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Frequency Analysis of Maximum Daily Rainfall for Flood Risk Management in Jazan Province Kingdom of Saudi Arabia: Excel-Based Model

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Abstract. the Kingdom of Saudi Arabia (KSA) is one of the most arid countries in the world, rainfall is almost rare except for the southwestern area of KSA, where the Jazan Province is located. The study aims to analyze rainfall distribution to find out the appropriate distribution for the Jazan Province through annual rainfall data for the Jazan Province to provide a database for hydrological studies and flood risk assessment. The data of 25 rainfall stations were used for periods ranging from 19 to 59 years (1960-2018) for the average annual rainfall and the daily maximum. An Excel sheet has been prepared with the distributions used (log-normal, Pearson type III, log-Pearson type III, GEV, and Gumbel) in the analysis (model). Based on the RMSE criterion, the results showed that the GEV distribution is the best probability distribution for 36% of stations. Followed by distributions log-Pearson III, Gumbel type I, log-normal, and Pearson type III with percentages of 32%, 16%, 12%, and 4% of the total studied stations, respectively. The model showed effectiveness in the analysis, as its results were validated by the Hyfran Plus program, it is recommended to use the model.
Keywords: Rainfall distribution, Probability distributions, RMSE, Jazan Province, KSA.

Introduction

One of the world's hottest and driest arid desert countries is the KSA. With an average of 112 mm of rainfall annually, most of the country is classified as a desert (Shereif., 2014). An estimated 158.47 billion m^3 of precipitation fall on KSA each year (Al-Rashed and Sherif, 2000). The rainfall pattern in KSA is characterized by a not equal distribution over various areas, and its timing and amount are highly variable from year to year (Awni et al, 2012). The rainfall in most of the KSA regions is rare and generally decreases from October until April (Atlas, 1984). Over the other months, there was almost no rainfall except for the southwestern area of KSA (Almazroui, 2011). The southwestern area of KSA is characterized by precipitation events during the whole year because of topographically driven thermal rain (Abdullah and Al-Mazroui, 1998; Al-Mazroui, 1998).

Hydrologists require effective techniques to help them predict impacts related to high precipitation risks, both in gauged and ungauged regions. Estimating the rainfall values associated with different periods of return in years is the initial step in any evaluation process. Based on observed maximum daily precipitation values, precipitation frequency analysis techniques are used to obtain this information. For hydrologists to confidently forecast the expected precipitation at high return periods, finding a regional distribution for the frequency of precipitation within a particular region is seen to be invaluable information. The choice of the optimal distribution to fit the annual extreme rainfall recorded data is a crucial decision in frequency analysis. Because of the significant spatial variability of the rainfall maximum values, hydrologists view this step as difficult and it continues to be a major source of uncertainty in engineering practice. Furthermore, even at the single site scale, numerous probability models were put out to represent the real distribution of maximum yearly records (Rao and Hamed, 2000; World Meteorological Organization (WMO), 2009; Salinas et al, 2014). Even within the same nation, different regional distributions are advised for use in codes of practice. According to Bulletin 17B (Griffis and Stedinger, 2007), the log-Pearson type III was determined to be appropriate for use in the USA, whereas the generalized extreme value distribution (GEV) and log-Pearson type III were selected for Australia (Ball et al, 2016). Most European nations, including Germany, Austria, Spain, Italy, and Austria, chose to use the GEV distribution (Salinas et al, 2014). However, Finland and Spain employed the Gumbel distribution (Salinas et al, 2014). For the Arab region, options are also open. In Dubai in the UAE, the Master Plan of the Sewerage, Drainage, and Irrigation found that Gumbel, 2-parameter Gamma, log-Pearson type III distributions are best suited for a maximum of annual hydrological parameters and the extreme values (Dubai Municipality, 2010), while in Egypt, the Gumbel distribution was found to be most suitable for estimating maximum daily precipitation (Ministry of Housing, Utilities and Urban Development, 2008). In KSA, the Gamma distribution was used for the coastal and mountainous areas within Jeddah (Awadallah, 2015). Other studies found that the Gumbel distribution worked best for sub-daily rainfall records in various KSA cities (Ewea et al, 2017), also, it was the most suitable for Makkah (Ewea et al, 2018). While, based on the RMSE criterion the three-parameter log-normal and the two-parameter log-normal performed best in Madinah (Abdulrazzak et al, 2019). In addition, the study concluded that the best distribution to describe the distribution of daily maximum precipitation in KSA is the log-Pearson type III distribution (Abdeen et al, 2020). According to the information above, it seems that there isn't a recognized regional distribution for maximum rainfall data that can be used in arid areas, even within the same nation (such as in KSA), which may be because of the country's large territory and varied rainfall patterns.

