct the tests of goodness of fit by using chi-square quantity (see reference 18). Figure (4) shows the values of chi-square test for evaluating the goodness of fit according to different probability distributions for 0.16 hr, 0.33 hr, 0.5 hr, 1hr, 2hr, 3hr, 6hr, 12hr and 24hr durations.

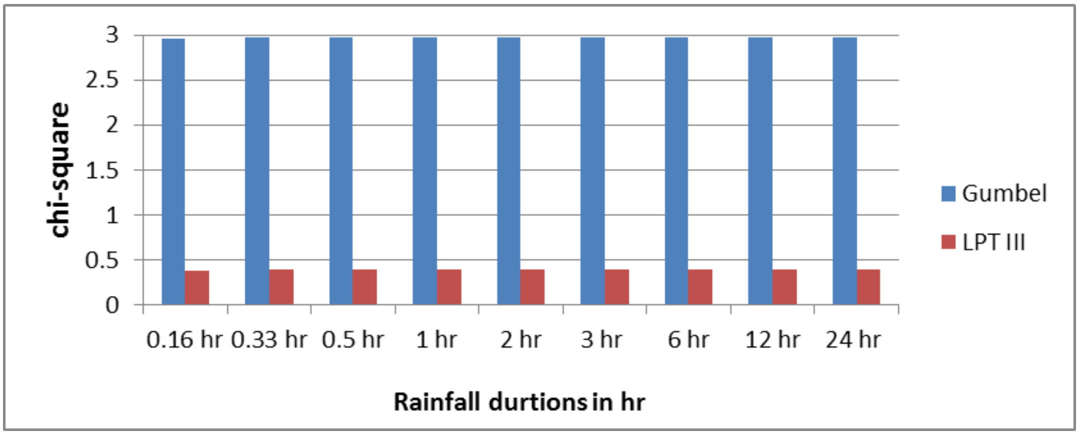

Figure 4: Goodness of fitting results by chi-square Test.

8. Results and Discussion

The purpose of this study was to get IDF curves and derive an empirical formula to estimate the rainfall intensity at Nasiriyah city in Iraq. Data collected maximum daily rainfall and estimation of short duration rainfall for 36 years and each duration (10, 20, 30, 60, 120, 180, 360, 720, 1440) min. There is no much difference in rainfall amount in the recorded years; this might be because that Nasiriyah city has flat topography where variations of precipitation is not large and maximum daily rainfall amount recur every ten year. Rainfall estimates in mm and their intensities in mm/hr for various return periods and different durations were analysed using the two techniques: (Gumbel and LPT III). The results are listed in Tables 5 and 6. According to the IDF curves, rainfall estimates are increasing with increase in the return period and the rainfall intensities decrease with rainfall duration in all return periods. Rainfall intensities rise in parallel with the rainfall return periods. The results obtained from the two methods have good consistency. Figure 2 and 3 show results of the IDF curves obtained by Gumbel and LPT III methods for Nasiriyah city. It was shown that there were small differences between the results obtained from the two methods, where Gumbel method gives slightly higher results than the results obtained by Log Pearson III method. The resulted two equations for Gumbel, LPT III, the parameters and the average values obtained by analyzing the IDF data by applying the procedures described on section (6) shows in Table (7).

Also, goodness of fit tests were used to choose the best statistical distribution among those techniques. It was found that the chi-square values obtained by Easy fit software 5.6 for the two methods all the data fit the distributions at the level of significance of α =0.05, which yields $X_{critical}$ < 7.814. The study showed that the LPT III given best estimation with smallest X^2 for all durations.

The final plotted curve on normal scale for Log Pearson III distribution as shown on Figure (5).

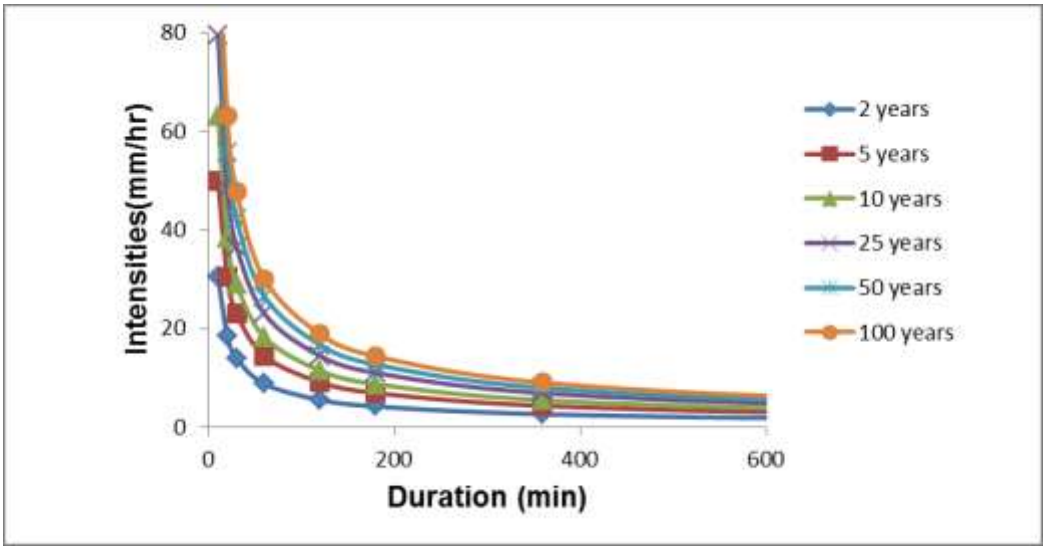

Figure 5: Intensity - Frequency - Duration Curves of Nasiriyah City (on normal scale).

9. Conclusions

1- This research presented equation intensity rain for Nasiriyah city, which is possible to be useful in finding the optimal design of the gutter and find the inlet locations on the roads.
2- This equation will make a good guide to estimate the rainfall intensity for any specific return period at different durations.
3- Maximum intensity occur at return period 100 years with duration of 10 minute.
4- Minimum intensity occur at return period 2 years with duration of 24 hours.
5- The goodness of fit test by chi-square showed the Log Pearson type III was the best distribution compared with Gumble distribution.

10. References

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