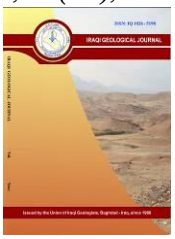
Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



Testing the Optimal Distribution of Rainfall Using Hyfran-Plus Software and Deriving Rainfall Intensity Duration Frequency (IDF) Curves for Al-Adhaim Basin, Iraq

Sahar M. Resen[1*], Abdulhussain A. Abbas[1], and Zuhal A. Hamza[1]

[1] Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq

* **Correspondence:** pgs.sahar.mundher@uobasrah.edu.iq

Received:
14 November 2025
Accepted:
16 February 2026
Published:
30 April 2026

Abstract

One of the most advanced ways to address the risk posed by natural hazards is to analyse rainfall events in each catchment accurately. This enables experts to make informed decisions and ensure compliance with safety standards and optimal hydraulic design. Examining rainfall events in the Al-Adhaim Basin in Iraq is particularly important in this respect. By performing a frequency analysis and selecting the most suitable distribution, one can obtain likely storm hyetographs and intensity curves, and observe the harmonic behaviour of rainfall patterns. Herein, eleven theoretical probability distributions, functions, including exponential, General Extreme Value, Gumbel, Weibull, normal, log normal (3 parameters), gamma, inverse gamma, generalised gamma, and Pearson Type III were developed to simulate the properties of the observed probability using the Hyfran Plus program. The best probability distribution was selected using the Akaike information criterion and the Bayesian Information Criterion. Among the evaluated probability distributions, the Gumbel distribution was objectively identified as the most appropriate for maximum-likelihood frequency analysis within the research region. In light of this, the Soil Conservation Service technique type II was used to produce synthetic storms lasting 24 hours to distribute rainfall depth, both cumulative and incremental, in the dry and semiarid region, with return periods of T = 5, 10, 25, 50, and 100 years. Based on these artificial storms, rainfall intensity-duration-frequency curves were produced.

Keywords: Al-Adhaim basin; Hyfran-Plus; Probability distribution functions; Gumbel distribution; return periods; IDF curves

1. Introduction

Regarding climate change impacts, Iraq is among the Middle Eastern countries most affected, characterized by variable conditions across many of its regions (Hassan and Hashim, 2020). Due to a mix of natural and artificial factors, Iraq is the fifth most climate-vulnerable nation (Habeeb, 2022). Planning and sensible management of water resources are necessary to preserve water wealth and make the best use of all the water provided by the hydrological cycle. Water is among the most precious natural resources for nations and a fundamental component of their growth and development. Because it contributes to agriculture, human and industrial use, and groundwater recharge, rainfall is one of the most critical water sources. The design, production, and management of rainwater have attracted significant attention in recent years. Inadequate data on rainfall during sudden storms is the primary issue facing the administration and planning of rainwater projects. Rainfall patterns worldwide have

changed due to climate change induced by human activity, and researchers must examine this phenomenon. Designing hydraulic structures to reduce and manage flood hazards requires careful consideration of intensity, duration, and return periods (Dawood and Mawlood, 2023). Several research studies have determined the optimal rainfall probability distribution in different regions around the world. The primary processes for establishing Intensity-Duration-Frequency (IDF) connections involve evaluating several likelihood distributions and selecting the best-fitting one to represent rainfall occurrences. Researchers presented many methods for preparing IDF curves, some of which can be used in specific locations and others that require recalibration. For instance, the Corps of Engineers in the United States Department of Agriculture collaborated with the Soil Conservation Service in 1986 to develop four models that divided the US into numerous climate zones. These models (SCS I, SCS IA, SCS II, and SCS III) show the maximum cumulative daily rainfall distributions (rainfall distribution patterns) for the S-Curve, which can be used in places with similar climates worldwide (Chow et al., 1988). Some research employed monthly data, such as Husak et al. (2007), which examined the variance in Africa's monthly precipitation using the Gamma distribution across numerous defined sites. Their study employed the Kolmogorov-Smirnov test to assess the fit quality and then compared the results with those from the Weibull distribution. According to their findings, 98% of rainfall events in the study area are well described by the Gamma distribution. Nevertheless, this study has significant limitations because it considers only the Gamma and Weibull distribution parameters and ignores other formulae. As a result, from 1984 to 2010, Al-Suhili and Khanbilvardi (2014) conducted a meteorological study in Sulaimania, Iraq, to construct the optimal monthly rainfall distribution at three rain gauge locations using a frequency analysis model. For the Yalamlam area in the Saudi Arabian Kingdom, Kawara and Elsebaie (2022) calculated Intensity-Duration-Frequency (IDF) curves. Based on daily rainfall readings over 30 years, the data were analyzed. To determine the expected depth of rainfall, two distribution parameters-Log-Pearson type III and Gumbel were used. According to their findings, there isn't much of a difference between the two models. Mahdi and Mohamedmeki (2020) developed empirical formulae for calculating intensity-duration curves in Baghdad, Iraq, by examining three frequency distributions: the lognormal, Gumbel, and log-Pearson Type III. They discovered that the three models were reasonably close to one another at a 10% significance level. The traditional method employed by Kareem et al. (2022) to derive the IDF curve in Erbil city was the Indian Meteorological Department (IMD) rainfall distribution method, using the Gumbel and LPT III (Log Pearson type III) distributions. They observed that the outcomes of the Gumbel and LPT III procedures did not differ significantly. Al-Awadi et al. (2023) analyzed extreme daily rainfall in Karbala City using frequency analysis to assess its future recurrence. Several theoretical probability distributions were evaluated, and the exponential distribution performed best. Based on these results, the Soil Conservation Service Type II method was applied to generate 24-hour synthetic storms for various return periods in arid and semi-arid regions, and frequency curves for rainfall intensity and duration were created. Dawood and Mawlood (2023) focused on constructing the IDF curve for the highest daily rainfall in Erbil, Iraq. They discovered that the SCS Type II distribution for 24-hour rainfall was most suited for dry and semi-arid locations. They statistically examined the data using six different distributions using the Hyfran Plus program. The reliability tests indicated that the optimal distribution for the data was the inverse gamma distribution. The objective of this study is to introduce an integrated and innovative rainfall frequency analysis framework for the Al-Adhaim River Basin by systematically comparing a wide range of probability distribution models and identifying the optimal model for extreme rainfall estimation. Unlike previous studies that relied on a limited number of distributions, this research evaluates eleven probability distributions using long-term rainfall records (1981–2022) through Hyfran Plus software. The selected optimal distribution is then employed to develop reliable Intensity–Duration–Frequency (IDF) curves based on the SCS Type II 24-hour rainfall distribution method for multiple return periods (5, 10, 25, 50,

and 100 years). This approach improves the reliability of extreme rainfall characterization and provides a more robust understanding of storm hyetograph behavior in a hydrologically important river basin

2. Area of Study and Collection

2.1. Area of Study

The area of study is located in northeastern Iraq, near the Iranian border, between latitudes 34º 00' 00" to 35º 42' 00" N and longitudes 43° 40' 00" to 45º 30' 00"E. The basin covers approximately 12,561 km², as shown in Fig. 1.