The study aims to analyze rainfall distribution to find out the appropriate distribution for the Jazan Province through annual rainfall data for the Jazan Province, the data of 25 rainfall stations were used for periods of time ranging from 19 to 59 years (1960-2018) for the average annual rainfall and the daily maximum. Since there is a lack of detailed systematic study on rainfall distribution in the literature on flood risk assessment in the Jazan Province, this study is an attempt at a systematic analysis of rainfall distribution in such a region for flood risk assessment and provide a database for hydrological studies.

1. Study Area.

The Jazan Province is located in the southwest of the KSA (Figure 1), between latitude 16°45'N to 17°30'N and longitude 42°15'E to 43°00'E (Saad et al, 2011; Abdalla, 2016). It is the smallest area in KSA. It extends for 300 km along the southern coast of the Red Sea, just north of Yemen. It has an area of 11,671 km^2 (Mahmoud and Alazba, 2014). The Jazan Province can be classified into three areas as follows: (1) is the coastal plain located between the marshes along the coast of the Red Sea and the foothills. (2) the foothills between the coastal plain and the mountain range, with a height ranging from 0 to 300 m above sea level. (3) the Asir Mountains extend east of the coastal plain from north to south along the Red Sea, with a sudden elevation of more than 3000 m. The main basins are located in the Jazan Province. The region is characterized by a hot and humid climate throughout the year, with average annual rainfall ranging from 200 to 500 mm in the coastal plain and 500 to 700 mm in the mountains in the eastern part (Saad et al, 2011). This reflects the effect of the topography. Precipitation occurs during spring and summer; the average evaporation rate is about 2000 mm/year (Abdalla, 2016).

KSA is divided into many hydrological areas, each containing several hydrological network stations (Abo-Monasar and Al-Zahrani, 2014). The total number of precipitation stations across the KSA is about 400. The density of precipitation gauges differs greatly from region to region, but averages about one station per 600 km^2. The precipitation stations were installed based on the accessibility of the site and the amount of precipitation. The number of stations in the southwestern area of KSA is about 50 (Al-Zahrani and Husain, 1998). The data for 25 rainfall stations were used for time periods ranging from 19 to 59 years (1960-2018). Figure 2 shows the locations of the studied rainfall stations (2a) and the mean annual Isohyetal map (2b) in the southwestern part of KSA.

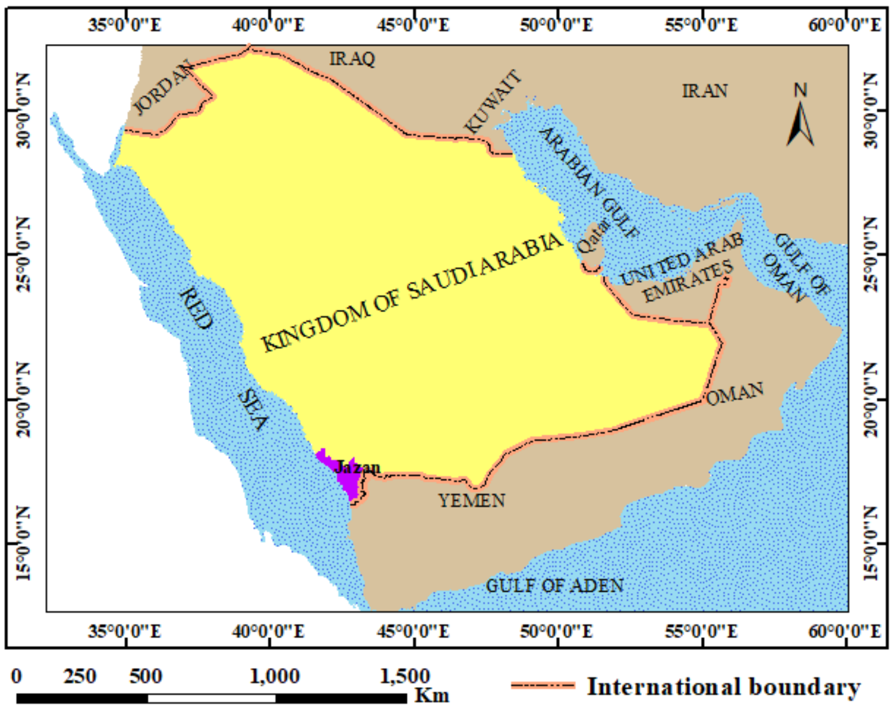

Figure 1. Location map of the Jazan Province.

