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ARTICLE

Develop an Empirical Model to Forecast Rainfall Intensity as a Function of Probability For Al-Diwaniyah City in Iraq

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ABSTRACT

The study aims to develop an empirical model to predict the rainfall intensity in Al-Diwaniyah City, Iraq, according to a statistical analysis based on probability and the specific rainfall return period. Rainfall data were collected daily for 25 years starting in 2000. Daily rainfall data were converted to rainfall intensity for five duration periods ranging from one to five hours. The extreme values were checked, and data that deviated from the group trend were removed for each period, and then arranged in descending order using the Weibull formula to calculate the probability. Statistically, the model performance with a return period of two years is considered good when compared with observed results and other methods such as Talbot and Sherman with a coefficient of determination (R^2) > 0.97 and Nash-Sutcliffe efficiency (NSE) > 0.80. The results showed that a mathematical equation was obtained that describes the relationship between rainfall intensity, probability, and rainfall duration, which can be used for a confined return period with a 50% probability. Therefore, decision-makers can rely on the model to improve the performance of the city's current drainage system during flood periods in the future.

Keywords: Rainfall Intensity; Probability of Flood; Al-Diwaniyah City; Empirical Model

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1. Introduction

The rainfall intensity (RI) changes and varies over short periods temporally and spatially, in arid and semi-arid regions, and becomes more dangerous with the increasing impact of climate change, which affects the design capacity of stormwater drainage systems and increases the likelihood of flooding; therefore, it is necessary to develop a future strategy for rainfall forecasting [1]. To implement the strategic plan, obtaining long-term historical information regarding the intensity and depth of rainfall is necessary to analyze flood volumes based on probability and return period (RP), which requires obtaining advanced statistical techniques [2]. Many previous studies have determined the relationship between RI with duration and probability of occurrence using different statistical methods. In 2017, Intensity-Duration-Frequency (IDF) curves were developed statistically to forecast the RI in Medina, Saudi Arabia, using Gumbel and Log Pearson Type III (LPT) distributions in three areas. The rainfall data were collected daily from three different locations in Medina City, then converted to RI by dividing the rainfall in each station by durations ranging from 10, 20, 30 minutes, and 1, 2, 3, 6, 12, to 24 hours, while RP varied from 5 to 200 years. The results indicated that RI can be estimated in unmeasured areas by deriving an equation that links frequency intensity with RI [3].

In 2022, empirical equations were developed using the LPT and Gumbel formulas to predict the RI in Dohuk city, Iraq. The hourly rainfall values were derived from the daily rainfall using the Indian equation. They used six intervals from 2 to 100 years and eight different durations from 10 to 1440 minutes. Statistically, they used coefficient of determination (R^2) to test the reliability of the model. The results show that the empirical equations used to estimate the RI values give more accurate results from the IDF curve [4].

In 2012, a relationship was developed to predict RI for Basrah city in Iraq, based on IDF curves. The data was collected daily from the meteorological station in Basrah city from 1980 to 2010. To estimate the duration of RI, several methods were used, such as the Talbot, Sherman, and Gumbel formulas. The equation of the Indian Meteorological Department (IMD) method was used to convert the data of daily rainfall to hourly. The results showed that maximum and minimum RI occurred at a RP of 100 years with five-minute duration and at a RP of two years with 120 minute duration, respectively [5].

In 2018, RI with durations of 0.25, 0.5, 0.75, 1, 2, 3, 4, 6, 9, 12, and 18 hours was forecast from daily rainfall in Kalang, Malaysia. The annual extreme rainfall data were collected from 143 rain stations and then converted to sub-daily duration using the equation of the IMD method. An outlier test was used to remove any values that tend to deviate from the trend of the path of the RI. The results found that it's possible to gain empirical equations to predict the RI with different durations with high efficiency, with R^2 not less than 0.9, as well as the rainfall events with short durations lasting 15, 30, and 45 minutes, which were identified as the most frequent in the study area, accounting for 32%, 47%, and 57% of the total daily rainfall, respectively [6].

In 2021, an equation of the IMD method was developed to convert daily rainfall data to sub-daily data in regions where sub-daily data was available. The data were collected daily and sub-daily from different Meteorological stations worldwide, encompassing diverse climate situations in countries like China, Iran, Austria, and Barbados. The RP and RI were calculated using the Weibull formula and the Gumbel distribution equation, respectively. The results of the model developed were compared with observed data and gave a good match with R^2 greater than 0.78. These findings suggest that the above method can reliably estimate sub-daily data of the rainfall based on daily data with high accuracy [7].

In 2014, IDF curves were developed in Karbala, Iraq, for different RP varying from 2 to 100 years and created as equations to predict RI. The data was collected annually from 1960 to 2013. They used eight durations, starting from 10 minutes and finishing at 1440 minutes, also several statistical methods, such as Gumbel and LPT, were used to get the RI; and the model was assessed and gave good performance with R^2 greater than 0.98. The results show that the LPT is the best method for predicting RI with low standard errors [8].

In 2023, an empirical model was developed that links the relationship between RI, duration, and probability to forecasting the RI in Malang, Indonesia. The developed model was estimated by comparing the results of the model with the results of other models, such as Sherman and Talbot formulas, and achieved good performance with NSE and Percent bias (Pbias) values ranging from 0.91–0.99 and 2.4–3.2, respectively. The values of RI observed was calculated by dividing it by its duration, and the Weibull formula was used to estimate the occurrence of probability at any duration. Statistically, they used the Shapiro test on the RI observed. The study concluded that the developed model shows good agreement between RI with small recurrence intervals from 2 to 10 years, and less accuracy with large recurrence intervals [9].

Various techniques, such as the LPT and Gumbel distribution with different RP, were used to estimate RI in Baghdad, Iraq, for 11 years starting in 2004. The data were collected daily and converted to eight smaller time divisions, such as; 15, 30, 60 minutes, and 2, 3, 6, 12, 24 hours using the IMD method; furthermore, they used different RP varying from 2 to 100 years. The results found that there was no difference between the two methods used to obtain the IDF when using rainfall data for periods ranging from 0.25 hours to 24 hours [10].

In 2024, Gumbel and LPT methods were used to derive an empirical formula to estimate RI with the different RP and rainfall duration for Salah Al-Din in Iraq from 1990 to 2022. The IMD method was used to obtain rainfall for sub-daily data. Furthermore, the rainfall duration used to build the model changes from 10 to 1440 minutes, while the RP changes from 2 to 100 years. The results showed an inverse relationship between RI and duration, they also recommended using the empirical equations to predict RI [11].

