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RAINFALL INTENSITY PROBABILITY FOR DESIGN OF DRAINAGE SYSTEM IN BASRAH CITY, SOUTH OF IRAQ

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ABSTRACT

The main objective of this research is to derive relationship between rainfall intensity and recurrence interval at Basrah City, south of Iraq. Four common frequency analysis techniques (Gumbel, Powell, VenTe Chow, and Log Pearson Type III distribution) were used to develop this relationship from observed rainfall intensity data during the interval (1971-2000).The first three methods (Gumbel, Powell, and VenTe Chow)presented similar estimated relationship between the rainfall intensity and recurrence interval, while the estimated values of rainfall intensity by Pearson Type III distribution method are higher estimation compared with other methods, whilst, VenTe Chow method is presented the minimum estimated values. Based on the estimated values of rainfall intensity for recurrence intervals 25 and 50 year, the appropriate values of rainfall intensity for design the road drainage and highway drainage are 43 and 50 mm/hr respectively in Basrah City. It is very useful to conduct a study in the future to evaluate the optimal value of the recurrence interval for a set of possible design rainfall recurrence intervals, according to this proposed interval, the corresponding construction of drainage networks, maintenance and operation costs are evaluated.

Keywords: basrah city, rainfall intensity, recurrence interval, frequency analysis technique.

1. INTRODUCTION

The total rainfall and its intensity for a certain period of timeare variable from year to another. The variation for depth of rainfall and its intensity depend on theclimate type and the length of thestudied period. It can be noted in arid and semi-arid areas, there is a significant change in the value of rain from time to another. Due to the significant variation in rainfall and its intensity in a consider time, the design and construction of storm water drainage systems and flood control systems are not depend only on the average of long-term rainfall records but on particular depths of precipitation that can be predicted for a certain probability or return period. These depths of rainfall can only be determined through a comprehensive analysis of a long time series of historical rainfall data.The historical rainfall data series are distinguished by medium and standard deviation, this information cannot be randomlyused to predict the rainfall depths that can be estimated with a specific probability or return period for design and management of storm water drainage. Application of this technique to a data set can lead to misguiding results where the actual properties of the distribution are neglected. To avoid mistake, it is necessary to verify the integrity of the assumed distribution before estimating the design depths of the rainfall.

There is a need for information of the extreme amounts of rainfall for various durations in the design of hydraulic structures and control storm runoff, such as dams and barriers,and conveyance structuresetc.The information that is used hydraulic structure design is usually expressed as a relationship between Intensity-Duration-Frequency (IDF) of rainfall [1].The most important is the rainfall intensity of a certain period and the duration of rain. When the intensity is above the threshold for a particular type of soil there will be induced surface runoff.The IDF curves are illustrative examples of the amount of water that falls within a specified period of time in watershed areas[2].(IDF) is one of the most important tools for assessing the risks of water resources and also used for planning, design and operation in water resources engineering. Many studies were conducted on rainfall analysis and the regionalization of the IDF curves for different areas [3].

In Basrah City, south of Iraqi, rising water levels in the city's streets when starting rainfall during the winter season is a common problem due to inadequate drainage system. It can be observed in the design of storm water drainage systems; the intensity of rainfall which is used for processing design is equal to 17 mm / hr. In order to solve this problem, it should be known the rain intensity and the appropriate return period in design calculations. In the present study, maximum annualof rainfall intensity series is considered for Rainfall Frequency Analysis (RFA). Rainfall can be described in an area if the intensity, duration and frequency of the various storms occurring in that area are known[4, 5, and 6].The objective of this study is to derive IDF relationship of rainfall at Basrah City, south of Iraq.Four common frequency analysis techniques were used to develop the IDF relationship from rainfall data. These techniques are: Gumbel, Powell, VenTe Chow and Log Pearson Type III distribution.

2. STUDY AREA AND DATA SET

Basrah City is located in the southernmost part of Iraq and is considered as one of the largest oil cities in Iraq and in the Middle East. It depends on Shatt Al-Arab River for human consumption, agriculture and industry. It is located between longitude lines (47^o 30' and 48^o 30') and latitude lines (30^o 00' and 30^o 30') as illustrated in Figure-1. The city of Basra is one of the warmest cities in the world, where the temperature of the air in the summer to reach 50 ^{o}C, also is characterized by high humidity during the seasons of the year due to its close to the Arabian Gulf.

