Tikrit Journal of Engineering Sciences (2025); 32(2): 1906

DOI: http://doi.org/10.25130/tjes.32.2.22

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Statistical Analysis of the Maximum Annual Rainfall Data at Al-Shuwaija Marshes in Wasit Governorate, Iraq

Rana Abdul-Kader Salih [a], *Mohammed Rashid Al-Juhaishi* [*b], *Ali Khairi Ibrahim* [b], *Saif Ali Abdul Reda Jabr* [b]

a *Technical Engineering College of Baghdad, Middle Technical University, Baghdad, Iraq.*

b *Water Resources Department, Collage of Engineering, University of Baghdad, Baghdad, Iraq.*

Keywords:

Nonparametric test; Kolmogorov-Smirnov test; Annual rainfall; Goodness-of-fit test; Al-Shuwaija Marshes.

Highlights:

- *Five statistical probability distributions were used.*
- *Model the maximum annual rainfall for each of the five locations in and around Al-Shuwaija Marshes.*
- *Selecting the best probability distribution is based on the goodness-of-fit test using the Kolmogorov-Smirnov test.*
- *Two of the five stations had a normal distribution.*
- *The other two stations had Log-Normal distribution as the best fit for the maximum annual rainfall.*
- *Only one station had the Gamma distribution.*

ARTICLE INFO

Article history:

Received	03 Dec.	2023
Received in revised form	24 Dec.	2023
Accepted	22 Jan.	2025
Final Proofreading	29 Mar.	2025
Available online	31 May	2025

Citation: Salih RA, Al-Juhaishi MR, Ibrahim AK, Jabr SAA. **Statistical Analysis of the Maximum Annual Rainfall Data at Al-Shuwaija Marshes in Wasit Governorate, Iraq**. *Tikrit Journal of Engineering Sciences* 2025; **32**(2): 1906.

http://doi.org/10.25130/tjes.32.2.22

****Corresponding author:***

Mohammed Rashid Al-Juhaishi

Water Resources Department, Collage of Engineering, University of Baghdad, Baghdad, Iraq.

Abstract: Five statistical distributions were used in this study to model the maximum annual rainfall at five metrological stations in and around Al-Shuwaija Marshes in Wasit governorate, Iraq. These stations are Badra, Sumar, Kut, Ilam, and Mehran. Selecting the best probability distribution is based on the test of goodness-of-fit using the Kolmogorov-Smirnov test. Data was collected from 2000 to 2020 from Iraqi and Iranian metrology authorities. This data is subdivided into two sub-samples: the first is from 2000 to 2013 for building the model, and the second is from 2014 to 2020 to validate the model. The Kolmogorov-Smirnov test results showed that for some stations, there was more than one frequency distribution that fit the data as they had the same minimum SIG value. In these cases, the t-test and F-test results were used as criteria to aid in selecting the best-fit distribution. For the Badra station, the Log-Normal frequency distribution (61.663, 0.502) was the best-fit distribution with the SIG value of 0.998. For the Sumar station, three distributions had the same SIG value (0.998) Normal, Log-Normal, and Gamma, with the best-fit for Log-Normal (69.008, 0.593) selected according to the t-test 0.146, 0.024, and 0.093 between a three generated data using each of these distributions and the observed one. The same observation was found for the Kut station, except that the best-fit distribution was the Normal distribution (55.746, 30.7323) with a SIG value of 0.879. As for the Ilam station, the results indicated that the Normal and the Gamma distributions had the same SIG value; the last was selected as the best one according to the t-test results 0.081, 0.010. and 0.263. for the Mehran station, the Normal distribution was the best one that fitted the maximum rainfall data. For each station, three series were generated using the model. Each generated series was tested against the observed using the validation data period. The Kolmogorov-Smirnov test indicated that the distribution could generate data drawn from the same population as the observed data with respect to frequency.

توزيعات احتمالية إحصائية لنمذجة بيانات هطول الأمطار في أهوار الشويجة في محافظة واسط، العراق

رنا عبدالقادر صالح [١]، محمد راشد الجحيشي [٢]، علي خيري ابراهيم [٢]، سيف علي عبد الرضا [٢]

[١] الكلية التقنية الهندسية / الجامعة التقنية الوسطى / بغداد - العراق.

[٢] قسم هندسة الموارد المائية / كلية هندسة / جامعة بغداد / بغداد - العراق.