In 2019, an empirical model to forecast RI was applied in the Watershed of Poroga, Indonesia. The data was collected daily from 2013 to 2016 at the meteorological station in Poroga, also, field data of rainfall was collected for different periods from one hour to eight hours. They used the Mononobe formula and the Alternating Block Method to estimate RI based on the ultimate rainfall depth to convert daily rainfall to sub-daily rainfall. The results showed that areas with limited rainfall data can use an empirical model with high reliability and depend on the Mononobe formula to convert daily to hourly data. In addition, daily rainfall data should be gathered over a minimum of 10 years for optimal rainfall prediction outcomes [12].

In 2019, four techniques, such as LPT, Powell, Gumbell, and Ven Chow, were used to construct the relationship between the interval recurrent and RI in the south of Iraq. They used the historical data for the rainfall for 30 years, from 1971 to 2000. They used some methods, such as the Weibull formula, to forecast the recurrent interval. Statistically, they used the Chi Square test to check the performance model. The results suggest the necessity of implementing statistical models for sewer network design to prevent flooding and ensure proper drainage infrastructure [1].

In 2018, an empirical model to predict the RI with limited probability and duration was developed that connects specific duration and probability with RI in Malang, Indonesia. The data on rainfall was obtained daily over five years from the Kedungkandang station, then converted to intensity in hours by dividing the maximum rainfall by duration. Five durations were used, from one to five hours, to construct the model by increasing by one hour. They used the Weibull formula to analyze data for the probability; furthermore, the model was validated by comparing the results of model with results of other methods, such as the Ishiguro, Sherman, and Talbot formulas, and achieved a good match with NSE and R^2 values of more than 99% and 94%, respectively. The findings show RI can be predicted using empirical models, especially for short durations [13].

In 2020, probability models were developed to forecast RI in Ikeja, Nigeria. The data were collected daily over 25 years, from 1986 to 2010, from a meteorological station in Abuja. The RP of the RI events ranged from 2 to 100 years, while the durations varied from 5 to 45 minutes, as well as 1 to 7 hours. Statistically, they used R^2 and mean square error (MSE) to evaluate the performance of the model results. Their results showed that for a limited RP, the RI tended to decrease during a restricted RP, while the duration tended to increase [14].

In 2020, RI was studied to derive IDF curves using the periodogram technique in Kuwait; the data on maximum annual rainfall were collected from 2006 to 2017, and R^2 were used to assess the model. The study aimed to reconstruct and update IDF curves using historical records of RI to avoid sudden flooding effects and their impact on water drainage systems in settlement areas [15].

In 2014, the distribution of the RI was analyzed in South Carolina. The maximum rainfall was collected daily from 2000 to 2009 from the weather station in Lages, South Carolina. They used the Gumbel method to find the RI with RP from 2 to 20 years and the Tallbot formula to express the relationship between the duration and intensity. The results showed that it is possible to rely on the empirical models to predict the rainfall intensity with suitable match [16].

In 2022, a new method was used to build IDF curves in Quito City, Ecuador. The data were collected from 12 meteorological stations daily over 20 years. They used IDF curves that are connected by mathematical equations to model RI. They use the Sherman formula, the Gamma distribution to construct events of rainfall. R^2 and NSE were used to assess the model performance; the results showed it's possible to recognize events of RI depending on duration [17].

In 2023, IDF curves were derived in five cities in the north of Iraq, Sinjar, Mosul, Rabia, Talafer, and Talabta, for over 30 years starting from 1990. The data were collected daily from all the above cities and then converted to hourly and sub-hourly data varying from 10 to 1440 minutes using the reliable empirical equation IMD method. Gumbel distribution, Log distribution, and PT were used to forecast the rainfall intensities as a function of probability distribution with different RP from 2 to 100 years. To determine the most appropriate distribution of data from the three methods used, they used the Chi-squared, Kolmogorov-Smirnov, and Anderson-Darling tests. The results showed that for every RP, the Gumbel test gives the best results for RP 10, 5, and 2 years, and the RI has an inverse relationship with duration, as well as the RI increases with increased duration [18].

In 2023, RI for the short term was derived in Robe City, Ethiopia. Three empirical equations were used: equation of the IMD method, the Modified Indian Meteorological Method, and the Ethiopian Road Method to convert daily rainfall data to sub-daily data. The data were collected from five stations in the study area over 30 years, starting from 1989. To build the model, the duration time changes from 5 minutes to 12 hours, while the RP changes from 2 to 100 years. The results of the empirical model were compared with other probability methods, such as LPT and Gumbel methods. They are finding that the modified Indian meteorological department best method to estimate the RI [19].

In 2022, IDF curves to forecast RI were developed in several areas in Nigeria. The data on daily rainfall was collected over 40 years, starting in 1974, from the Abuja meteorological station, then the data was analyzed to get the maximum rainfall annually; after that, the Gumbel method was used to estimate the RI. A homogeneity test was performed to check whether the data are homogeneous, and R^2 was used to compare the results of the observed and the results of the empirical models, and a good match is indicated by R^2 greater than 0.98. The results found that the Talbot is the best formula to estimate the RI with different RP ranging from 2 years to 100 years [20].

In 2024, IDF curves were developed to forecast RI in Paraiba, Brazil. Various methods were used to estimate the probability distributions, such as Weibull, Gumbel, Pearson, and Generalized Extreme Values (GEV). The daily rainfall data were collected from 263 meteorological stations from 1994 to 2020 using the rainfall disaggregation method. The values of maximum rainfall were calculated with duration between 5 minutes and 24 hours, and the RP changes from 2 years to 100 years. The series of daily distributions of rainfall was validated using the Kolmogorov-Smirnov test. Furthermore, R^2 was used to get a good match between observed results and model results, and gave a good match. The results show we can predict the RI using empirical models with high accuracy [21].

In 2016, IDF curves were derived in Saudi Arabia based on daily rainfall events from 28 meteorological stations over 25 years. More than 13 equations were developed for different regions of Saudi Arabia to predict the RI were derived with high accuracy. The model was developed according to the RP reaching 100 years, and durations change from 10 minutes to 120 minutes. Also, the Gumbel method was used to evaluate the probability of extreme distribution was used. The results of the models were verified by comparing them with the results of the observed and gave a good match with R^2 greater than 0.95. The results showed that it's necessary to update IDF curves every 5 to 10 years due to effects of climate change. Furthermore, the empirical model can be relied upon to predict the RI with good results, so it is possible to depend on the curves to improve the infrastructure of the sewer to prevent the flooding in the future [22].