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Rainfallstarts in October and until May. Maximum depth of rainfall values are often recorded in January, while it may be vanished during the summer season.The weather during the winter season is mild during the day to relatively cold at night; the climate is considered in this time of the year healthy and agreeable.Rainfall intensity in (mm) of depth for 60 minutes duration is obtained from meteorological recording station in Basrah City.A statistical summary of the annual maximum rainfall intensity during (1971-2000) is illustrated in Table-1. The minimum intensity during this interval is equal to (0 mm/hr), while the maximum value is equal to (53.3 mm/hr). Standard deviation is used to measure dispersion around the mean, it could be noted that the dispersion of intensity during observation period is equal to (11.686); the large value indicates that the data is more spread.Asymmetry of distribution is named skewness. The skewness value may be taking negative, positive, or undefined value.Positive skewness coefficient value indicates that the tail on the left side is shorter than the right side. For normal distribution,the excess kurtosis is equal to zero; for a kurtosiscoefficient having value above 0 refers the tails are heavier than the normal distribution. The frequency distribution of rainfall intensity for observing period in the study area is presented in Figure-2. The highest frequent value of rain intensity is from 10 mm/hr to 15 mm/hr.

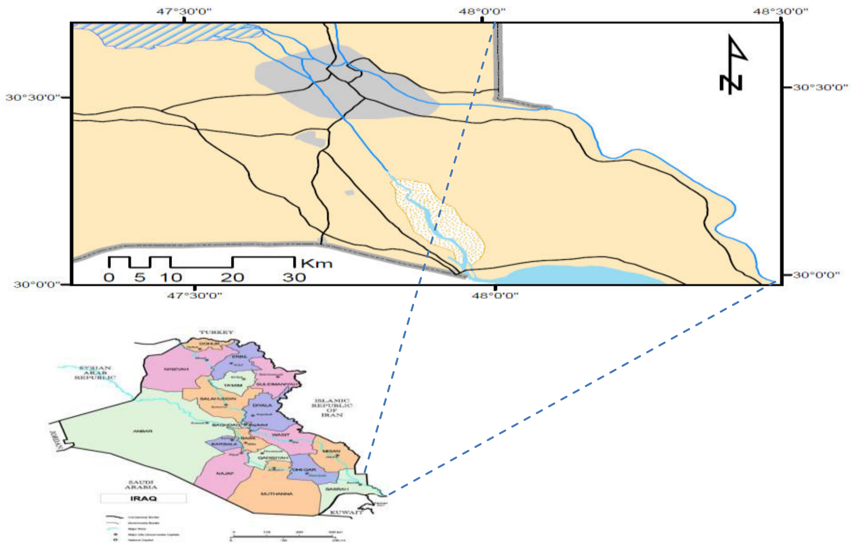

Figure-1. Location of study area in reference to the map of Iraq.

Table-1. Statistical summary of the annual maximum Rainfall intensity during (1971-2000).

Minimum	**0.00**	**Median**	**12.1**
Maximum	53.3	Coefficient of variation	0.751
Average	15.57	Skewness coefficient	1.5
Standard deviation	11.686	Kurtosis coefficient	4.74

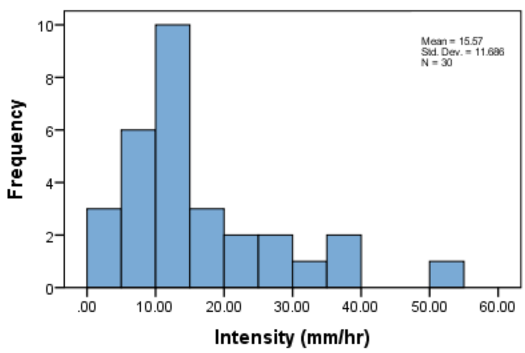

Figure-2. Frequency distribution of the annual maximum Rainfall intensity during (1971-2000).