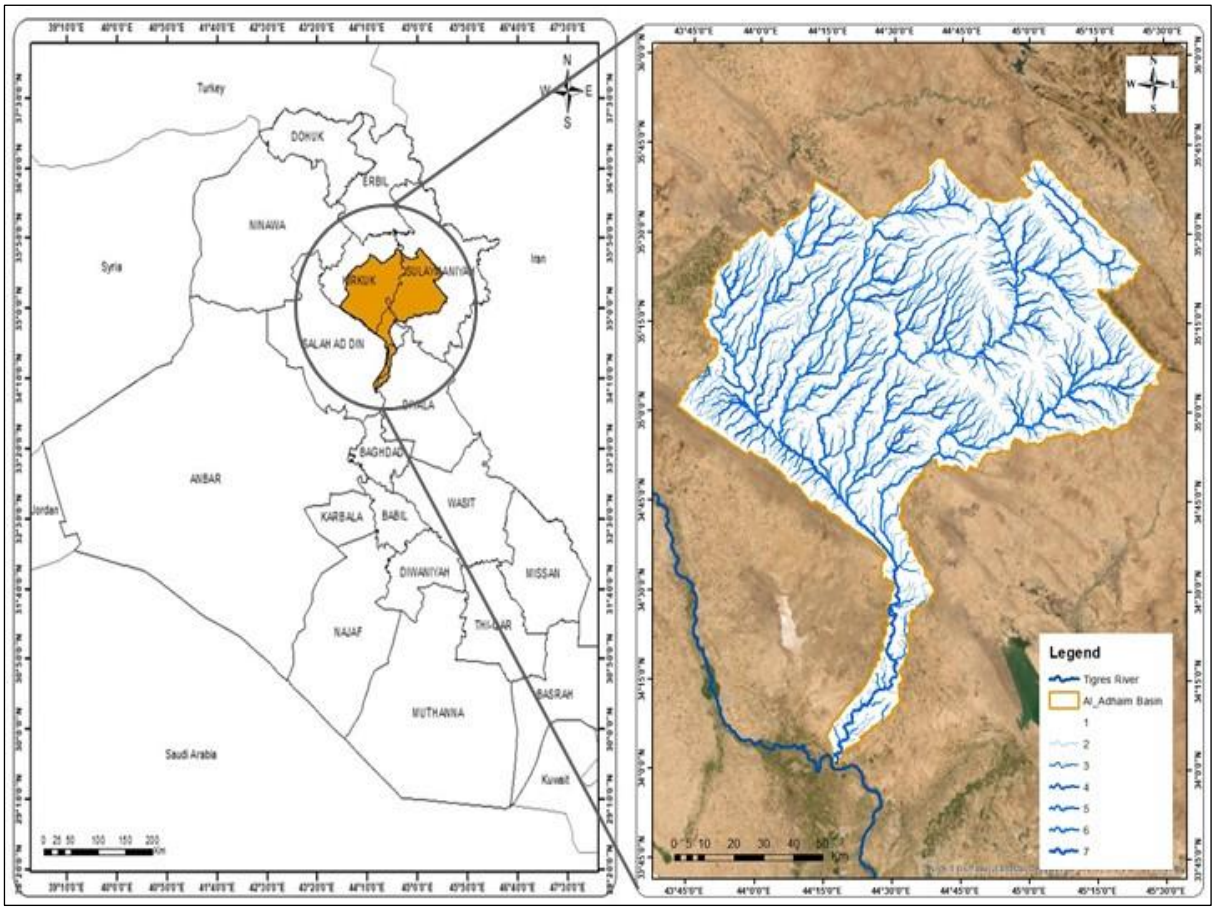


Fig.1. The study area's location

It lies all through the Iraqi boundaries. It runs from the Lower Zab basin in the north to the Diyala River in the south, Shwan Secrema-Dagh in the east, and the Himreen Mountains in the west. Al-Adhaim Dam was built on the Al-Adhaim River in 2000. It is located around 134 km northeast of Baghdad and 65 km southeast of Kirkuk. This dam's drainage basin is located in Iraq, specifically in the Governorates of Salahaddin, Diyala, Sulaymaniyah, and Kirkuk (Mhaina, 2017). In reality, basin features are governing parameters that affect surface runoff both directly and indirectly. These characteristics provide a sufficient description of the catchment area in terms of rainfall and other variables, such as drainage density and form. This paper supports this endeavour by providing future rainfall event predictions for the area, which are essential components of various hydrological studies. These predictions provide crucial information regarding water management and may alert to flash flood risks that could endanger human life or impede economic activity. The study's conclusions will be beneficial to the decision-makers and project planners working on these projects. For this reason, the Al-Adhaim river basin was designated as the primary focus of the analysis.

2.2. Rainfall Data

To ensure the efficient management of water resources, agricultural activities, and disaster mitigation, accurate precipitation forecasts are essential. In much of Iraq, the rainy season runs from October to April. The average rainfall increases from southwest to northeast due to topographical effects (Hamdan et al., 2021). The Province of Kirkuk's main freshwater supply is the Al-Adhaim River. The river is around 330 kilometres long. About 15 km south of the Balad district, the river joins the Tigris River. Every year, from November to May, there are floods, mainly fuelled by rainfall. Note that it did not rain throughout June, July, August, and September, whilst the temperature ranged from 2 to 48 °C. Al-Adhaim may be categorised as an arid catchment because woodlands cover 71% of its surface, while agricultural land accounts for 29% (Hamdan et al., 2021). The Al-Adhaim flow system falls within the category of irregular flow systems that rely heavily on precipitation (Abdulla and Al-Badranih, 2000). The study employed data from the NASA Prediction of Worldwide Energy Resources website (https://power.larc.nasa.gov/data-access-viewer/) covering the period from 1981 to 2022, and focused on three meteorological stations based on their geographical coordinates. Fig. 2 indicates that annual rainfall in the upper basin (upstream region) ranged from 31.63 to 485.16 mm, progressively declining toward the river mouth, with a range of 26.35 to 442.97 mm. Increased rainfall leads to rising water levels and increased flow velocities in the river basin.