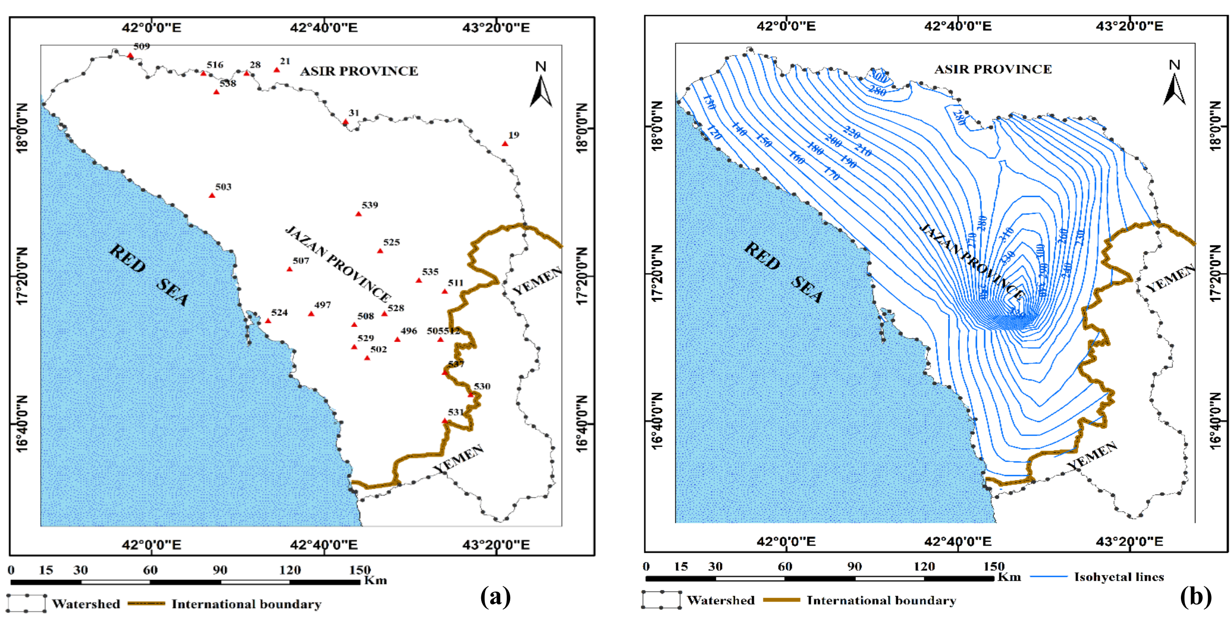

Figure 2. The locations of the studied rainfall stations (a) and the mean annual Isohyetal map (b) in the southwestern part of KSA.

2. Methodology.

The methodological approach can be summarized in the following points:

1. Collecting average annual and maximum daily rainfall data from meteorological stations in the Jazan Province.
2. Frequency analyzes are applied to the maximum daily rainfall (mm),
3. Best fitting of the maximum daily rainfall data using the suitable common probability distribution as given in Table 1. It shows a general summary of common pdf formulas, f(x), and the corresponding frequency factor (K_T) used for predictions.
4. The most suitable probability distributions are chosen based on the root mean square error (RMSE) criterion (Cheng et al, 2017),

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\hat{R}_i - R_i\right)^2}$$

(Ri) is the actual measured rainfall quantity (mm), ($\hat{R}i$) is the predictable rainfall quantity through the best distributions, and (n) represents the number of rainfall events for each station.

5. The time duration of the recorded rainfall data obtained ranges from 19 to 59 years. Several different frequency distributions have been fitted to the maximum daily rainfall for each station to obtain the best distribution. The distribution functions used are log-normal, Pearson type III, log-Pearson type III, GEV, and Gumbel. According to (Chow et al, 1988), the best fit to the distribution function is determined by RMSE.
6. An Excel sheet has been prepared with the distributions used in the analysis. The validity of the model was tested by Hyfran Plus, a well-known program for analyzing rainfall data.