3. PROBABILITY DISTRIBUTIONS

The probability distribution of any event can be defined as a mathematical function which provides the possibility of that event occurring for a particular return period. By using further technical terms, the probability distribution may be defined asdepiction of a random phenomenon through of theevents probabilities.There are generally used theoretical distribution functions that have been applied in different regions around the world; (e.g. Gumbel, Powell, VenTe Chow and Log PearsonType III distribution) [7-9]. Four probability techniques were used to develop the relationship between rainfall intensity, duration and return periods from the annual maximum rainfall intensity data in the studied area.The following techniques are used in this

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study: Gumbel, Powell, VenTe Chow and Log Pearson Type III distribution.

3.1 Gumbel'smethod

The Gumbel theory of distribution is appliedfor modeling the maximum or minimum of a number of events for various distributions.It is useful to predict the chance of a severe earthquake, rainfall, flood or other natural disaster.The possibility of utilizing an application for the Gumbel distribution for representing the distribution of maximum value relates to theory of extreme value, it could be observed that it is expected to be beneficial if the studied sample data is of the normal or exponential type. This distribution was used to calculate rainfall intensity for return periods from five years to 150 years. According to the extreme event distribution, the probability of occurrence of rainfall intensity is illustrated by:

$$Probability\ of\ occurrence = 1 - e^{-e^{-y}} (1)$$

Where:

y : Reduced variate, is given by

$$y = -0.834 - 2.303\log(\log\frac{T}{T-1}) (2)$$

$$X_T = \log(\log\frac{T}{T-1}) (3)$$

T: Recurrence interval

The relationship between the reduced variate (y) and variate (rainfall intensity) is linear and is given by following equation

$$y = \sigma_n\left(\frac{I-\bar{I}}{\sigma}\right) + \bar{y}_n (4)$$

Where:
σ_n: Reduced standard deviation) and $\bar{y}_n$: Reduced mean are functions of the sample size (n), as given in Table-2.

Frequency intensity (I) in mm/hr for 60 minutes duration with a specified recurrence interval (T) in year is illustrated by the following equation

$$I_T = \bar{I} + K\sigma (5)$$

Where:

The frequency factor $K = \frac{y-\bar{y}_n}{\sigma_n}$
I_T : Annual intensity peak
$\bar{I}$: Arithmetic mean of intensity
σ : Standard deviation

Table-2. Reduced mean ($\bar{y}_n$) and reduced standard deviation (σ_n)as functions of size sample (n).

Sample size n	$\bar{y}_n$	σ_n	Sample size n	$\bar{y}_n$	σ_n
10	0.4952	0.2457	45	0.5436	1.1518
15	0.5128	1.0206	50	0.5465	1.1607
20	0.5236	1.0628	55	0.5504	1.1681
25	0.5309	1.0915	60	0.5521	1.1747
30	0.5362	1.1124	65	0.5536	1.1803
35	0.5403	1.1283	70	0.5548	1.1854
40	0.5436	1.1413	75	0.5549	1.1898

3.2 Powell's method

Powell's method is also a powerful method to describe of rainfall data. In this method, a modification in the value of K in Eq. (5)is presented in the following equation

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

Where:
γ : Euller's constant

3.3 VenTe Chow's method

V.T. Chow is presented another modification of the Gumbel's method; this modification is applied by using the frequency factor:

$$I_T = a + bX_T (7)$$

Where:
a,b: parameters are estimated from the observed data by the method of moments. The method of least squares is used for deriving the following equation:

$$\sum I = an + b\sum X_T$$
$$\sum(IX_T) = a\sum X_T + b\sum(X_T^2) (8)$$

Plotting position has been specified for each value of intensity (I), when using the descending order of maximum intensity. For example, if an annual maximum intensity (I_T) has a rank m, the recurrence interval for this rank is

$$T = \frac{n+1}{m}$$

According to recurrence interval, equation (3) will convert for the following form:

$$X_T = \log(\log \frac{n+1}{n+1-m})(9)$$

3.4 Log Pearson type III distribution

The Log-Pearson type III distribution has beenthe most common technique in the distribution of hydrological frequency analyzes since the recommendation of the Water Resources Council (1967, 1982) of the United States with regard to its use as a favourite technique.This probability distribution is a statistical method for representing the frequency distribution data that is suitable for predicting the flood design of a river and rainfall frequency analysis. When calculating the statistical information of a river flood or rainfall information, a frequency distribution can be created. The advantage of this method is precisely that the extrapolation of event values with periods of return that exceed the observed flood events can be predicted. The mathematical expression for this theoretical distribution is illustrated in the following equations:

$$I^* = \log I_i(10)$$

$$I_T^* = \bar{I}^* + K^*\sigma^* \quad (11)$$

$$\bar{I}^* = \frac{1}{n}\sum_{i=1}^{n} I^*(12)$$

$$\sigma^* = \left[\frac{1}{n-1}\sum_{i=1}^{n}(I^* - \bar{I}^*)^2\right]^{1/2}(13)$$

Where:

I_T^*, $\bar{I}^*$, and σ^*: Annual intensity peak, arithmetic mean of intensity, and standard deviation respectively but based on the logarithmic transformation for I_i

K^* : Pearson frequency factor which depends on recurrence interval (T) and skew coefficient (g).

Skew coefficient is calculated by the following equation [10-11]

$$g = \frac{n\sum_{i=1}^{n}(I_i^* - \bar{I}^*)^3}{(n-1)(n-2)(\sigma^*)^3}(14)$$

K^*value can be determined from tabulated values in many references, such as [10,12], Table-3 shows the values of Pearson frequency factor for different recurrence interval.

Table-3. Pearson frequency factor for different recurrence interval.

T (year)	2	5	10	25	50	100	200
K*	0.05	0.853	1.245	1.643	1.89	2.104	2.294

4. RESULTS AND DISCUSSIONS

The total rainfall and its intensityat a specific locationfor a certain period arehighly variable from year to another. This variation in the amount is due to the type of climate and the length of the studied period. It can be observed in dry climate there is a significant variation in the value of rainfall from period to another. For the observation period (30 years), it can be noted; there is a large disparity between the maximum intensity (53.3 mm/hr) and minimum value (0.0 mm/hr). The average value gives a clear perception for the normal value of rainfall in the area, or it can be used to get an idea of the annual rainfall departure from the normal range, or compare climatic zones.From the statistical information of the intensity rainfall, the value of the average value in BasrahCity is 15.57, while the value of the standard deviation is relatively high(11.68), the large value indicates that the data is more spread.Due to the large variation in rainfall values in the study area, the design of hydraulic structuresand control storm runoff do not depend on the average long-term rainfall records but at particular depths of rainfall that can be predicted for a given probability or recurrence interval. These depths of rainfall can only be determined through a comprehensive analysis of a long time series of historical rainfall data.There is a mistake when using the value of intensity rainfall (17 mm/ hr) for processing design of storm sewer network in Basrah City.

The first stage in the frequency analysis is arrange of the rainfall values in descending order so that the first value has (1) and the last value has a number n (number of observation). Later, the probability should be determined for each of the rainfall intensity. If the data is arranged in descending order, the higher value isthe first one, whilethe lower value is the last one. When ranking in the descending order, if there are a total number of observation (n) and the rank number of particular value is m, then the return period (recurrence interval) of the rainfall intensity is obtained by one the following method (Table-4).Statistical techniques are used to estimate the probability of the recurrence intervalfor a given rainfall event. The return period is based on the probability that the significant event will be equal or exceeded in any particular year.

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Table-4. Methods for estimating recurrence interval of ranked data.

Method	Recurrence Interval (T)
(California method , 1923) [13]	$\frac{n}{m}$
(Hazen, 1930) [14]	$\frac{n}{m-0.5}$
(Weibull, 1939) [15]	$\frac{n+1}{m}$
(WMO, 1983) [16]	$\frac{n+0.12}{m-0.44}$

The annual rainfall intensity was subsequently ranked from higher value to lower value and the corresponding recurrence interval wasobtainedby using various methods (Table-5). It can be observedthat all the methods used in this study gave similar values in the middle of distribution while there was some variance between these methods for extreme values with a high return period. The probability P (expressed as percentage of time) of the rainfall intensity magnitude (having return period T) is obtained by the following equation:

$P = \frac{1}{T} \times 100\%$(15)

A probability plot is a plot of the rainfall intensity versus their probabilities of exceedance as determined by California method (Figure-3). Rainfall intensity estimates in (mm/hr) for various recurrence intervals were analysed using four techniques: (Gumbel, Powell, VenTe Chow and Log Pearson Type III distribution). The results are illustrated in Table-6. It can be noted that the first three methods (Gumbel, Powell, and VenTe Chow)gave similar estimated values while the estimated values of rainfall intensity byPearson Type III distribution method are higher than the rest of the methods, while, the minimum estimated values are obtained by VenTe Chow method.