الخلاصة

هذه الدراسة استخدام خمسة توزيعات احتمالية إحصائية مختلفة لنمذجة القيمة العظمى السنوية لهطول الأمطار في خمسة محطات للرصد شملت الهيدرولوجي واقعة في أهوار الشويجة والمناطق المجاور لها ضمن محافظة واسط في العراق .كل من محطات بدرة وسومروالكوت وإلهام تم جمع البيانات من عام . Kolmogorov-Smirnov ومهران. يعتمد اختيار أفضل توزيع احتمالي على اختبار جودة الملائمة باستخدام اختبار إلى عام 2020، وتم تجزئة هذه البيانات إلى عينتين فرعيتين، تقع الأولى بين عامي 2000 و 2013 لبناء النموذج والثانية للفترة من 2000 أنه بالنسبة لبعض المحطات، يوجد أكثر من Kolmogorov-Smirnov إلى 2020 للتحقق من صحة النموذج .أظهرت نتائج اختبار 2014 ،لتحديد التوزيع الاكثر ملائمه .بالنسبة لمحطة بدرة F و t تم استخدام اختباراتSIG. توزيع إحصائي واحد يناسب البيانات لأن لديهم نفس قيمة بالنسبة لمحطة سومر هناك توزيعات لها . SIG (0.998) فإن التوزيع الطبيعي بمتغيرات)61.663، 0.502 (هو الأفضل حيث كانت قيمة وغاما وكان التوزيع اللوغاريتمي الطبيعي)0.593 69.008 (هو الاكثر وهم التوزيع الطبيعي اللوغاريتمي الطبيعي SIG 0.998 نفس قيمة و 0.024 و 0.093 لثلاث متسلسلات عشوائية تم انشاؤها وبنفس الستراتيجية تم اتباعها لمحطة الكوت حيث 0.146 tملائمه وفق الاختبار بالنسبة لمحطة إيلام، تشير تساوي 0.879 SIGكان التوزيع الطبيعي هو التوزيع الاكثر ملائمه بمتغيرات)55.746 ، 30.7323 (مع قيمة بالنسبة لمحطةt تساوي 0.879 ولكن تم اختيار الاول وفق اختبار و SIG النتائج إلى أن كلا من توزيع غاما والتوزيع الطبيعي لهما نفس قيمة يتم الحصول على ثلاث متسلسلات لكل محطة باستخدام أفضل توزيع مناسب. يتم اختبار كل من. مهران التوزيع الطبيعي كان هو الاكثر ملائمه إلى أن التوزيع قادر على توليد البيانات بنفس Kolmogorov-Smirnov هذه المتسلسلات التي تم إنشاؤها مقابل البيانات المقاسة .أشار اختبار التوزيع للبيانات المقاسة.

الكلمات الدالة: أهوار الشويجة، الامطار السنوبة، جودة الملائمة باستخدام اختبار Kolmogorov-Smirnov.

1.INTRODUCTION

Rainfall prediction models are essential for effective water resource management, hydraulic design, and mitigating the impacts of floods and droughts. Analysis of historical rainfall data, including patterns and distributions, enables the development of these crucial tools, informing decisions related to water allocation, controlling floods, irrigation, and the sustainable development of natural resources. Fitting probability distributions using past data is important in engineering hydrology [1-16]. However, this strategy is often complicated since it requires tremendous estimation methods [17, 18]. Many researchers have tried to use the statistical frequency distribution for prediction. Sharma and Singh [19] used Gamma distribution to fit rainfall data at representative stations in India. Bhargava et al. [20] confirmed that the seasonal rainfall distribution significantly influenced the yield. Rama Rao et al. [21] investigated the daily rainfall data at Bijapur from 1921 to 1970. Khudri and Sadia [22] concluded that the Gamma four-parameter distribution was suitable for 50% of the stations in Bangladesh, while for other stations, no distribution fitted the data. Mandal and Choudhury [23] found that Normal (N) distributions best fitted to the annual summer seasons and Rainfall data from the post-monsoon period are crucial for water resource management on Sagar Island. While, Weibull (W2), Log-Normal (LN2), and Pearson Type 5 best fit the monsoon, pre-monsoon, and winter seasons, respectively. Anil [24] indicated that Log-Normal (LN2) was the suitable distribution, including India's annual maximum daily rainfall. Amin et al. [25] found that the Log-Person Type 3 was the best-fit distribution in the northern daily water samples collected from designated regions across Pakistan for annual maximum calculation. Bhakar et al. [26] concluded that the Gumbel distribution was the best-fit distribution for simulating the monthly maximum precipitation values in India. Lee [27] indicated that the precipitation pattern of 50 percent of the stations in the e Chia-Nan plain area of Taiwan is best fitted with LP3 distributions. Ogunlela [28] concluded that the LP3 distribution was the most suitable for meeting the maximum daily precipitation in Nigeria. Xeflide et al. [29] confirmed that the LN2 distribution is the best-fit distribution to model one to five consecutive days' maximum rainfall for Accra, Ghana. Olofintoye et al. [30] found that 40% of the stations in Nigeria obey Pearson Type 3 (P3) distributions, while 50% of the stations followed LP3. Sen and Eljadid [31] found that the Gamma distribution was the best fit for monthly maxima rainfall in arid regions in Libya. Arora and Singh [4] found that the LP3 distribution was the best fit for the monthly maxima rainfall in arid regions in Libya, and this conclusion was convenient with the U.S. Water Resources Council (USWRC) in 1967. Al-Mansory [32] studied six distributions to find the best-fit distribution for the highest monthly rainfall for the Basrah station from 1900 to 2000. The author indicated that the Person Type 3 and Gumbel were the best-fit distributions. Al-Suhili and Khanbilvardi [33] used different frequencies, i.e., Log-Normal, Normal, Exponential, Weibull, and Two parameters Gamma type, to fit the monthly rainfall data from 1984 to 2010 in Sulminya, north of Iraq. The Gamma, Weibull, and

Exponential distributions were the best fits for the three stations studied. Alghazali et al. [34] examined three distributions to best fit the data for 13 stations in Iraq. The results of the Kolmogorov-Smirnov test indicated that none of the frequency distributions used fit the rainfall data. The present study analyzes annual rainfall data from five hydrological monitoring stations in and around the Al-Shuwaija Marsh to determine the best-fit probability distribution method. A marsh is considered an important natural depression that extends parallel to the Tigris River, with an area of 250 km² and a ground level of 14 (m.a.m.s.l). The marsh is filled with rainwater and torrential rains from the east through the Galal Badra and Tursaq Rivers during the rainy season. The marsh starts to fill at the beginning of the year in January, reaching its highest storage volume at the end of April. The surface water is drained from Al-Shuwaija Marshes to the Tigris River through the Um-Aljury regulator.