Table 1. The summary of common pdf formulas, f(x), and the corresponding frequency factor (K_T).

Distribution	Probability density function PDF	X_T	K_T
Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2} \quad -\infty < x < \infty$	$X_T = \mu_x + K\,\sigma_x$	$K = t = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3}$ $W = \sqrt{\ln\left(\frac{1}{P(t)^2}\right)}$ $P(t) = 1 - \frac{1}{T}$ $C_0 = 2.5155$, $C_1 = 0.8028$, and $C_2 = 0.0103$ $d_0 = 1.4328$, $d_1 = 0.1893$, and $d_2 = 0.0013$
Log normal	$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{(\ln x - \mu)^2}{2\sigma^2}\right]$ $x > 0$	$X_T = e^{(\mu_y + K\,\sigma_y)}$	
Gumbel	$f(x) = \frac{1}{\alpha} \exp\left[-\left(\frac{x-\beta}{\alpha}\right) - e^{-\left(\frac{x-\beta}{\alpha}\right)}\right]$ $-\infty < x < \infty$	$X_T = \mu_x + K\,\sigma_x$	$K = -\frac{\sqrt{6}}{\pi}\left(0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right)$
Pearson type III	$f(x) = \frac{1}{\alpha\Gamma(\beta)}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x-\gamma}{\alpha}\right)} \quad \gamma < x < \infty$	$X_T = \mu_x + K\,\sigma_x$	$K = t + (t^2-1)\frac{\gamma_x}{6} + \frac{1}{3}(t^3 - 6t)\left(\frac{\gamma_x}{6}\right)^2 - (t^2-1)\left(\frac{\gamma_x}{6}\right)^3 + t\left(\frac{\gamma_x}{6}\right)^4 + \frac{1}{3}\left(\frac{\gamma_x}{6}\right)^5$
Log Pearson type III	$f(x) = \frac{1}{\alpha x\Gamma(\beta)}\left[\frac{\log(x) - \gamma}{\alpha}\right]^{\beta-1} e^{-\left(\frac{\log(x)-\gamma}{\alpha}\right)}$	$X_T = e^{(\mu_y + K\,\sigma_y)}$	$K = t + (t^2-1)\frac{\gamma_y}{6} + \frac{1}{3}(t^3 - 6t)\left(\frac{\gamma_y}{6}\right)^2 - (t^2-1)\left(\frac{\gamma_y}{6}\right)^3 + t\left(\frac{\gamma_y}{6}\right)^4 + \frac{1}{3}\left(\frac{\gamma_y}{6}\right)^5$
GEV	$f(x) = \frac{1}{\alpha}\left[1 - K\left(\frac{x-u}{\alpha}\right)\right]^{1/K-1} e^{-\left[1-K\left(\frac{x-u}{\alpha}\right)\right]^{1/K}}$ $K < 0 \quad C_s > 1.1396 \quad u + \frac{\alpha}{K} < x < \infty$ *Type II* $K > 0 \quad C_s < 1.1396 \quad -\infty < x < u + \frac{\alpha}{K}$ *Type III* $K = 0 \quad C_s = 1.1396$ *Type I*	$X_T = \mu_x + K\,\sigma_x$	$K = A_\alpha + \beta_\alpha\left[\left(-\ln\left(1 - \frac{1}{T}\right)\right)^{\frac{1}{\alpha}} - 1\right]$ $\beta_\alpha = \left[\Gamma\left(1 + \frac{2}{\alpha}\right) - \Gamma^2\left(1 + \frac{1}{\alpha}\right)\right]^{-0.5}$ $A_\alpha = \left[1 - \Gamma\left(1 + \frac{1}{\alpha}\right)\right] * \beta_\alpha$
Two-Parameter Gamma	$f(x) = \frac{1}{\alpha^\beta\Gamma(\beta)} x^{\beta-1} e^{-\left(\frac{x}{\alpha}\right)} \quad \alpha, \beta > 0, x > 0$	$X_T = \alpha\beta + \gamma + K_T\sqrt{\alpha^2\beta}$	$K_T = \frac{\chi^2 C_s}{4} - \frac{2}{C_s}$ $C_s = \mu_3/{\mu_2}^{3/2}$ $\chi^2 = \gamma\left[1 - \frac{2}{9\gamma} + t\sqrt{\frac{2}{9\gamma}}\right]^3$ $\gamma = 2\beta, \quad \beta = \left(\frac{2}{C_s}\right)^2$
Exponential	$f(x) = \frac{1}{\alpha} e^{-\alpha x} \quad \alpha > 0, x > 0$		