Al-Diwaniyah city is an important city in Iraq, serving as a commercial link between the southern and central governorates of Iraq, with many land transportation routes passing through it. The governorate experienced heavy rainfall in a short time, particularly in 2000 and 2003, causing significant flooding, particularly in residential areas. This flooding caused extensive property damage, threatened the lives of residents, and disrupted internal trade due to the inability of the city's sewage systems to absorb these large amounts of rainfall [23].

Therefore, it is necessary to update RI data on a regular and continuous basis, relying on dependable models, as there are no near-real-time rainfall records in Diwaniyah Governorate. This study aims to develop an empirical model for RI as a function of a specific probability and RP. This model will help predict RI and can assist local authorities in making appropriate decisions when designing hydraulic structures over specific periods to control flooding and improve the city's existing drainage system.

2. Material and Methods

2.1. Study Area

The study area is located in Diwaniyah Governorate in Iraq between longitudes (44.5° - 45.9°) E and latitudes (30.5° - 32.5°) N, with an area of 8153 km^2 as shown in **Figure 1** [24]. The climate in the city is part of the dry climate, with average maximum and minimum temperatures of 36.5°C and 12.2°C respectively. Temperatures increase to 50°C between June and August, and decrease to 2°C from December to March. As for the rain in the region, it is little as it increases between December and April and is absent from June to August with an average of 106 mm. As for its surface is flat and has little slope with land height ranges between 4–12 meters above sea level; nearly three-fourths of the area consists of an alluvial plain, and the remainder is depressions [25].

Figure 1. Location of Al-Diwaniyah city in Iraq [26].

2.2. Data Collection

Daily rainfall data were collected from the Al-Diwaniyah Meteorological Station, which is located at 31.98° latitude and 44.95° longitudes from 2000 to 2024, and then converted to a shorter time period using the IMD method equation. These latter ones are very important and used in different locations worldwide with good accuracy; they can convert daily to sub-daily rainfall efficiently with little effort, especially in sites that do not have an hourly time interval[27,28].

$$P_t = P_{24}(t/24)^{0.33} \quad (1)$$

Where, P_t is the rainfall required at time t (mm) and P_{24} is the daily rainfall (mm). The periods were divided into five equal periods, starting from one hour with an interval of one hour, where most flood incidents occur after five hours of rainfall, so this period was the maximum rainfall period[9]. The current study used the minimum rainfall events of 0.6 mm/day to construct the empirical model for all durations to reduce rainfall events only.

One of the simple, internationally accepted experimental methods, the Weibull formula, is also used to compute the probability of occurrence[29].

$$P = \frac{m}{1+n} \times 100 \quad (2)$$

Where, P is a probability (%), m is the mattress number of RI and is ranked in descending order, and n is the value number.

The linear equation that relates the probability and RI is obtained by analyzing RI for each period; as shown in equation 3[1].

$$\text{Log (RI)} = A + BX \quad (3)$$

Where, RI is the rainfall intensity, X is the probability, and A, B are coefficient values.

2.3. Observation Methods

Sherman developed a formula that connected RI, duration, and frequency, which was used for rainfall periods greater than or equal to 2 hours to analyze RI as shown in equations 4 to 6[13]:

$$RI = \frac{a}{t^b} \quad (4)$$

$$a = \frac{\sum \log RI \sum \log t^2 - \sum \log t \log RI \sum \log t}{n \sum \log t^2 - (\sum \log t)^2} \quad (5)$$

$$b = \frac{\sum \log RI \ \sum \log t - n \sum \log t \log RI}{n \sum \log t^2 - (\sum \log t)^2} \quad (6)$$

On the other hand, Talbot used the formula shown in equations 7 to 9, and by plotting the relationship between duration and RI, the constant variables a and b can be obtained[30,31]:

$$RI = \frac{a}{t+b} \quad (7)$$

$$a = \frac{\sum RI.t \ \sum RI^2 - \sum RI^2.t \sum RI}{n \sum RI^2 - (\sum RI)^2} \quad (8)$$

$$b = \frac{\sum RI.t \ \sum RI - n \sum RI^2.t}{n \sum RI^2 - (\sum RI)^2} \quad (9)$$

Where: RI is the rainfall intensity of in mm/hr, t is the rainfall duration in hr; a, b = constants that depend on the rainfall data and study area size; and n = number of data.

2.4. Outliers Test

Adjustments to extreme values are very important and are one of the recommendations approved by the United States Council of Water Resources on technical issues related to water resources. The values that deviate significantly from the group trend of the dataset are called outliers; this data points must be removed from the analysis due to its statistical effect on the results. Outlier values can arise for various reasons, the most important of which are the possibility of failure in the measuring equipment; or the presence of true extreme values that are valid but rare, which deviate significantly from the path of the remaining values. These values can lead to incorrect conclusions in statistical analysis, thus reducing the accuracy of the developed model[32]. The equations that are used to identify the maximum and minimum limits of outliers are as follows:

$$u_h = u^- + L_n \times S_D \quad (10)$$

$$u_L = u^- - L_n \times S_D \quad (11)$$

Where, u_h is the upper threshold value of outliers, u^- is an average value, L_n is a factor that depends on the sample data number, S_D is a standard deviation to sample , and u_L is a Lower value threshold of outliers.

2.5. Model Performance

The following statistical criteria were used to demonstrate the efficiency of the model's performance: R^2, NSE, and Pbias[33].

1. Coefficient of determination (R^2): This coefficient provides the variance as a proportion between the observed and simulated values, changing between 0 and 1; it also serves as a reference for the relationship between the observed and simulated variables as a linear function. The closer the value is to 1, the more accurate the results are, but if it is close to 0, the accuracy is low.
2. Nash Sutcliffe (NSE): This indicator is important in hydrological modeling, and describes the proportional value of remaining variable; when compared to the variance of the observed data, ranging from (∞ to 1). When the NSE value is close to 1, this indicates good agreement between observed and simulated values.
3. Percentage bias (Pbias): This measures the amount of convergence and divergence between the measured and simulated values and it is estimated as a percentage; the best value of Pbias is close to zero.

Table 1 shows the permissible limits for statistical criteria to accept or reject the model.

Table 1. Performance ratings for statistics [34–36].

Performance Rating	Pbias (%)	R^2	NSE
Very good	Pbias < ± 10	$0.8 \le R^2 \le 1.0$	0.75 < NSE ≤ 1.00
Good	± 10 ≤ Pbias < ± 15	$0.7 \le R^2 \le 0.75$	0.65 < NSE ≤ 0.75
Satisfactory	± 15 ≤ Pbias < ± 25	$0.5 \le R^2 \le 0.6$	0.50 < NSE ≤ 0.65
Unsatisfactory	Pbias > ± 25	$R^2 < 0.5$	NSE ≤ 0.50

2.6. Methodology Analysis

Usually, many rainfall storms occur in a season and have characteristics like frequency, intensity, area, and duration. The RI, duration, and frequency strongly correlate with the historical records data in the study area; therefore, we can get the relationship between the RI with various durations by plotting on log-log or natural-scale paper, duration against the intensities for the different storms.