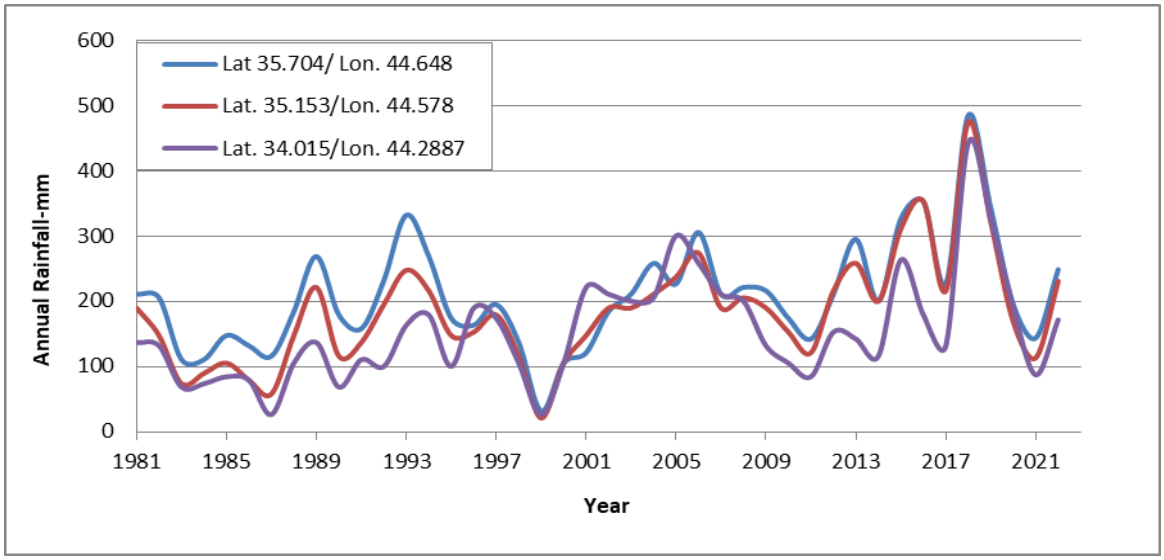


Fig. 2. Annual rainfall at three study region stations (1981–2022, NASA data)

3. Methodology

3.1. Hyfran-Plus Software

Originally developed by a team of researchers from INRS University in Canada, HYFRAN-PLUS is a commercial standalone software product that was first intended for hydrological frequency analysis but is now marketed more widely as software for fitting a variety of distributions with variable tail weights to iid data using a wide range of estimating techniques, initially intended for hydrological analysis of frequency. HYFRAN-PLUS incorporates what they term a Decision Support System (DSS), which provides diagnostics in graphical format, allowing the user to compare various models. The primary benefit of HYFRAN-PLUS is the availability of a simple interface to utilize for individuals with limited computing skills (Gilleland et al., 2013). The research area's (Al Adhaim basin) yearly maximum daily rainfall data were identified, and statistical distributions were fitted using hydrological frequency analysis (HYFRAN-PLUS MODEL). It shows how crucial long-term rainfall data analysis is

for managing water resources, gathering and characterising rainfall data, and calculating rainfall-depth values (XT) for various return periods (T).

3.1.1. Probability distribution and the application of numerical instruments

The most effective way to perform frequency analysis is the maximum likelihood approach, which may yield the best parameter estimates with the least mean-squared error across a variety of scientific disciplines (Miura, 2011). Thus, the maximum likelihood technique has been employed to estimate the parameters for the eleven distributions. Eleven distinct probability distribution methodologies have been used to establish relationships between recurrence periods (T = 5, 10, 25, 50, and 100 years) and rainfall depth events. These distribution methods are Exponential, Gamma, Inverse Gamma, Generalized Gamma, Gumbel, Weibull, Normal, Log Normal, Log Normal (3 parameter), and Pearson Type III. These techniques rank among the most often applied distributions for modelling and estimating severe events in any hydrological system. The hydrological frequency analysis using HYFRAN software version 1.2 was utilised in this work to derive statistical distributions for estimating rainfall probability

3.1.2. Analyze distributions using numerical criteria

The results were evaluated by choosing a suitable distribution using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) criteria. These criteria are based on the empirical probability discrepancy (Dawood et al., 2021). The fitted distribution is calculated using Eqs. 1 and 2 as follows:

$$\mathrm{AIC} = -2\log^{f0}(\mathrm{L}) + 2\,\mathrm{k}, \quad (1)$$

$$\mathrm{BIC} = -2\log(\mathrm{L}) + 2\,\mathrm{k}\log(\mathrm{n}), \quad (2)$$

Where n is the sample size, k is the number of parameters, and L is the likelihood.

The distribution with the lowest BIC and AIC is the one that best fits the data. The comparison's findings showed that the Gumbel distribution is the best fitting in the study area.

3.1.3. Graph observation on probability paper

Plotting observations on a probability paper was done using an empirical probability formula. The following (Eq.3) is the formula's format (Rahman et al., 2023):

$$F[x(k)] = (k - a)/(n - 2a + 1), \quad (3)$$

The empirical probability formula, the most commonly used in practice, matches specific instances. More specifically, the formula was:

- Weibull formula for a=0 F[x(k)]=k/(n+1)
- Chegodayev formula for a=0.3 F[x(k)]=(k-0.3)/(n+0.4)
- Cunnane formula for a=0.4 F[x(k)]=(k-0.4)/(n+0.2)
- Hazen formula for a=0.5 F[x(k)]=(k-0.5)/n

Where: k is the rank and n is the number of observations. The Hazen formula was appropriate for use in the current study.

3.2. Estimating Rainfall Using a Short Duration for the IDF Curve

The United States Department of Agriculture in 1986 (Dullo et al., 2017) classified the intensity of rainfall during a 24-hour storm into four categories based on the geographic regions of the storm. The SCS II type is employed in both semi-arid and arid areas and is used in this study.