2.BACKGROUND

To identify the best-fit distribution for annual rainfall data at five meteorological stations (as detailed above), five candidate distributions were evaluated. Distribution parameters were estimated using SPSS v26, and goodness-of-fit was assessed. The Kolmogorov-Smirnov test was used to select the most appropriate distribution for each station. The equations of the distributions are presented below.

2.1.Normal

Normal is a fundamental probability distribution in statistics. It is given by [1, 33],

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{1}{2\sigma^2}(x-\mu)^2\right] \qquad (1)$$

where μ represents the mean (location parameter), and σ denotes the standard deviation (scale parameter).

2.2.Log-Normal Distribution:

The probability density function (pdf) method is presented as follows [1, 33].

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} exp\left[-\frac{1}{2\sigma^2}(logx-\mu)^2\right] \qquad (2)$$

where μ represents the mean of the log-transformed variable x.

2.3.Exponential Distribution:

The Poisson distribution of a probability density function is written as [1, 33]:

$$f(x) = \frac{1}{\mu} exp * \left[\frac{x}{\mu}\right] \qquad (3)$$

where μ denotes the distribution's parameter numbers.

2.4.Weibull

The probability density function of the Weibull distribution is written as [1, 33]:

$$f(x) = \frac{a}{b^{-a}} x^{a-1} * \exp - \left[\frac{x}{b}\right]^a \qquad (4)$$

where *a* represents the shape parameter, and *b* represents the scale parameter.

2.5.The Gamma Distribution PDF

$$f(x) = \frac{a}{b^a}\left(\frac{a}{r(a)}\right)x^{a-1*} exp\left[\frac{x}{b}\right] \qquad (5)$$

The Kolmogorov-Smirnov is defined as follows [5]:

$$D_n = Max|F_n(y) - F(y)| \qquad (6)$$

$$F_n(y) = \frac{\pi(\{i \in \{1,2,..,n\}: y_i \leq y\})}{n} \qquad (7)$$

$$F(y) = \int_0^y f(x)dx \qquad (8)$$

where $F_n(y)$ represents the cumulative distribution function, and *F(y)* represents the theoretical cumulative distribution function.

3.MATERIALS AND METHODS

Al-Shuwaija is a natural rectangular depression, surrounded by the Tigris River from the west and south, the Iranian highlands on the east, and the island's lands in the north. It is 5 km long and 25 km wide. It is located 6 kilometers north of the city of Kut, between the coordinates of latitudes (3619295.02 and 3624649.61) and longitudes (605137.67 and 572767.30). The area has long, cold winters and dry summers. The rain on the Iran-Iraq borders near this location is considered the major source of its water. Rainfall data were collected from five stations around Al-Shuwaija. Two of these stations, Badra and Kut, are inside the Iraqi borders, while the other three stations; Mehran, Ilam, and Sumar; are inside the Iranian borders [35]. The geographical distribution of the rainfall stations near the Shuwaija Marshes is depicted in Figure 1. UTM coordinates for these stations are detailed in Table 1. Rainfall data spanning 2000-2020, provided by the Iraqi and Iranian meteorological authorities, was employed in this study. Model development utilized data from 2000-2013, while data from 2014-2020 served for verification. Goodness-of-fit was assessed using the Kolmogorov-Smirnov test. Table 2 shows the descriptive statistics of the selected stations around Al Shuwaija Marshes.

Table 1 Geographic Coordinates and Elevations of Rainfall Stations.

Station Type	Station Name	UTM Coordinates		Elevation	Average of Maximum Annual
		Northing	Easting	(m.a.m.s.l)	Precipitation (mm)
Rainfall	Badra	3664983.36	587693.42	69	85.22
	Sumar	3748963.22	546238.97	297	98.05
	Kut	3600509.15	565728.99	14	69.79
	Ilam	3717575.69	629909.85	1337	102.09
	Mehran	3664101.01	610096.86	150	88.88

Table 2 Statistical Analysis of the Main Stations in the Al-Shuwaija Area.