Many past studies used developed equations derived from empirical models, and the majority linked the rainfall intensity with probability and duration time, as shown in the equations below [9,13,16].

$$I_p = 31.92 \exp -0.0022\ p + 6.69 \exp -0.026\ p/t \quad (12)$$

$$I_p = 25.555e^{-0.035p} + t^{-1}.(0.0239p - 2.7938) \quad (13)$$

$$I_p = 2050.Tr^{0.2}.(t + 20)^{-0.89} \quad (14)$$

Where, I_p is the RI, p is the probability, t is the duration time, and Tr is the RP of rainfall.

The following steps are used for analysis to obtain the RI applied in an empirical model:

1. Collect rainfall data daily from 2000 to 2024.
2. Convert daily rainfall data to sub-daily from one to five hours with one-hour intervals between them using equation 1.
3. Rearrange the data into groups according to five time periods for rainfall, from one to five hours.
4. Extract RI for the sorted data, then remove all data that are outlets from the trend, and perform a t-test and normality test on that data.
5. Find the relationship between the RI of the empirical model to be formed as a function of probability and duration time as below:
   - Arrange the RI in descending order, from highest to lowest values.
   - Use the Weibull formula to calculate the rainfall probability.
   - Drawing the relationship between the RI and probability for each group duration and extract the relationship between them.
6. The probability values are replaced starting from 5% up to 95% with an increase of 5% in the equations that were formed in step 5 for each duration time.
7. Drawing the relationship between the RI and the inverse of the rainfall duration from 1 to 5 hours for each of the probability periods, and extracting the best linear equation between the values which is in the form:

$$y = A + BX \quad (15)$$

Where, y is an intensity, x is an inverse of duration, and A, B are a coefficients.

8. Extract coefficients A and B for each probability period,

then draw the relationship between coefficients with the probability.

9. Compare the results obtained with the results from other models (Sherman and Talbot) for each time period.
10. Verify the accuracy of the model results using the statistical criteria NSE, R^2, and Pbias.

3. Results and Discussion

The results of outlier values show that some values have deviated from the trend of the group; therefore, they must be removed from the dataset analysis when deriving the empirical model, as shown in **Table 2**. The total number of outlier data points was 26, and these values gradually decreased from 8 at one-hour duration to 3 at five-hour duration.

The details of the *t*-test results show that it is within the permissible limits as shown in **Table 3**, The Smirnov-Kolmogorov test was applied to evaluate how well a normal distribution fits the given data. The results of this test indicate that the data follow a normal distribution.

Table 2. Test of outliers in different duration.

Duration (hr)	u_h	u_L	No of Outliers Data
1	24.91	0	8
2	14.02	0	7
3	10.07	0	4
4	8.167	0	4
5	6.99	0	3

Table 3. Results of t-test for different durations.

Duration (hr)	1	2	3	4	5
$t_{critical}$	1.649	1.649	1.649	1.649	1.649
$t_{statistical}$	1.541	1.541	1.541	1.541	1.541

3.1. Relation between Rainfall Intensity and Probability

After analyzing data from each group with interval duration of one to five hours, the relationship was constructed as a linear function in the form of equation 3.The horizontal axis represents the probability of the occurrence of RI, while the y-axis represents the logarithm of RI.

Figure 2 shows that the intensity of rain increases with the increase in the period of its occurrence. In addition, the intensity decreases as the duration shortens, and the directions of the curves agree with what the researchers have reached[4,37].

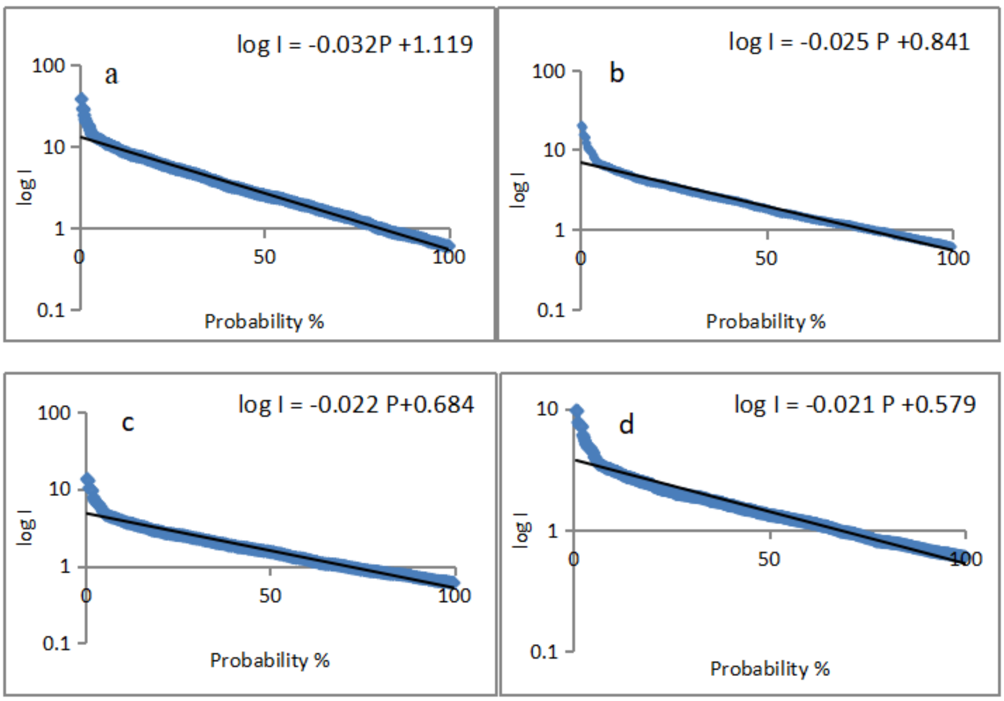

Figure 2. *Cont.*

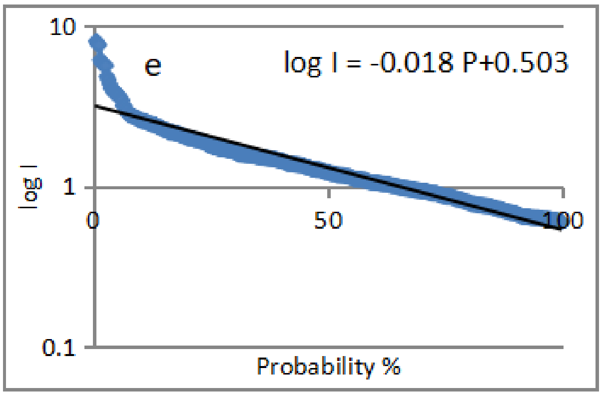

Figure 2. Relationship between log I and probability of occurrence (p) for each duration (t): (a) 1 hr; (b) 2 hr; (c) 3 hr; (d) 4 hr; (e) 5 hr.