For Short-Duration Sub-Daily Derivation precipitation Bell ratio data, according to the SCS II type, were utilized (Awadallah and Younan, 2012; Chow et al., 1988), as shown in Table 1. The short-duration rainfall depth is obtained at (5, 10, 20, 30, 60, 120, 180, 360, 720, 1440) minutes by multiplying the

rainfall depths of the chosen best statistical distribution by the Bell ratio. Afterwards, they were used to create rainfall intensity-frequency curves. The IDF curves (intensity-duration-frequency) are determined for return periods by multiplying each short-duration rainfall depth by the one-hour duration factor (Chow et al., 1988).

Table 1. Bell Ratios for a 24-hour period

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

4. Results and Discussion

4.1. Rainfall Data Statistics

The sample statistics are displayed in the Hyfran-Plus program's basic statistics window. The sample size (n), the skewness coefficient (Cs, which quantifies the degree and direction of asymmetry of the data distribution), the kurtosis coefficient (Ck), the average (Ave), the standard deviation (SD), the variation coefficient (Cv), and the minimum and maximum values (Min and Max) are among these statistics. The software automatically calculates the average of three stations' yearly rainfall data (1981–2022) for the study region as soon as the data are loaded into the spreadsheet, as shown in Table 2. Additionally, the histogram of observation data and the non-exceedance probability are displayed in Figs. 3 and 4. The Hazen formula is used to compute the empirical distribution of the non-exceedance probability for (a=0.5).

Table 2. Statistical values for the study area's annual rainfall data

n	Min.	Max.	Ave.	SD	Med.	Cv	Cs	Ck
43	21.1	475	184	84.4	190	0.459	1.02	4.79

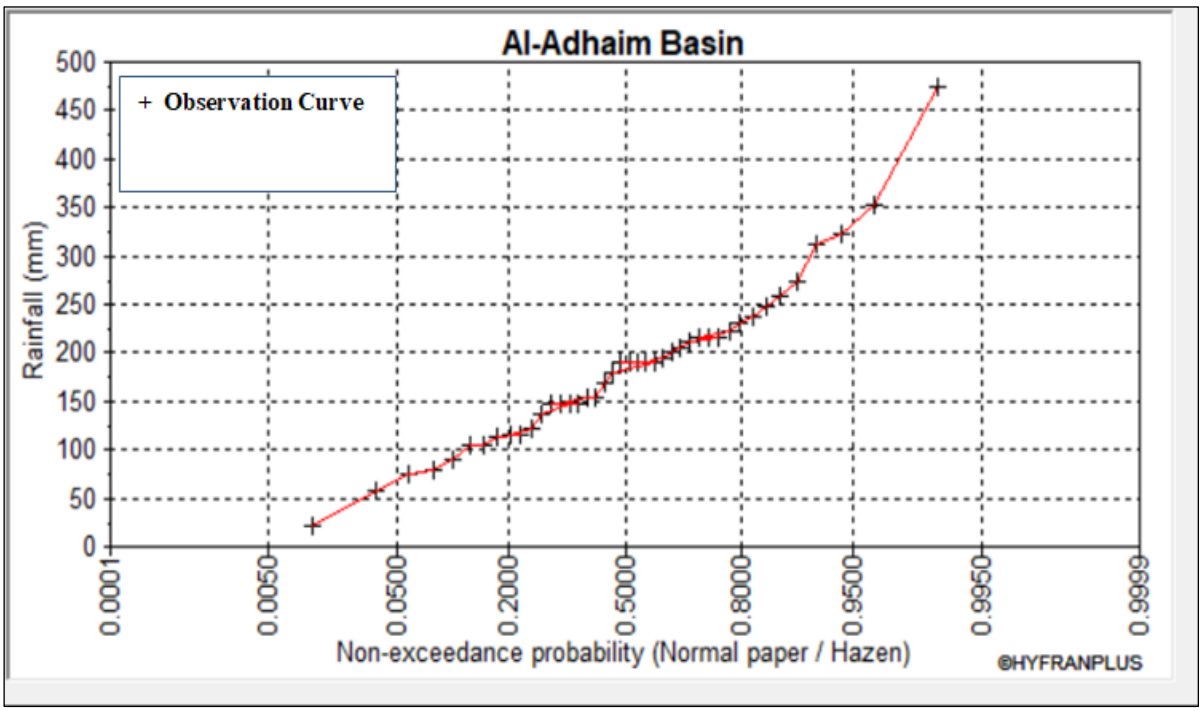


Fig. 3. Observation of the dataset on probability paper

The results suggest that the most common rainfall frequencies varied from 186 to 248 mm.