Stations	Statistic					
	Min.	**Max.**	**Mean.**	**Std. D**	**No.Skewness**	**No.Kurtosis**
Badra	21.3	213.7	85.22	45.94	1.45	2.49
Sumar	20.8	236.1	98.05	52.56	0.89	1.01
Kut	18.5	185.0	69.79	39.82	1.60	2.92
Ilam	26.9	245.2	102.09	52.09	1.08	1.54
Mehran	22.4	207.1	88.88	45.05	1.22	1.750

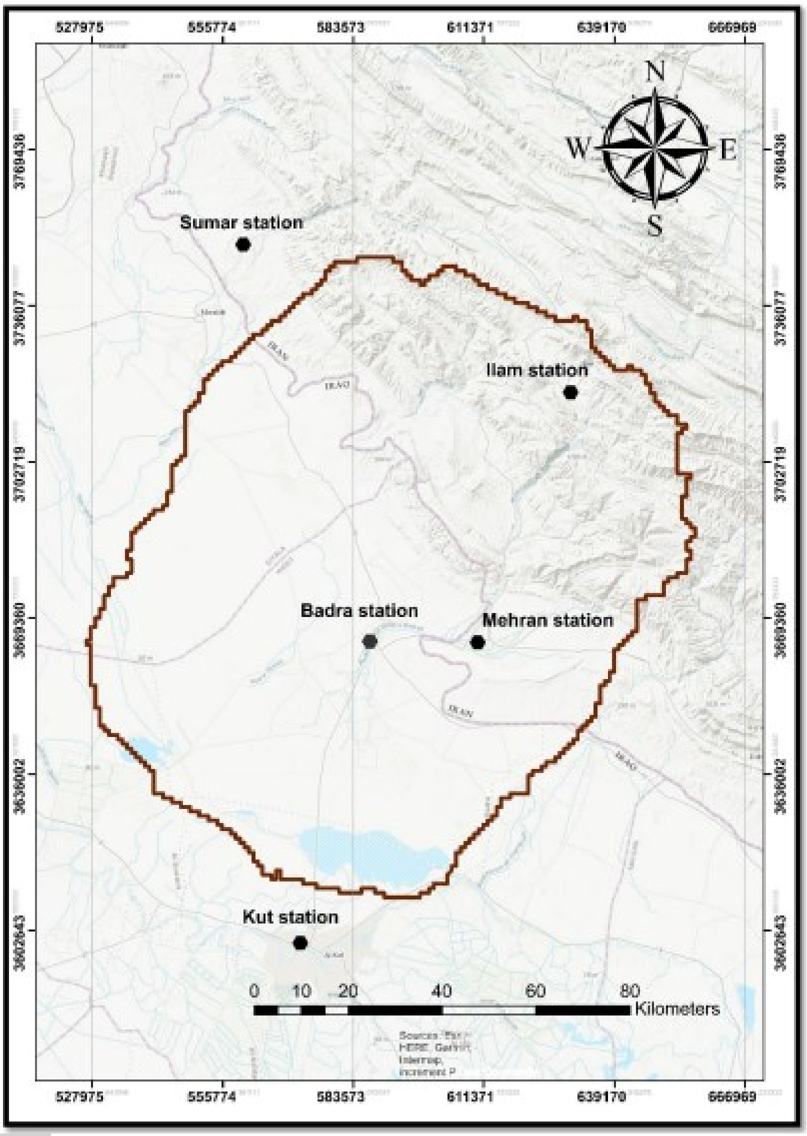

Fig. 1 The Locations of the Rainfall Stations Near Al-Shuwaija Marshes.

4.RESULTS AND DISCUSSION

The Kolmogorov-Smirnov test best fit SIG values were obtained using the SPSS version 26 software, indicating the rejection or acceptance of the null hypothesis depending on its value. Statistical significance at the $\alpha = 0.05$ level was determined by a p-value less than 0.05. In this case, the null hypothesis was rejected, suggesting that the data do not conform to the tested distribution. Figure 2 shows the p-p plot for each station, including the best statistical distributions for the data of the 13 years (2000-2013). Table 3 shows the parameters obtained from the fitting with the statistical distributions and a value of the SIG test for the Kolmogorov-Smirnov test to compare distributions that resulted from the comparison with the original data of the 13 years (2000-2013). The best-fit distribution for each station is identified in Table 3 based on the highest p-value. Because the Sumar, Kut, and Ilam stations had multiple distributions with similar goodness-of-fit (SIG values), additional criteria were needed for selection. Mean and variance comparisons were performed using the t-test and F-test, respectively. Table 4 tabulates the selected distribution for each station, chosen based on the highest p-value from the t-test and F-test results. For the Badra station, the Log-Normal distribution with parameters (61.663, 0.502) was identified as the best fit for annual maximum rainfall ($p = 0.998$). At the Sumar station, where three candidate distributions exhibited similar goodness-of-fit (p = 0.998), the Log-Normal distribution (69.008, 0.593) was selected based on comparing means and variances using the t-test and F-test. The same selection criterion was applied to the Kut station, where the normal distribution (55.746, 30.7323) was chosen from the Normal, Log-Normal, and Gamma distributions, which all showed comparable fit (p = 0.998). Similarly, for the Ilam station, the Normal and Gamma distributions had the same SIG value. The Gamma distribution (4.251, 0.052) was selected as the best one using the same criteria. For the Mehran station, the Normal distribution was (73.569, 38.7375). The selected best-fitted frequency distributions cited above with their corresponding estimated parameters are based, as mentioned above, on the data of (2000-2013). To verify these obtained frequency distributions, they were used to generate data for seven years and compared to the observed seven years of data (2014-2020), i.e., not used in the fitting process. For each station, three sets of generated series were used. Table 5 shows the results of the Kolmogorov-Smirnov independent two-sample test and indicated that all significance values (SIG) were positive. Thus, the null hypothesis was accepted, which exceeded the 0.05 threshold, confirming that the capability of the developed frequency distribution models to generate maximum annual rainfall data is statistically indistinguishable in frequency distribution from the observed data. Table 6 details the frequency of annual rainfall exceedances for observed and generated data (based on best-fit distributions) across a range of thresholds and stations. The results for the Sumer station showed excellent agreement between the observed and generated exceedance frequencies over the seven-year period. The Kut and Ilam stations showed the same results. For the Badra station, the performance was good for the threshold if values >20 and > 110. For thresholds >50 and >80, the generated series always gave frequencies greater than the observed one. For a threshold value greater than 140, the generated series gives zero frequency of occurrence compared to one in the observed series. For the Mahram station, the performance was good for all the threshold values except for the threshold values >140 mm. This study's rainfall frequency models provide a strong foundation for forecasting, hydrological applications, and related research. They are critical to inform decision-makers about extreme precipitation events, including floods and droughts. Knowledge of extreme rainfall patterns is also highly relevant to disciplines, such as agriculture, environmental science, and the built environment. Table 7 shows the return period for different maximum annual rainfall interval values calculated from 1000 years' data generated employing the distribution that best fits the data. In General, all the stations exhibited the behavior of a high return period for the low values between (<20) and for high values (>140). Another observation common for all the stations is the decrease in the return period as the rainfall increased to a certain median value, followed by an increase in the return period as the value of rainfall increased. To compare the return period results obtained for the five stations, it is observed that for high rainfall (>110), the return period value decreased as the station elevation increased, except for the Sumer station. For low rainfall (<20), the return period value increased as the station elevation decreased, except for the Sumer station. For the rainfall (>20 and < 110), the variation in the return period for the stations was reduced.