Also the coefficients A and B can be calculated for the different rainfall durations according to **Table 4**. The values of parameters A and B that were extracted from the linear equations after analysis for each period are listed in **Table 4**.

Table 4. Coefficients A and B for linear equation at various rainfall periods.

Rainfall Intensity	I_{1h}	I_{2h}	I_{3h}	I_{4h}	I_{5h}
A	1.119	0.841	0.684	0.579	0.503
B	−0.032	−0.025	−0.022	−0.021	−0.018

To construct the relationship between RI, duration, and probability, different values of probability were taken starting from 5% to 95 % and substituted on the five equations formed in each group of duration interval and extracted RI. As a result, a total of 96 RI values across various durations were obtained, as shown in **Table 5**. For each probability percentage in **Table 5**, five values of RI for different durations from one to five hours will be consistent. Those values will be drawn where the y-axis represents intensity, while the inverse of the duration interval for five time periods from one to five hours, which is the period of their occurrence on the x-axis. Consequently, nineteen linear equations will be formed by choosing the best straight line between the values. **Figure 3** shows examples of the analysis with various probabilities, and also illustrates that by increasing the percentage probability the coefficient of determination will decrease, but it remains within the permissible limits.

Table 5. The analysis calculates the rainfall intensity based on the probability from 5% to 95% and for periods from 1 to 5 hr.

P%	Rainfall Duration (t, hr)				
	One Hour	Two Hour	Three Hour	Four Hour	Five Hour
5	11.429	6.209	4.385	3.535	2.979
10	9.727	5.470	3.908	3.199	2.722
15	8.279	4.819	3.483	2.894	2.488
20	7.047	4.246	3.105	2.618	2.275
25	5.998	3.741	2.767	2.368	2.079
30	5.106	3.291	2.466	2.142	1.902
35	4.345	2.904	2.198	1.938	1.737
40	3.698	2.558	1.959	1.753	1.589
45	3.148	2.254	1.746	1.586	1.452
50	2.679	1.986	1.556	1.435	1.327
55	2.280	1.749	1.387	1.298	1.213
60	1.941	1.542	1.236	1.174	1.109
65	1.652	1.358	1.101	1.062	1.013
70	1.406	1.197	0.981	0.961	0.927
75	1.197	1.054	0.874	0.869	0.847
80	1.018	0.929	0.779	0.787	0.775
85	0.867	0.818	0.695	0.712	0.708
90	0.738	0.721	0.619	0.644	0.647
95	0.628	0.635	0.552	0.583	0.591

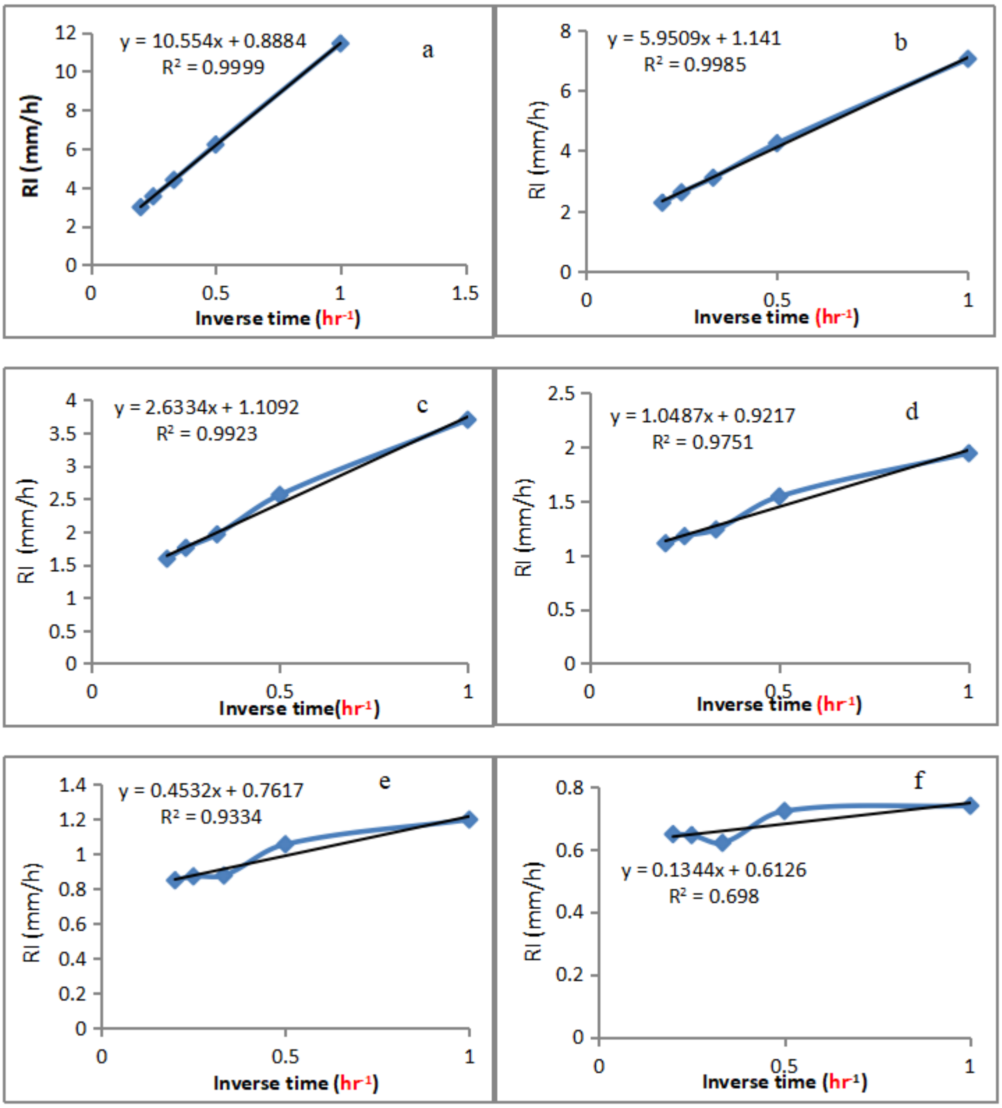

Figure 3. Examples of the relationship between intensity (I) and inverse duration (1/t) for the different probability of occurrence (p): (a) 5%; (b) 20%; (c) 40%; (d) 60%; (e) 75%; (f) 90%.