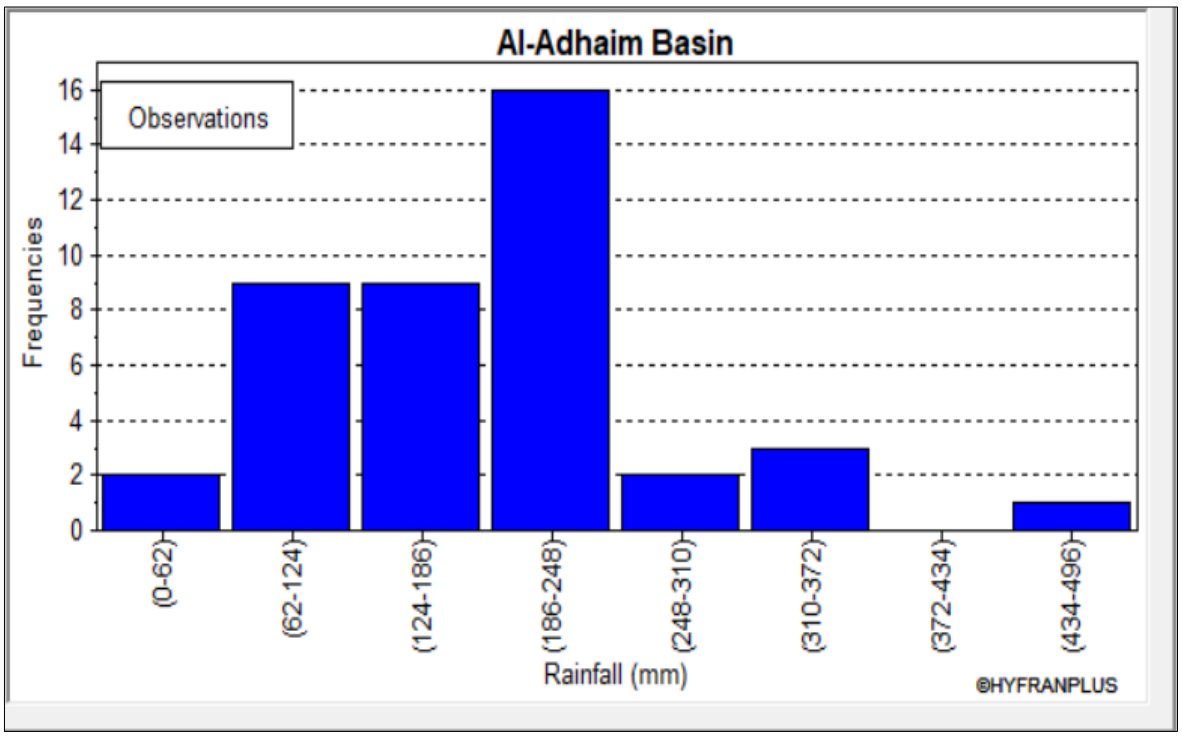


Fig. 4. Frequency histogram of the observed data

4.2. Determining the Depth of Rainfall Using Various Probability Distributions

Probability analyses of severe rainfall in this study are described by 11 distributions: GEV, Exponential, Gumbel, Weibull, Normal, Lognormal, Lognormal (3 parameters), Gamma, Inverse Gamma, Generalized Gamma, and Pearson Type III. In this case, the default 95% confidence interval was used. The theoretical distribution parameters in Table 3 are calculated using the maximum-likelihood method in Hyfran-Plus.

Table 3. Statistical Values of Probability Distribution Function Parameters by HYFRAN-PLUS

Distribution methods	Estimated parameters
Exponential	$\alpha =$ 166.733, $m =$ 17.1202
GEV	$\alpha =$ 70.7768, $k =$ 0.0715461, $u =$ 148.278
Gumbel	$\alpha =$ 71.2782, $u =$ 144.955
Weibull	$\alpha =$ 207.202, $c =$ 2.2995
Normal	$\mu =$ 183.853, $\sigma =$ 84.3839
Log normal	$\mu =$ 5.09658, $\sigma =$ 0.537848
Log normal (3 param.)	$m =$ -166.857, $\sigma =$ 0.231211, $\mu =$ 5.83307
Gamma	$\alpha =$ 0.0240078, $\lambda =$ 4.4139
Generalized Gamma	$\alpha =$ 0.00737515, $\lambda =$ 1.83255, $S =$ 1.65137
Inverse Gamma	$\alpha =$ 381.785, $\lambda =$ 2.81823
Pearson Type III	$\alpha =$ 0.0381129, $\lambda =$ 9.76698, $m =$ -72.4115

The rainfall data were analyzed and interpreted using the Hyfran-Plus program to determine the optimal distribution function. The program allows one to create probability charts for a set of probability distributions: GEV, Exponential, Gumbel, Weibull, Normal, Lognormal, Log Normal (3 parameters), Gamma, Inverse Gamma, Generalized Gamma, and Pearson TypeIII as presented in Fig. 5. For each of the five return periods, Table 4 displays the data forecast produced by the statistical distribution.