Table 3 Results of the Kolmogorov-Smirnov Goodness-of-Fit Test of Five Distributions for Rainfall Stations.

Distribution	Parameters	Badra	Sumar	Kut	Ilam	Mehran
Normal	μ	69.223	80.177	55.746	82.231	73.569
	σ	37.2631	43.9684	30.7323	39.8854	38.7375
	SIG	0.879	0.998	0.879	0.998	0.998
Log-Normal	μ	61.663	69.008	49.695	73.731	65.546
	σ	0.502	0.593	0.493	0.496	0.506
	SIG	0.998	0.998	0.879	0.879	0.879
Weibull	a	78.481	90.968	63.113	93.184	83.339
	b	2.240	1.956	2.261	2.308	2.250
	SIG	0.570	0.879	0.570	0.879	0.570
Exponential	μ	0.014	0.012	0.018	0.012	0.014
	SIG	0.570	0.879	0.570	0.879	0.879
Gamma	a	3.451	3.325	3.290	4.251	3.607
	b	0.050	0.041	0.059	0.052	0.049
	SIG	0.879	0.998	0.879	0.998	0.570

Table 4 Comparison of Means and Variances between Observed and Generated Series (2014-2020) Using T-Tests and F-Tests.

Distribution	Series No	Badra		Sumar		Kut		Ilam		Mehran	
		T Test	F Test	T Test	F Test	T Test	F Test	T Test	F Test	T Test	F Test
Normal	1	0.003	0.007	0.111	0.113	0.063	0.081	0.040	0.041	0.026	0.026
	2	0.101	0.101	0.031	0.033	0.048	0.048	0.044	0.045	0.027	0.027
	3	0.032	0.035	0.084	0.085	0.160	0.161	0.041	0.044	0.049	0.049
Log-Normal	1			0.146	0.146	0.032	0.048				
	2			0.024	0.026	0.034	0.039				
	3			0.093	0.093	0.244	0.244				
Weibull	1										
	2										
	3										
Exponential	1										
	2										
	3										
Gamma	1			0.032	0.032	0.052	0.058	0.081	0.085		
	2			0.067	0.067	0.051	0.053	0.010	0.018		
	3			0.043	0.047	0.037	0.039	0.263	0.263		

Table 5 The Significance Level (SIG) of the Kolmogorov-Smirnov Test for the applied Frequency Distributions for the Five Stations near Al-Shuwaija Marshes (2000-2013).

Distribution	Generated Series No	Badra	Sumar	Kut	Ilam	Mehran
Normal	1		0.203	0.056	0.203	0.056
	2		0.203	0.203	0.203	0.203
	3		0.541	0.203	0.056	0.203
Log-Normal	1	0.002	0.056	0.056		
	2	0.056	0.056	0.203		
	3	0.203	0.203	0.203		
Weibull	1					
	2					
	3					
Exponential	1					
	2					
	3					
Gamma	1		0.056	0.203	0.203	
	2		0.056	0.203	0.012	
	3		0.203	0.056	0.203	

Table 6 Comparison of Observed and Generated Series (2014-2020).