Table 6 shows the values of parameters A and B of the linear equations for different probabilities ranging from 5% to 95 %.

Table 6. Coefficients A and B for each probability.

P %	A	B
5	0.8884	10.554
10	1.0133	8.7433
15	1.0945	7.224
20	1.1411	5.9509
25	1.1602	4.8854
30	1.1581	3.9950
35	1.1398	3.2522
40	1.1092	2.6334
45	1.0697	2.1192
50	1.0241	1.6927
55	0.9740	1.3398
60	0.9217	1.0487

Table 6. *Cont.*

P %	A	B
65	0.8682	0.8093
70	0.8146	0.6132
75	0.7617	0.4532
80	0.7102	0.3233
85	0.6603	0.2184
90	0.6126	0.1344
95	0.5671	0.0675

After that, two line equations were built by drawing a relation between coefficients A and B with different probabilities and then combining them together as shown in **Figure 4**. Equation 16 represents the amount of RI for the model.

$$I_m = 18.151e^{-0.051}P + (1.2182 - 0.0057P)/t \qquad (16)$$

Where, I_m is the rainfall intensity in $mm.hr^{-1}$, P is the probability percent of the model, and t is the interval duration in hr.

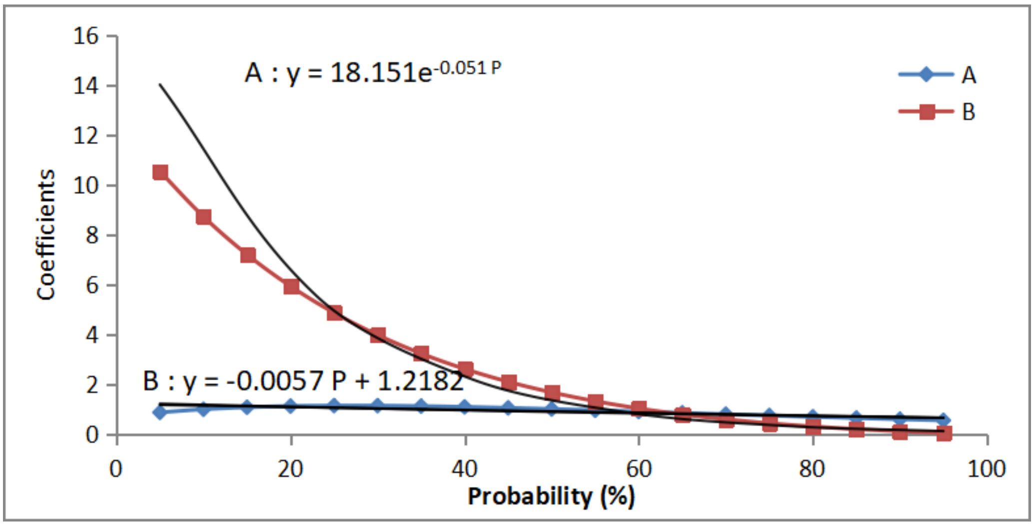

Figure 4. Relation between probability and coefficient A and B.

3.2. Observed Model Results

The RI of the observed model was calculated for five different durations of rainfall intervals, ranging from one to five hours by substituting a two-year RP and a 50% probability in equation 15. The results of the RI values are listed in **Table 7**.

For the other models results, the values of RI were calculated for five time periods using the Sherman and Talbot methods, and the results were used to compare with the empirical model results. **Table 8** shows the RI analysis for a two-year return period.

Table 7. Observed rainfall intensity with 50% probability.

Rainfall duration (hr)	1	2	3	4	5
Rainfall Intensity (mm/hr)	2.679	1.986	1.556	1.435	1.327

Table 8. The contrast between different methods with model results.

No	T hr	RI	RI.t	RI^2	$RI^2.t$	log t	log RI	Log t. log RI	$logt^2$
1	1	2.68	2.68	7.18	7.18	0	0.43	0	0
2	2	1.99	3.97	3.95	7.89	0.30	0.29	0.09	0.09
3	3	1.56	4.67	2.42	7.26	0.48	0.19	0.09	0.23
4	4	1.44	5.74	2.06	8.24	0.60	0.16	0.10	0.36
5	5	1.33	6.65	1.76	8.81	0.69	0.12	0.08	0.40
Total		9.0	23.71	17.37	39.38	2.07	1.19	0.36	1.17

Also, RI was calculated for each method, where the parameters a and b are extracted and substituted in equations (4–6) to find RI from the Sherman formula, similarly substituted in equations (7–9) to find RI from the Talbot formula. Finally, the values obtained from the observed, empirical model, Sherman formula, and Talbot formula are listed in **Table 9**. On the other hand, intensity versus duration with two years as a duration interval was drawn as shown in **Figure 5**.

Table 9. Values of intensity over two years for different models.

Duration	$I_{observed}$	I_{Talbot}	$I_{Sherman}$	I_{model}
hr	mm/hr			
1	2.679	2.611	2.665	2.606
2	1.986	2.045	1.954	2.012

Table 9. *Cont.*

Duration	$I_{observed}$	I_{Talbot}	$I_{Sherman}$	I_{model}
hr		mm/hr		
3	1.556	1.681	1.629	1.813
4	1.435	1.427	1.432	1.772
5	1.327	1.239	1.296	1.655

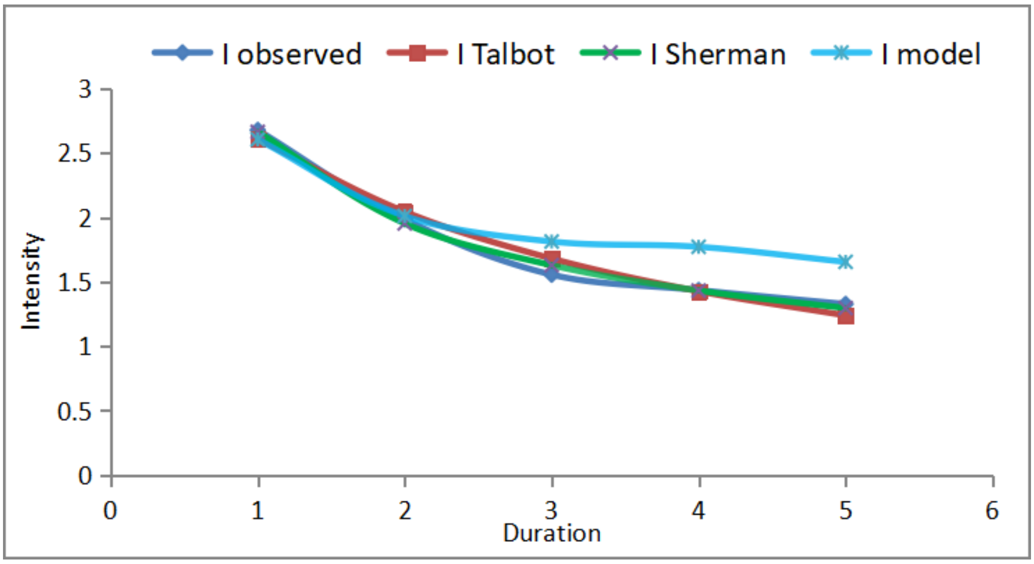

Figure 5. The comparison of RI result with the return period (Tr) of 2 years.