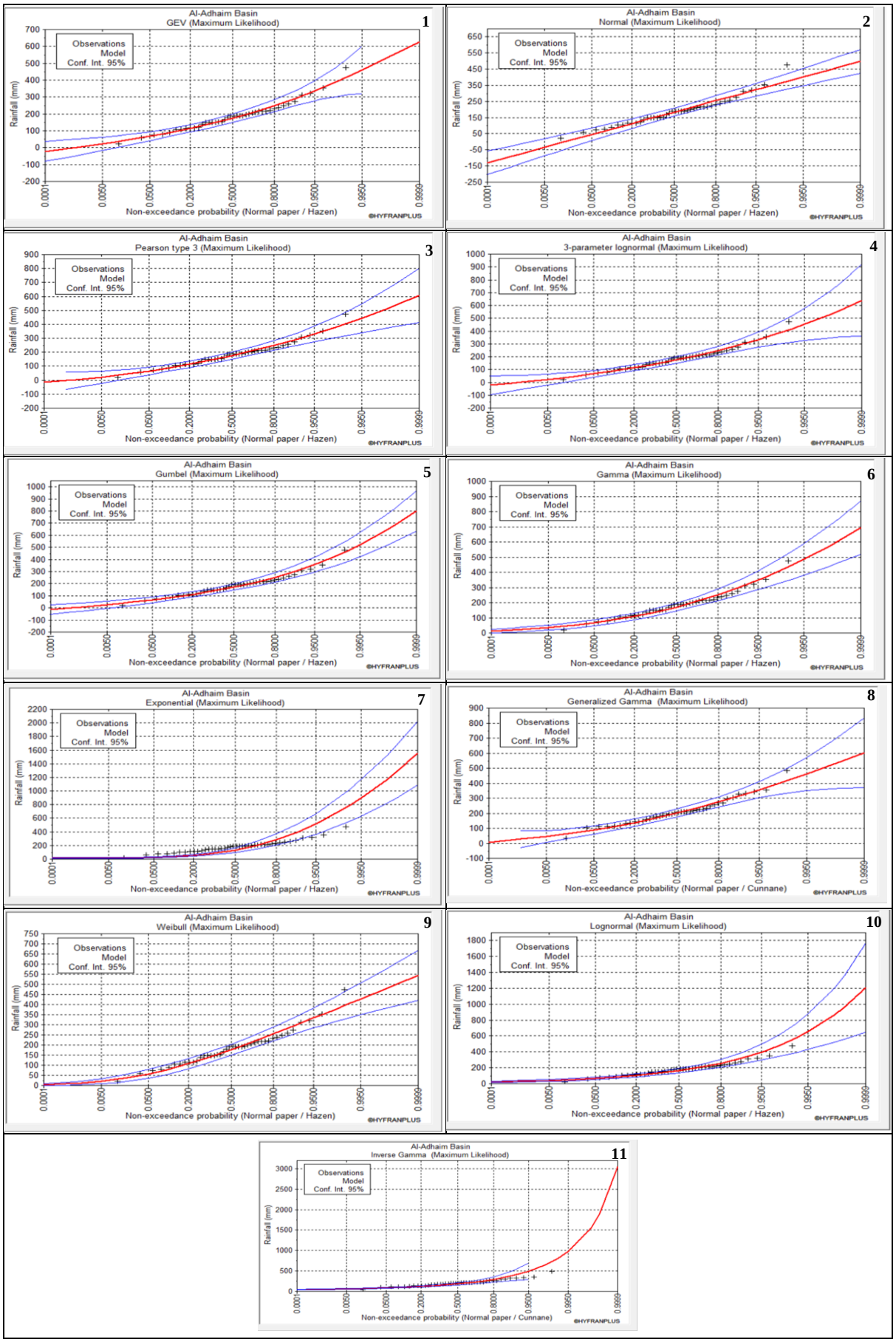


Fig. 5. Probability graphs for the eleven selected distributions

Table 4. Rainfall depth using statistical forecast across five return intervals

Distribution methods	Return periods (years)				
	5	**10**	**25**	**50**	**100**
Exponential	285	401	554	669	785
GEV	249	295	351	389	426
Gumbel	252	305	373	423	473
Weibull	255	298	344	375	403
Normal	255	292	332	357	380
Log normal	257	326	419	493	571
Log normal (3 param.)	248	292	345	382	418
Gamma	251	301	362	404	446
Generalized Gamma	251	296	348	382	414
Inverse Gamma	272	384	575	766	1010
Pearson Type III	249	293	344	379	412

4.3. Testing the Best Probability Distribution Based on AIC and BIC

The most widely used techniques for selecting the best models from the examined distributions are AIC and BIC. These techniques determine which distributional class provides the most accurate assessment of the subject event. The disparity between the empirical probability and the fitted distribution, with a penalty that depends on the distribution's number of parameters, underlies both criteria. When the BIC and AIC values were computed, the Gumbel distribution had the lowest values among all distributions studied, as shown in Tables 5 and 6 for return periods of 5,100 years, respectively.

Table 5. HYFRAN-PLUS Outputs for Comparing Probability Distributions (5-Year Return Period)

Model	**Nb param.**	**XT**	**P(Mi)**	**P(Mi | x)**	**BIC**	**AIC**
Gumbel (Maximum Likelihood)	2	251.86	9.09	33.16	494.32	490.84
Weibull (Maximum Likelihood)	2	254.84	9.09	18.94	495.44	491.96
Gamma (Maximum Likelihood)	2	250.63	9.09	17.61	495.58	492.11
3-parameter lognormal (Maximum Likelihood)	3	247.87	9.09	7.22	497.37	492.15
GEV (Maximum Likelihood)	3	248.94	9.09	6.98	497.44	492.22
Pearson type 3 (Maximum Likelihood)	3	249.12	9.09	6.35	497.62	492.41
Normal (Maximum Likelihood)	2	254.86	9.09	4.68	498.24	494.76
Generalized Gamma (Maximum Likelihood)	3	251.37	9.09	4.22	498.44	493.23
Lognormal (Maximum Likelihood)	2	257.02	9.09	0.84	501.68	498.21
Inverse Gamma (Maximum Likelihood)	2	272.46	9.09	0.00	516.20	512.73
Exponential (Maximum Likelihood)	2	285.46	9.09	0.00	521.25	517.77

Table 6. HYFRAN-PLUS Outputs for Comparing Probability Distributions (100-Year Return Period)

Model	**Nb param.**	**XT**	**P(Mi)**	**P(Mi | x)**	**BIC**	**AIC**
Gumbel (Maximum Likelihood)	2	472.84	9.09	33.16	494.32	490.84
Weibull (Maximum Likelihood)	2	402.55	9.09	18.94	495.44	491.96
Gamma (Maximum Likelihood)	2	445.63	9.09	17.61	495.58	492.11
3-parameter lognormal (Maximum Likelihood)	3	417.81	9.09	7.22	497.37	492.15
GEV (Maximum Likelihood)	3	425.71	9.09	6.98	497.44	492.22
Pearson type 3 (Maximum Likelihood)	3	412.04	9.09	6.35	497.62	492.41
Normal (Maximum Likelihood)	2	380.19	9.09	4.68	498.24	494.76
Generalized Gamma (Maximum Likelihood)	3	414.21	9.09	4.22	498.44	493.23
Lognormal (Maximum Likelihood)	2	571.37	9.09	0.84	501.68	498.21
Inverse Gamma (Maximum Likelihood)	2	1014.38	9.09	0.00	516.20	512.73
Exponential (Maximum Likelihood)	2	784.95	9.09	0.00	521.25	517.77

Where XT: Rainfall depth, P(Mi): A priori probability, P(Mi | x): A posteriori probability (Method of Schwartz), BIC: Bayesian information criterion, and AIC: Akaike information criterion.

The results of the frequency analysis of the Gumbel distribution that was fitted to the annual rainfall data collected by NASA are shown in Table 7.

Table 7. The Gumbel Distribution's frequency analysis results

T	Q	X_T	σ_{X_T}	Confidence interval
100	0.99	473	45.1	385 - 561
50	0.98	423	39.2	346 - 500
25	0.96	373	33.3	308 - 438
10	0.90	305	25.6	255 - 356
5	0.80	252	19.9	213 - 291

Where, (T) is the return period, this is computed as T=1/p, p is the probability of exceeding the rainfall depth (XT), the probbility of non-exceedance (q=1/p), (σ_{X_T}) is the quantile standard deviation and the default confidence level of 95% for the confidence interval.

The extreme annual rainfall (Gumbel distribution) is shown in Fig. 6, together with the theoretical probability (red line), the confidence interval (blue line), and the sample data (+).