Station name	Series	Lower	Upper	FQ P>20	FQ P>50	FQ P>80	FQ P>110	FQ P>140*
Badra	Observed	34.00	145.63	7.00	4.00	1.00	1.00	1.00
	Generated1	18.81	112.16	6.00	5.00	4.00	1.00	0.00
	Generated2	36.95	128.65	7.00	5.00	2.00	2.00	0.00
	Generated3	22.62	118.43	5.00	5.00	3.00	1.00	0.00
Sumar	Observed	36.75	165.74	7.00	5.00	2.00	1.00	1.00
	Generated1	41.09	149.73	7.00	6.00	2.00	2.00	1.00
	Generated2	35.44	154.21	7.00	5.00	3.00	2.00	1.00
	Generated3	35.59	147.24	7.00	5.00	3.00	2.00	1.00
Kut	Observed	24.90	118.41	7.00	2.00	1.00	1.00	0.00
	Generated1	13.85	111.99	6.00	3.00	1.00	1.00	0.00
	Generated2	4.41	88.73	6.00	4.00	2.00	0.00	0.00
	Generated3	22.43	107.80	7.00	3.00	1.00	0.00	0.00
Ilam	Observed	42.28	160.00	7.00	6.00	3.00	1.00	1.00
	Generated1	28.47	147.11	7.00	6.00	3.00	2.00	1.00
	Generated2	6.01	121.79	6.00	6.00	4.00	2.00	0.00
	Generated3	49.69	165.85	7.00	6.00	2.00	1.00	1.00
Mahran	Observed	32.44	151.82	7.00	5.00	3.00	1.00	1.00
	Generated1	-1.91	106.54	6.00	6.00	4.00	0.00	0.00
	Generated2	20.02	125.30	7.00	5.00	3.00	2.00	0.00
	Generated3	19.30	116.41	6.00	5.00	3.00	1.00	0.00

FQ: Frequency of occurrence

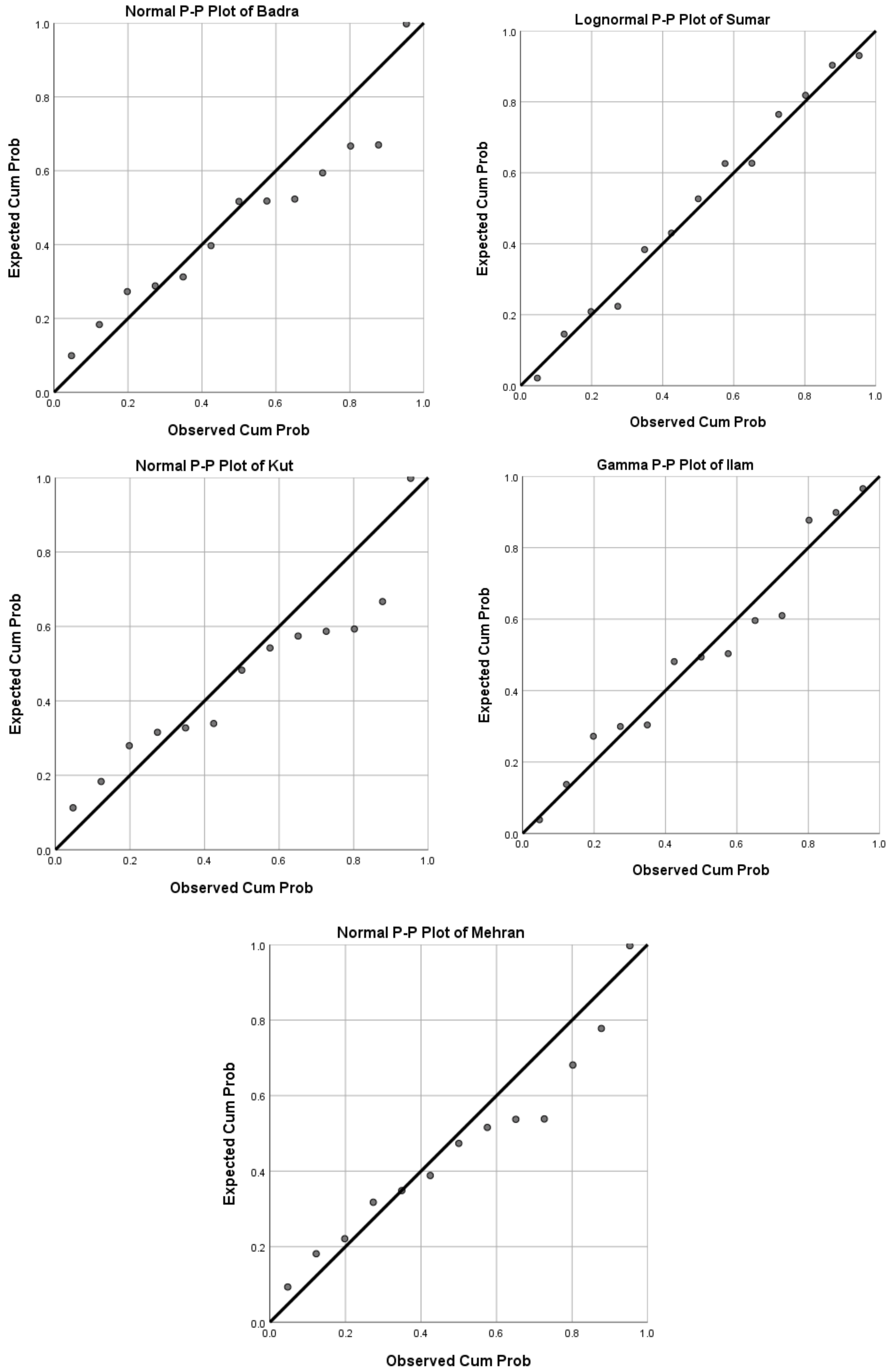

Fig. 2 Evaluation of Statistical Distribution Fit Using Probability-Probability (P-P) Plots. (*Cum = Cumulative probability).