According to **Figure 5**, the intensity-duration curve shows a close match between the model-estimated values and the observed values, as well as the Sherman and Talbot values. However, the accuracy and quality of the relationship tend to decline, with the values in perfect agreement for a one-hour duration and almost perfect for a two-hour duration; then, they gradually decline at the third, fourth, and fifth-hour durations.

Due to the number of rainfall data series being small for building the empirical model over a long period, their quality is lower when compared to rainfall data series with a short period, in both quantity and quality. In rainy months, high rainfall is frequently of short duration because the probability of events is high. As a result, the empirical model's accuracy is high due to the availability of several series of data on rainfall, so the intensity with short durations gives more accuracy in the prediction of the results of rainfall intensity by the empirical model; on the other hand, when the duration is high, the accuracy of the model is low.

3.3. Correlation Analysis

To evaluate the model's performance, each model with two years of RP has been assessed using the correlation coefficient, NSE, and Pbias. According to the results of the statistical analysis, when compared with **Table 1**, the model performance is considered good due to high correlation values for 2-year RP. **Table 10** shows the values of the correlation analysis.

Table 10. Performance model for 2 years as a return period.

Methods	R^2	Pbias (%)	NSE
Talbot	0.98	−0.22	0.97
Sherman	0.99	−0.41	0.99
Model	0.97	−9.74	0.80

4. Conclusions

Based on daily rainfall values, short-term rainfall periods can be estimated with a high degree of reliability and a very high correlation coefficient. Moreover, the empirical model can be relied upon to estimate RI for a specific probability and duration. For different locations in Iraq, empirical mathematical relationships can be established that estimate short-term data from daily rainfall data. The equation that controls the RI in Al-Diwaniyah city using the empirical model is, $I_m = 18.151\ e - 0.051\ P + (1.2182 - 0.0057\ p)/t$, where I_m is the RI in mm/hr, p is a probability as a percentage of the rainfall, and t is the period that rain falls in an hour.

To ensure more accurate decisions on the management of hydrology in Iraq in the future, we recommend establishing a greater number of rain gauges across various parts of Al-Diwaniyah and different locations across Iraq in each governorate, applying the model for different time periods, less than one hour and more than 6 hours. Also suggest expanding the study area and updating the data periodically for specific periods not exceeding ten years, and conducting additional studies in different parts of Iraq to confirm the existence of a similar relationship between the probability, RI, and duration. Such efforts will support more precise decision-making in water resources management in Iraq and promote scientific research development.

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Conflicts of Interest

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References

[1] Al-Aboodi, A.H., Hassan, A.A., Ibrahim, H.T., 2019. Rainfall intensity probability for design of drainage system in Basrah City, South of Iraq. ARPN Journal of Engineering and Applied Sciences. 14(5), 954–961.
[2] Dawood, A.H., Mawlood, D.K., 2023. Derivation of the rainfall intensity-duration-frequency curve for Erbil City using SCS II method. Zanco Journal of Pure and Applied Sciences. 35(SpA), 1–10.
[3] Al-Amri, N.S., Subyani, A.M., 2017. Generation of rainfall intensity duration frequency (IDF) curves for ungauged sites in arid region. Earth Systems and Environment. 1(8), 1–12. DOI: https://doi.org/10.1007/s41748-017-0008-8.
[4] Amen, A.R.M., Kareem, D.A., Mirza, A.A., et al., 2022. Development of intensity-duration-frequency curves (IDF) for Dohuk City in Kurdistan Region of Iraq. Journal of Duhok University. 25(2), 366–379.
[5] Jaleel, L.A., Farawn, M.A., 2013. Developing rainfall intensity-duration-frequency relationship for Basrah City. Kufa Journal of Engineering. 5(1), 105–112. DOI: https://doi.org/10.30572/2018/KJE/511235
[6] Al Mamun, A., Salleh, M.N., Noor, H.M., 2018. Estimation of short-duration rainfall intensity from daily rainfall values in Klang Valley, Malaysia. Applied Water Science. 8(7), 1–10. DOI: https://doi.org/10.1007/s13201-018-0854-z
[7] Galoie, M., Kilanehei, F., Motamedi, A., et al., 2021. Converting daily rainfall data to sub-daily: Introducing the MIMD method. Water Resources Management. 35(11), 3861–3871. DOI: https://doi.org/10.1007/s11269-021-02930-3
[8] Hussein, A.K., 2014. Deriving rainfall intensity-duration-frequency relationships for Kerbala City. AL Muthana Journal for Engineering Sciences. 3(1), 25–37. DOI: https://doi.org/10.52113/3/eng/mjet/2014-03-01/25-37
[9] Harisuseno, D., Prasetyorini, L., Fidari, J.S., 2023. An empirical model of rainfall intensity as a function of rainfall duration and probability of occurrence. Journal of Water and Land Development. 56(I–III), 182–193. DOI: https://doi.org/10.24425/jwld.2023.143759
[10] Al-Awadi, A.T., 2016. Assessment of intensity dura-

tion frequency (IDF) models for Baghdad City, Iraq. Journal of Applied Sciences Research. 12(2), 7–11.