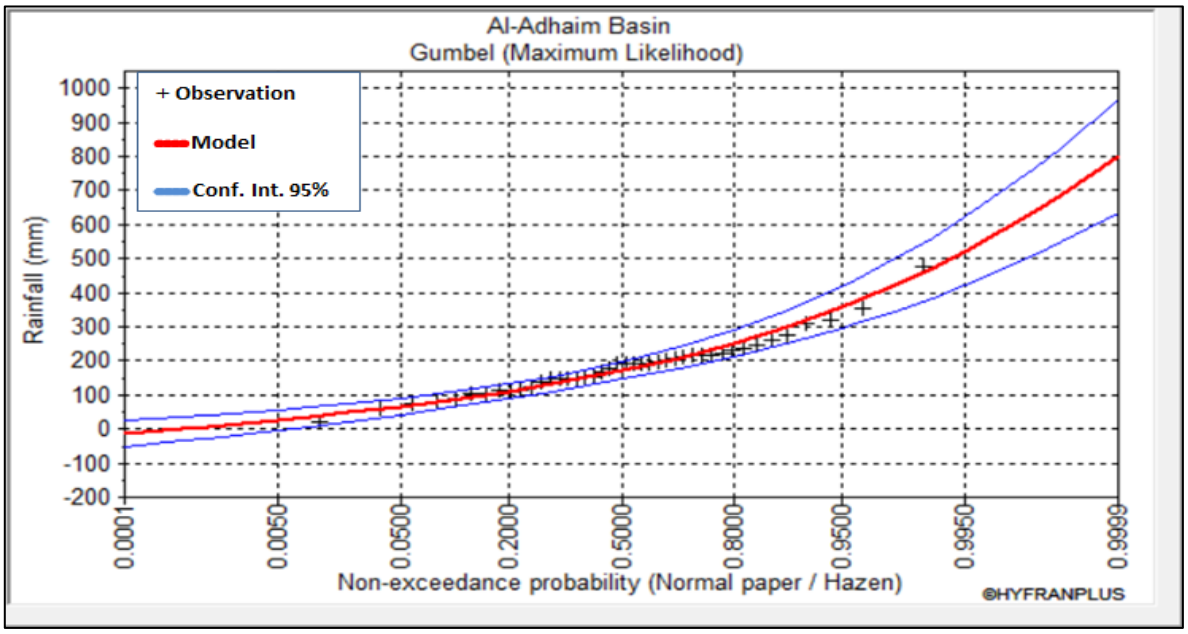


Fig. 6. Gumbel distribution graph (maximum likelihood)

4.4. Development of (IDF) Curves for the Al-Adhaim River Basin

To develop and manage hydraulic systems in the US and other regions by transforming data on actual rainfall into data with shorter durations. Rainfall depths for return periods with short durations (between five minutes and twenty-four hours) in this experiment using the SCS type II temporal rainfall distribution of (5, 10, 25, 50, and 100) years, as shown in Table 8. To obtain the findings, multiply the Gumbel distribution's rainfall depths by the Bell ratio. The data from Table 7 are used to generate IDF curves for the research region by multiplying each rainfall depth by a factor of 1 hour, as shown in Fig. 7, where the rainfall intensity is exactly proportional to return periods and inversely proportional to duration. The maximum rainfall intensity in mm/hr at 5 min can be specified as 393.12, 475.8, 581.88, 659.88, and 737.88 for T = 5, 10, 25, 50, and 100, respectively. It is apparent that over the 24-hour period, rainfall intensity increased with increasing return period.

Table 8. Rainfall depth during a short duration

D(min) / RP (yr)	5	10	20	30	60	120	180	360	720	1440
5	32.76	50.40	70.56	85.68	110.88	143.64	158.76	189	221.76	252
10	39.65	61	85.4	103.7	134.2	173.85	192.15	228.75	268.4	305
25	48.49	74.6	104.44	126.82	164.12	212.61	234.99	279.75	328.24	373
50	54.99	84.6	118.44	143.82	186.12	241.11	266.49	317.25	372.24	423
100	61.49	94.6	132.44	160.82	208.12	269.61	297.99	354.75	416.24	473

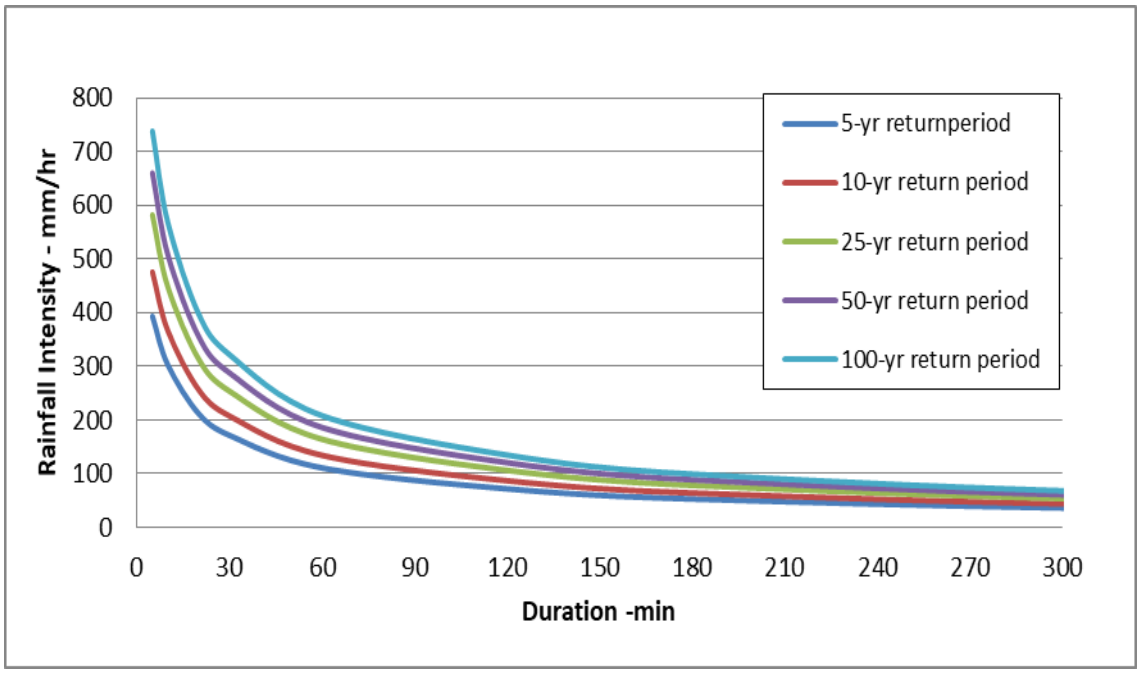


Fig. 7. Intensity duration frequency curves for the Al-Adhaim basin

5. Conclusions

This study analysed rainfall frequency in the Al-Adhaim basin for the period 1981–2022 using 11 probability distributions in the HYFRAN-Plus program to generate incremental and cumulative synthetic storms over 24 hours. The study's findings led to the following conclusions being made:

- Rainfall data may be statistically analysed to identify the highest rainfall values for a given time, accounting for various return durations and statistical distributions.
- Based on the evaluation of eleven theoretical probability distributions, the Gumbel distribution demonstrated the best fit to the observed rainfall data, as indicated by the lowest values of the AIC and BIC criteria, reflecting the most accurate representation of extreme rainfall behaviour in the study area.
- To analyse and compare storm variability across different return periods, the short-duration Bell ratio distribution was applied to determine the design rainfall depth for each return period. The 24-hour synthetic storms, generated for both cumulative and incremental rainfall distributions using the SCS Type II method for arid and semi-arid regions, provide a robust framework for analyzing storm characteristics. Rainfall intensities were calculated at different depths (mm/h), and IDF curves were constructed for return periods of 5, 10, 25, 50, and 100 years.
- The results indicate that rainfall intensity increases with longer return periods but decreases with increasing storm duration. At 5 minutes, the highest intensity was observed for the 100-year return period, reaching 737.88 mm/hr, while the lowest was observed for the 5-year return period, at 393.12 mm/hr.

• Finally, the obtained results provide a robust quantitative basis for hydrological design and can inform more effective flood risk assessment and stormwater management planning in the Al-Adhaim basin.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could influence the work reported in this study.

ORCID

Sahar M. Resen: https://orcid.org/0009-0003-3694-6201

Abdulhussain A. Abbas: https://orcid.org/0000-0003-1759-3984

Zuhal A. Hamza: https://orcid.org/0000-0002-6767-3205

References

Abdulla, F., Al-Badranih, L., 2000. Application of a rainfall–runoff model to three catchments in Iraq. Hydrological Sciences Journal, 45(1), 13–25. https://doi.org/10.1080/02626660009492303.

Al-Awadi, A.T., Al-Saadi, R.J.M., Mutasher, A.K.A., 2023. Frequency analysis of rainfall events in Karbala city, Iraq, by creating a proposed formula with eight probability distribution theories. Smart Science, 11(3), 639-648. https://doi.org/10.1080/23080477.2023.2220916.

Al-Suhili, R.H., Khanbilvardi, R., 2014. Frequency analysis of the monthly rainfall data at Sulaimania region, Iraq. American Journal of Engineering Research, 3(5), 212–222.

Awadallah, A.G., Younan, N.S., 2012. Conservative design rainfall distribution for application in arid regions with sparse data. Journal of Arid Environments, 79, 66–75. https://doi.org/10.1016/j.jaridenv.2011.11.032.

Chow, V.T., Maidment, D.R., Mays, L.W., 1988. Applied Hydrology. McGraw-Hill Book Company, New York. https://doi.org/10.1126/science.96.2486.184.

Dawood, A.H., Mawlood, D.K., Al-Ansari, N., 2021. Flood modeling on Koya catchment area using Hyfran, Web Map Service, and HEC-RAS software. ARO-The Scientific Journal of Koya University, 9(2), 107-111. https://doi.org/10.14500/aro.10824

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.

Dullo, T.T., Kalyanapu, A.J., Teegavarapu, R.S., 2017. Evaluation of changing characteristics of temporal rainfall distribution within 24-hour duration storms and their influences on peak discharges: case study of Asheville, North Carolina. Journal of Hydrologic Engineering, 22(11), 05017022. https://doi.org/10.1061/(asce)he.1943-5584.0001575.

Gilleland, E., Ribatet, M., Stephenson, A.G., 2013. A software review for extreme value analysis. Extremes, 16(1), 103-119. https://doi.org/10.1007/s10687-012-0155-0.

Habeeb, H.B., 2022. Assessing the contribution of tax revenues to overall economic growth expansion in the Iraqi economy during the course of the years 1990-2020. World Economics and Finance Bulletin, 15, 95-103.

Hamdan, A.N.A., Almuktar, S., Scholz, M., 2021. Rainfall-runoff modeling using the HEC-HMS model for the Al-Adhaim River catchment, northern Iraq. Hydrology, 8(2), 58. https://doi.org/10.3390/hydrology8020058.

Hassan, W.H., Hashim, F.S., 2020. The effect of climate change on the maximum temperature in Southwest Iraq using HadCM3 and CanESM2 modelling. SN Applied Sciences, 2(9), 1494. https://doi.org/10.1007/s42452-020-03302-z.

Husak, G.J., Michaelsen, J., Funk, C., 2007. Use of the gamma distribution to represent monthly rainfall in Africa for drought monitoring applications. International Journal of Climatology: A Journal of the Royal Meteorological Society, 27(7), 935-944. https://doi.org/10.1002/joc.1441.

Kareem, D.A., Amen, A.R.M., Mustafa, A., Yüce, M.I., 2022. Comparative analysis of developed rainfall intensity–duration–frequency curves for Erbil with other Iraqi urban areas. Water, 14(3), 419. https://doi.org/10.3390/w14030419.

Kawara, A.Q., Elsebaie, I.H., 2022. Development of rainfall intensity, duration and frequency relationship on a daily and sub-daily basis (case study: Yalamlam Area, Saudi Arabia). Water, 14(6), 897. https://doi.org/10.3390/w14060897.

Mahdi, E.S., Mohamedmeki, M.Z., 2020. Analysis of rainfall intensity-duration-frequency (IDF) curves of Baghdad city. In IOP Conference Series: Materials Science and Engineering, 888 (1), 012066. https://doi.org/10.1088/1757-899x/888/1/012066.

Mhaina, A.S., 2017. Modeling Suspended Sediment Load Using SWAT Model in Data Scarce Area-Iraq (Al-Adhaim Watershed as a Case Study). MSc thesis, University of Technology, Baghdad.

Miura, K., 2011. An introduction to maximum likelihood estimation and information geometry. Interdisciplinary Information Sciences, 17(3), 155-174. https://doi.org/10.4036/iis.2011.155.

NASA POWER Data. Online Data Access Viewer. Available at: https://power.larc.nasa.gov/data-access-viewer/.

Rahman, N.F.A., Mondelly, Y., Tai, V.C., Mohammad, M., Shariff, M.S.M., Khalid, K., Siew, E.L., 2023. Rainfall data analysis in Kerian River basin using HYFRAN-PLUS model, Malaysia. In Symposium on Intelligent Manufacturing and Mechatronics, Springer Nature, Singapore. https://doi.org/10.1007/978-981-97-0169-8_62.