Table-5. Recurrence interval of the ranked Rainfall intensity estimated with various methods.

Year	Intensity (mm/hr)	m	California	Hazen	Weibull	WMO
1985	53.5	1	30	60	31	53.79
1971	35.4	2	15	20	15.5	19.31
1986	35.3	3	10	12	10.33	11.77
1984	32.8	4	7.5	8.57	7.75	8.461
1978	26.3	5	6	6.67	6.2	6.605
1972	25	6	5	5.45	5.167	5.417
1991	21.7	7	4.29	4.62	4.429	4.591
1993	20.5	8	3.75	4	3.875	3.984
1992	18.7	9	3.33	3.53	3.444	3.519
1975	15.8	10	3	3.16	3.1	3.151
1996	15.5	11	2.73	2.86	2.818	2.852
1990	14	12	2.5	2.61	2.583	2.606
1982	12.8	13	2.31	2.4	2.385	2.398
1983	12.5	14	2.14	2.22	2.214	2.221
1973	12.2	15	2	2.07	2.067	2.069
1995	11.9	16	1.88	1.94	1.938	1.936
1977	11.6	17	1.76	1.82	1.824	1.819
1988	10.1	18	1.67	1.71	1.722	1.715
1979	10	19	1.58	1.62	1.632	1.623
1980	10	20	1.5	1.54	1.55	1.54
1989	10	21	1.43	1.46	1.476	1.465
1974	9.4	22	1.36	1.4	1.409	1.397
1994	9.2	23	1.3	1.33	1.348	1.335
1997	9.2	24	1.25	1.28	1.292	1.278
1987	8.4	25	1.2	1.22	1.24	1.226
1976	5.8	26	1.15	1.18	1.192	1.178
1981	5.5	27	1.11	1.13	1.148	1.134
1999	3.6	28	1.07	1.09	1.107	1.093
2000	0.4	29	1.03	1.05	1.069	1.055
1998	0	30	1	1.02	1.033	1.019

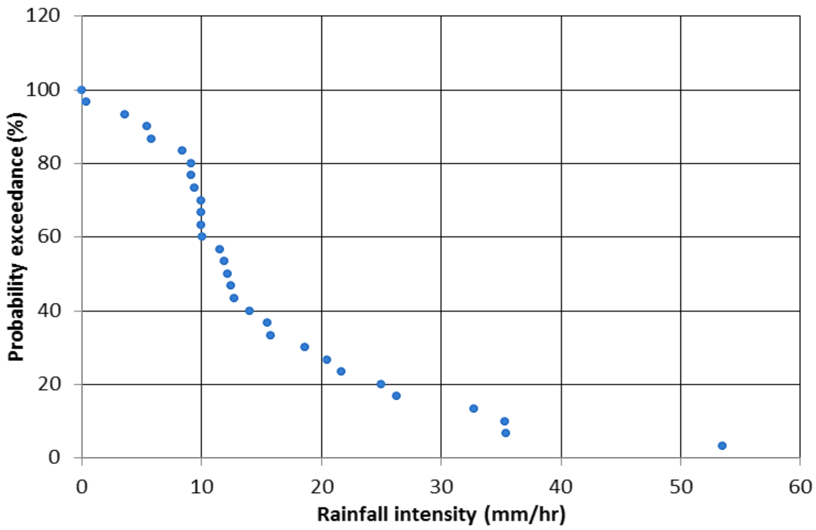

Figure-3. Probability plot of the Rainfall intensity in Basrah City.

Table-6. Estimated values of rainfall intensity for different recurrence interval by various frequency analysis techniques.