[11] Jamel, A.A.J., Dawood, Z.T., 2024. Generation rainfall intensity equations for intensity duration frequency (IDF) curves (case study: Salah Al-Din, Iraq). Instrumentation, Mesures, Métrologies. 23(4). DOI: https://doi.org/10.18280/i2m.230402

[12] Anggraheni, D., Gustoro, D., 2019. Rainfall distribution pattern of Progo Watershed in observational and empirical method. In: MATEC Web of Conferences. EDP Sciences. 280, 05005. DOI: https://doi.org/10.1051/matecconf/201928005005

[13] Limantara, L.M., Harisuseno, D.H., Devi, V.A.K., 2018. Modelling of rainfall intensity in a watershed: A case study in Amprong Watershed, Kedungkandang, Malang, East Java of Indonesia. Journal of Water and Land Development. 38(VII–IX), 75–84. DOI: https://doi.org/10.2478/jwld-2018-0044

[14] David, A.O., Nwaogazie, I.L., 2020. Optimization technique in rainfall-intensity-duration-frequency modelling for Ikeja, South-West, Nigeria. Nigerian Journal of Technology. 39(4), 1276–1285. DOI: https://doi.org/10.4314/njt.v39i4.37

[15] Aldosari, D., Almedeij, J., Alsumaiei, A.A., 2020. Update of intensity-duration-frequency curves for Kuwait due to extreme flash floods. Environmental and Ecological Statistics. 27(3), 491–507. DOI: https://doi.org/10.1007/s10651-020-00454-4

[16] Cardoso, C.O., Bertol, I., Soccol, O.J., Sampaio, C.A.D.P., 2014. Generation of intensity duration frequency curves and intensity temporal variability pattern of intense rainfall for Lages/SC. Brazilian Archives of Biology and Technology. 57, 274–283. DOI: https://doi.org/10.1590/S1516-89132013005000014

[17] Escobar-González, D., Singaña-Chasi, M.S., González-Vergara, J., et al., 2022. Intensity-duration-frequency curve for extreme rainfall event characterization in the high tropical Andes. Water. 14(19), 2998. DOI: https://doi.org/10.3390/w14192998

[18] Hussein, D.N., Al-Zakar, S.H., Yonis, A.M., 2023. Estimating the intensity equations for rain intensity frequency curves (Mosul/Iraq): Intensity equations for rain. Tikrit Journal of Engineering Sciences. 30(3), 38–48. DOI: https://doi.org/10.25130/tjes.30.3.5

[19] Bibi, T.S., 2023. Derivation of short-term design rainfall intensity from daily rainfall data for urban drainage design using empirical equations in Robe Town, Ethiopia. International Journal of Hydrology. 7, 63–71.

[20] Ilaboya, I.R., Nwachukwu, S.N., 2022. Development of intensity duration frequency (IDF) curves for rainfall prediction in some selected states in South-West Nigeria. Journal of Energy Technology and Environment. 4(2), 69–82. Available from: https://journals.nipes.org/index.php/jete/article/view/512

[21] Aragão, R.D., Costa, F.F.D., Rufino, I.A., et al., 2024. Intensity-duration-frequency equations (IDF) for the state of Paraíba, Brazil, and regionalization of its parameters. Revista Brasileira de Engenharia Agrícola e Ambiental. 28(10), 283679. DOI: https://doi.org/10.1590/1807-1929/agriambi.v28n10e283679

[22] Ewea, H.A., Elfeki, A.M., Al-Amri, N.S., 2017. Development of intensity-duration-frequency curves for the Kingdom of Saudi Arabia. Geomatics, Natural Hazards and Risk. 8(2), 570–584. DOI: https://doi.org/10.1080/19475705.2016.1250113

[23] Ministry Of Agriculture, Iraqi Agrometeorological Center. Available from: https://www.agromet.gov.iq/eng/index.php (cited 15 December 2024).

[24] Khalil, Z.H., Abdullaev, S.M., 2020. Sensitivity of winter crops to climate variability in the irrigated subtropics of Iraq (Al-Diwaniyah). Procedia Computer Science. 167, 1066–1079.

[25] Elmewafi, M., Kedy, S.K., Elnaggar, A.A., 2020. Changes of land cover in Diwaniyah Governorate and their impact on agricultural sustainability by using geomatics techniques. MEJ-Mansoura Engineering Journal. 40(3), 19–36.

[26] The Editors of Encyclopaedia Britannica. Al-Dīwāniyyah. Available from: https://www.britannica.com/place/Al-Diwaniyyah (cited 19 February 2025).

[27] Takeleb, A.M., Fajriani, Q.R., Ximenes, M.A., 2022. Determination of rainfall intensity formula and intensity-duration-frequency (IDF) curve at the Quelicai Administrative Post, Timor Leste. Timor-Leste Journal of Engineering and Science. 3, 1–10.

[28] Majeed, A.R., Nile, B.K., Al-Baidhani, J.H., 2021. Selection of suitable PDF model and build of IDF curves for rainfall in Najaf City, Iraq. Journal of Physics: Conference Series. 1973(1), 012184. DOI: https://doi.org/10.1088/1742-6596/1973/1/012184

[29] Ganamala, K., Kumar, P.S., 2017. A case study on flood frequency analysis. International Journal of Civil Engineering and Technology. 8(4), 1762–1767.

[30] John, A.S., Brema, J., 2018. Analysis of rainfall by intensity-duration-frequency (IDF) curves for Vamanapuram River Basin, Kerala. International Journal of Civil Engineering and Technology. 9(7), 403–411.

[31] Raghunath, H.M., 2006. Hydrology Principles Analysis Design, Revised second edition. New Age International Publishers: New Delhi, India.

[32] Chow, V.T., Maidment, D.R., Mays, L.W., 1988. Applied Hydrology. McGraw-Hill Book Company: Singapore.

[33] Sangüesa, C., Pizarro, R., Ingram, B., et al., 2023. Comparing methods for the regionalization of intensity-duration-frequency (IDF) curve parameters in sparsely-gauged and ungauged areas of Central Chile. Hydrol-

ogy. 10(9), 179. DOI: https://doi.org/10.3390/hydrology10090179

[34] Khudier, A.S., Hamdan, A.N., 2023. Estimation of suspended sediment loads in Diyala River watershed, Iraq, using SWAT model. Tikrit Journal of Engineering Sciences. 31(4), 46–57. DOI: https://doi.org/10.25130/tjes.31.4.5

[35] Khudier, A.S., Hamdan, A.N.A., 2023. Assessment of the impacts of land use/land cover change on water resources in the Diyala River, Iraq. Open Engineering. 13(1), 20220456. DOI: https://doi.org/10.1515/eng-2022-0456

[36] Khudier, A.S., Hamdan, A.N.A., 2024. Hydrological model of the Diyala River watershed in Iraq using Soil Water Assessment Tool. Al-Bahir Journal for Engineering and Pure Sciences. 4(2), 6. DOI: https://doi.org/10.55810/2313-0083.1061

[37] Kareem, D.A., Amen, A.R.M., Mustafa, A., et al., 2022. Comparative analysis of developed rainfall intensity-duration-frequency curves for Erbil with other Iraqi urban areas. Water. 14(3), 419. DOI: https://doi.org/10.3390/w14030419