Table 7 Return Periods in Year According to the Expected Values of the Maximum Annual Rainfall Using the Best Fit Distribution of Each Selected Station for One Hundred Years.

Rainfall Interval(mm)	Badra	Sumar	Kut	Ilam	Mehran
<= 20	109	316	39	243	66
20 < and <= 30	14	14	11	23	16
30 < and <= 40	8	9	9	14	14
40 < and <= 50	8	9	9	9	13
50< and <= 60	8	9	8	10	12
60 < and <= 70	9	10	10	10	10
70 < and <= 80	11	13	10	9	10
80 < and <= 90	15	15	15	12	10
90 < and <= 100	21	18	20	13	13
100 < and <= 110	24	22	39	17	15
110 < and <= 120	47	30	74	24	17
120 < and <= 130	49	39	138	23	31
130 < and <= 140	54	52	417	39	49
> 140	171	79	1000	79	172

5.CONCLUSIONS

An analysis and modeling study was conducted on the maximum annual rainfall at five stations: Badra, Sumar, Kut, Ilam, and Mehran. The following conclusions were drawn:

- The mean values of the maximum annual rainfall increased with the station elevation.
- Multiple frequency distributions could adequately model the maximum annual rainfall at some stations, as determined by the Kolmogorov-Smirnov test. However, selecting the best-fit distribution was challenging as these distributions yielded varying results in the t-test and F-test comparisons.
- For the Badra station, the Log-Normal (61.663, 0.502) was the best-fit distribution with the SIG value of 0.998. For the Sumar station, three distributions had the same SIG value (0.998), Normal, Log–Normal, and Gamma with the best-fit for Log-Normal (69.008, 0.593) due to the values of the t-test 0.146, 0.024, and 0.093 between a three generated data and the observed one. A similar observation was found for the Kut station, except that the best-fit distribution analysis selected was the Normal distribution (55.746, 30.7323) with SIG a value of 0.879. For the Ilam station, two distributions, Normal and Gamma, had the same SIG value; the last is selected as the best. For the Mehran station, the Normal distribution was the best.
- All the stations showed the behavior of a high return period for the low values between (<20) and for high values (>140). Also, the return period value increased as the station elevation decreased for low rainfall (<20), except for the Sumer station.

ACKNOWLEDGEMENTS

The researchers would like to express their gratitude to Prof. Dr. Basim Sh. Abe head of the Water Resources Department, College of Engineering, University of Baghdad, who encouraged the authors to conduct such research to benefit science and society.

NOMENCLATURE

$F_n(y)$	The empirical cumulative probability of observing values.
$F(y)$	The theoretical cumulative probability of estimated.
Cum	Cumulative probability
FQ	Frequency of occurrence
Greek symbols	
μ	Mean (location parameter)
σ	Standard Deviation (scale parameter)
Subscripts	
a	(shape parameter) and *b* (scale parameter)

REFERENCES

[1] Alam MA, Emura K, Farnham C, Yuan J. **Best-Fit Probability Distributions and Return Periods for Maximum Monthly Rainfall in Bangladesh.** *Climate* 2018; **6**(1):9.

[2] Kumar V, Shanu, Jahangeer. **Statistical Distribution of Rainfall in Uttarakhand, India.** *Applied Water Science* 2017; 7:4765-4776.

[3] Mamoon A, Rahman A. **Selection of the Best Fit Probability Distribution in Rainfall Frequency Analysis for Qatar.** *Natural Hazards* 2017; **86**:281-296.

[4] Arora K, Singh VP. **A Comparative Evaluation of the Estimators of the Log Pearson Type (LP) 3 Distribution.** *Journal of Hydrology* 1989; **105**(1-2):19-37.

[5] Yahya AM, Al-Zakar SH, Al-Mohseen KA. **Disaggregation Model of Tigris River Inflow into a Proposed Makhol Reservoir Using Parametric Approach.** *Tikrit Journal of Engineering Sciences* 2024; **31**(1):172-181.

[6] Oleiwi AS, Abed BS, Hasan BF. **Rainfall Prediction and Runoff Modelling under Climate Change Scenarios for Tigris River from Mosul to Baghdad Cities.** *International Journal of Design & Nature and Ecodynamics* 2023; **18**(3):537-546.

[7] Mohammed DR, Mohammed RK. **Climate Change's Impacts on Drought in Upper Zab Basin, Iraq: A**

Case Study. *Tikrit Journal of Engineering Sciences* 2024; **31**(1):161-171.

[8] Hasan BF, Abed BS. **Assessment of Climate Change Impact on Water Productivity and Yield of Wheat Cultivated Using Developed Seasonal Schedule Irrigation in Euphrates Basin.** *AIP Conference Proceedings* 2024.

[9] Farhan AA-R, Ismail AH, Abed BS. **Applying Box-Behnken Design with Statistical Optimization for Removal Vat Orange Dye from Aqueous Solution Using Kaolin.** *Journal of Engineering Science and Technology* 2021; **16**:1588-1600.

[10] Alzamily ZN, Abed BS. **Experimental and Theoretical Investigations of Seepage Reduction through Zoned Earth Dam Material with Special Core.** *Materials Today: Proceedings* 2022; **61**:998-1005.