Gumbel Method				Powell Method		VenTe Chow Method (a=1.81, b=-23.12)	Log Pearson Type III distribution
T (year)	y	K	I_T	K	I_T	I_T	I_T
5	1.497	0.864	25.66	0.902	26.1	25.25	25.86
10	2.247	1.538	33.53	1.546	33.62	32.78	36.48
25	3.194	2.389	43.48	2.359	43.12	42.3	51.73
50	3.897	3.021	50.85	2.962	50.17	49.36	64.26
100	4.594	3.648	58.18	3.561	57.16	56.37	77.53
150	5.001	4.013	62.45	3.91	61.24	60.46	84.28

In order to verify the assumed theoretical distribution provides an appropriate description of the observed data, the goodness of fit must be carried. This test is provide the strength of the relationship or fitting between the observed frequency of occurrences and the predicted frequencies determined from frequency analysis techniques. Chi-square test is used in this study; the mathematical equation of this test is illustrated below:

$$x^2 = \frac{\sum_{i=1}^{k}(O_i - E_i)^2}{E_i} \quad (16)$$

Where:

x^2: Random variable with $k-p-1$ degrees of freedom (k is the number of class interval and p is the number of parameters estimated by sample data)

O_i : Observed frequency in the ith class interval

E_i : Estimated frequency in the ith class interval

The theoretical distribution is accepted if $x^2$is lower than the tabulated values of Chi-square with $k-p-1$ degrees of freedom v and a significant level of α (could be expressed as 1-α as confidence level, typically 95% is selected as the confidence limit). The Chi-square test results are illustrated in Table-7. It can be observed all the frequency analysis techniques are suitable for fitting the observed data at the significance level (α=0.05). Figure-4 shows the relationship between the rainfall intensity and recurrence interval for four frequency analysis techniques.

Table-7. Results of Chi-square index for annual Rainfall intensity.

Frequency analysis technique	v	Theo. Chi-square	Obs. Chi-square
Gumbel	5	11.071	7.786
Powell	5	11.071	8.105
VenTe Chow	5	11.071	8.965
Log Pearson Type III	5	11.071	10.342

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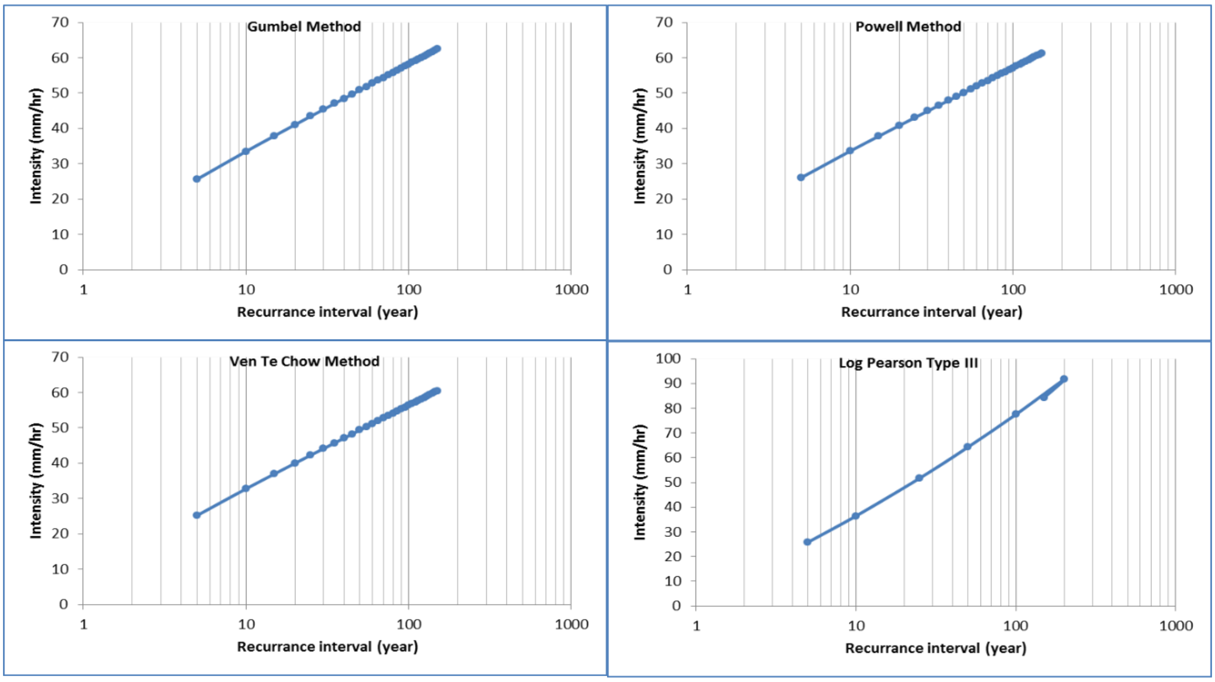

Figure-4. Rainfall intensity versus recurrence interval by various frequency analysis techniques.

Generally, the selection of a design recurrenceintervalmust be subject to economic assessment in which the benefits are compared with the costs of the construction and maintenanceof the drainage network. However, local flood damage data is not usually available to the degree of accuracy required for cost-benefit analysis. The decision taken on the basis of risks and threats to the public safety of the community is expected to be more appropriate. It is recognized that for new drainage systems or improved drainage in some existing areas, especially low lying areas or those in crowded urban areas, the recommended criteria may not be appropriate or achievable. The recurrence interval is selected by the designer, and through consultation with the owner, after established hydrological practice. Risk assessment is critical for choosing the recurrence interval. Table-8 can be used as a guideline for selecting the recurrence interval for the design of the drainage systems in conjunction with local expertise and regulations. It can be noted from this table, the appropriate value of recurrence intervals for road drainage and highway drainage are 25 and 50 year (the minimum value of proposed range) respectively. According to the estimated values of rainfall intensity by frequency analysis techniques (Table-6) for recurrence intervals 25 and 50 year, the appropriate values of rainfall intensity for design the road drainage and highway drainage are 43 and 50 mm/hr respectively (excluding the estimated values by Log Pearson Type III distribution, due to being high values compared to the rest of the three methods).In the case of the use of the maximum values of the proposed limits, the appropriate values of rainfall intensity for design the road drainage and highway drainage are 50 and 57 mm/hr respectively. It is very useful to conduct a study in the future to evaluate the optimal value of the recurrence interval for a set of possible design rainfall recurrence intervals, based on this proposed interval, the corresponding construction of drainage networks, maintenance and operation costs are evaluated.

Table-8. Guidelines for the selection of return period [17].

No.	Type of project	Recurrence interval (year)
1	Urban drainage [low risk] (up to 100 ha)	5 to 10
2	Urban drainage [medium risk] (more than 100 ha)	25 to 50
3	Road drainage	25 to 50
4	Principal spillways (dams)	25 to 100
5	Highway drainage	o 100

5. CONCLUSIONS

According to statistical summary of the annual maximum rainfall intensity during (1971-2000), the minimum rainfall intensity is equal to (0 mm/hr), while the maximum value is equal to (53.3 mm/hr). It could be noted from standard deviation (11.686) that the data is more spread. The highest frequent value of rain intensity is from 10 mm/hr to 15 mm/hr.Four frequency analysis techniques were used to develop the relationship between rainfall intensity and the recurrence interval (Gumbel, Powell, VenTe Chow and Log Pearson Type III distribution). It can beobserved from the estimated values of rainfall intensity that the first three methods (Gumbel, Powell, and VenTe Chow)gave similar estimated values while the estimated values byPearson Type III distribution method are higher than the rest of the methods, while, the minimum estimated values are obtained by VenTe Chow method. Four methods (California, Hazen, Weibull, and WMO) are used to determine the recurrence interval of the ranked rainfall intensity.All these methods presented similar values in the middle of distribution while there was some variance between these methods for a high recurrence interval. For verifying the assumed theoretical distribution provides an appropriate description of the observed data, the goodness of fit must be carried. All the frequency analysis techniques are suitable for fitting the observed data at the significance level (α=0.05).Based on the estimated values of rainfall intensity for recurrence intervals 25 and 50 year, the appropriate values of rainfall intensity for design the road drainage and highway drainage are 43 and 50 mm/hr respectively in Basrah City.

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