[11] Al-Rikab WJ, Abed BS. **Hydraulic Behaviour and Improving of Water Quality of the Chibayish Marshes.** *Materials Today: Proceedings* 2022; **60**:1459-1467.

[12] Suhaili RHSA, Nasser NO. **Water Quality Indices for Tigris River in Baghdad City.** *Journal of Engineering* 2008; **14**(3):2656-2668.

[13] Mustafa AS, Sulaiman SO, Hussein OM. **Application of SWAT Model for Sediment Loads from Valleys Transmitted to Haditha Reservoir.** *Journal of Engineering* 2016; **22**(1):184-197.

[14] Azzubaidi RZ. **Current and Modified Flood Discharge Capacity of a Reach of Tigris River between Kut and Amarah Barrages.** *Journal of Engineering* 2020; **26**(2):129-143.

[15] Al-Zaidy HSA, Al-Thamiry HAK. **Prediction Capacity of Euphrates River at Assamawa City.** *Journal of Engineering* 2020; **26**(4):111-122.

[16] Mazen H, Mohammed TA. **Tools for Drought Identification and Assessment: A Review.** *Journal of Engineering* 2023; **29**(10):90-105.

[17] Al-Suhili RH. **Frequency Analysis of Some of Water Quality Parameters of Shatt Al-Hilla River, Iraq.** *American Journal of Engineering Research* 2018; **7**(7):190-199.

[18] Sherif M, Almulla M, Shetty A, Chowdhury RK. **Analysis of Rainfall, PMP and Drought in the United Arab Emirates.** *International Journal of Climatology* 2014; **34**(4):1318-1328.

[19] Sharma MA, Singh JB. **Use of Probability Distribution in Rainfall Analysis.** *New York Science Journal* 2010; **3**(9):40-49.

[20] Bhargava P, Pradhan A, Das M. **Influence of Rainfall on Crop Production.** *JNKVV Research Journal* 1974; **8**(1):22-29.

[21] RamaRao B, Kavi P, Sridharan P. **Study of Rainy Days and Wet Spells at Bijapur.** *Annual Arid Zone Journal* 1975; **14**(4):371-372.

[22] Khudri MM, Sadia F. **Determination of the Best Fit Probability Distribution for Annual Extreme Precipitation in Bangladesh.** *European Journal of Scientific Research* 2013; **103**(3):391-404.

[23] Mandal S, Choudhury B. **Estimation and Prediction of Maximum Daily Rainfall at Sagar Island Using Best Fit Probability Models.** *Theoretical and Applied Climatology* 2015; **121**:87-97.

[24] Anil K. **Prediction of Annual Maximum Daily Rainfall of Ranichauri (Tehri Garhwal) Based on Probability Analysis.** *Indian Journal of Soil Conservation* 2000; **28**(2):178-180.

[25] Amin M, Rizwan M, Alazba A. **A Best-Fit Probability Distribution for the Estimation of Rainfall in Northern Regions of Pakistan.** *Open Life Sciences* 2016; **11**(1):432-440.

[26] Bhakar S, Iqbal M, Devanda M, Chhajed N. **Probability Analysis of Rainfall at Kota.** *Indian Journal of Agricultural Research* 2008; **42**(3):201-206.

[27] Lee C. **Application of Rainfall Frequency Analysis on Studying Rainfall Distribution Characteristics of Chia-Nan Plain Area in Southern Taiwan.** *Environmental Science and Geography Journal* 2005; **2**(1):31-38.

[28] Ogunlela A. **Stochastic Analysis of Rainfall Events in Ilorin, Nigeria.** *Journal of Agricultural Research and Development* 2001; **1**(1):39-50.

[29] Xeflide S, Kwaku, Duke O. **Characterization and Frequency Analysis of One Day Annual Maximum and Two to Five Consecutive Days Maximum Rainfall of Accra, Ghana.** *Journal of Engineering and Applied Sciences* 2007; **2**(5):27-31.

[30] Olofintoye O, Sule B, Salami A. **Best-Fit Probability Distribution Model for Peak Daily Rainfall of Selected Cities in Nigeria.** *New York Science Journal* 2009; **2**(3):1-12.

[31] Şen Z, Eljadid AG. **Rainfall Distribution Function for Libya and**

Rainfall Prediction. *Hydrological Sciences Journal* 1999; **44**(5):665-680.

[32] Al-Mansory H. **Statistical Analysis of Extreme Monthly Rainfall in Basrah City, South of Iraq.** *Mesopotamian Journal of Marine Science* 2005; **20**(2).

[33] Al-Suhili RH, Khanbilvardi R. **Frequency Analysis of the Monthly Rainfall Data at Sulaimania Region, Iraq.** *American Journal of Engineering Research* 2014; **3**(5):212-222.

[34] Alghazali N, Alawadi D. **Fitting Statistical Distributions of Monthly Rainfall for Some Iraqi Stations.** *Civil and Environmental Research Journal* 2014; **6**(6):40-46.

[35] Ali S, Abed BS, Rashid M. **Generation of IDF Equation Case Study Al-Shuwaija Watersheds (IRAQ-IRAN).** *Wasit Journal of Engineering Sciences* 2023; **11**(3):14-26.