Results and Discussion

The distributions used are Log-normal, Pearson type III, log-Pearson type III, GEV, and Gumbel. The distributions used are statistical techniques that were used to fit the frequency distribution data to predict the precipitation hyetograph. From the curve, the probabilities of return periods can be extracted.

Figures 3, 5, and 7 show relationships between the maximum daily rainfall depth (mm) and return period (years) of 25 rainfall stations in the Jazan Province depending upon the best probability distributions. The best distribution is chosen based on the lowest RMSE, which varies from station to station as shown in Table 2.

Tables 2 and 3 summarize the results obtained, which are detailed as follows: The results showed that 9 rainfall stations (A104, SA002, SA106, SA110, SA132, SA135, SA140, SA143, and SA145) have GEV distribution as the best probability distribution, as shown in Figure 4. While 8 rainfall stations (A106, A118, A121, SA101, SA104, SA111, SA129, and SA136) have log-Pearson III distribution, as shown in Figure 6. However, in Figure 6 it is noted that the log-Pearson III distribution is not suitable for stations A118 and SA104, although the distribution gave the lowest value for RMSE. This may be due to the nature of the data or for some reason. By looking at Figure 5, it can be said that the appropriate distribution for the A118 station data is the GEV distribution, while the Gumbel type I distribution is the most appropriate for the SA104 station data. Also, Gumbel type I distribution is the best probability distribution for 4 rainfall stations (SA001, SA102, SA107, and SA126), Log-normal distribution is the best probability distribution for 3 rainfall stations (SA108, SA116, and SA125), and Pearson type III distribution are the best probability distribution for SA144, as shown in Figure 8. Precipitation forecasts, mm, for the selected return period distribution based on the duration data are shown in Table 4.

Table 2. Root mean square errors (RMSE) for different rainfall stations in the Jazan Province.

Station symbol	Station number	Longitudes	Latitudes	Period	# of obs. (Year)	RMSE				
						Log-normal	Log-Pearson III	Pearson type III	GEV	Gumbel type I
A 104	19	43.366667	17.933333	1966 - 2002	37	9.36	4.79	3.99	***3.34***	3.64
A 106	21	42.483333	18.266667	1965 - 2002	38	23.38	***13.27***	16.16	15.69	15.70
A 118	28	42.366667	18.250000	1965 - 2002	53	79.02	***28.23***	43.19	42.61	41.51
A 121	31	42.750000	18.033333	1965 - 2014	50	22.73	***21.04***	24.67	24.63	24.39
SA 001	496	42.950000	17.050000	1967 - 1993	27	19.58	16.50	12.81	13.01	***12.77***
SA 002	497	42.616667	17.166667	1965 - 1993	29	55.16	11.18	4.72	***4.17***	4.61
SA 101	502	42.833333	16.966667	1998 - 2018	21	29.74	***20.15***	22.86	21.77	22.41
SA 102	503	42.233333	17.700000	1966 - 2001	36	23.41	5.42	4.11	3.03	***2.12***
SA 104	505	43.051817	17.032224	1960 - 2018	59	31.18	***17.87***	21.27	20.87	21.07
SA 106	507	42.533333	17.366667	1967 - 1994	28	14.99	9.61	9.02	***8.22***	8.65

SA 107	508	42.783333	17.116667	1966 - 2018	53	19.18	17.33	17.07	17.32	***16.92***
SA 108	509	41.916667	18.333333	1968 - 2005	38	***9.99***	10.82	11.24	10.61	11.2
SA 110	511	43.133333	17.266667	1988 - 2018	31	22.29	20.75	19.79	***19.74***	20.06
SA 111	512	43.116667	17.050000	1960 - 2016	57	26.05	***25.98***	26.46	26.09	26.10
SA 116	516	42.200000	18.250000	1968 - 1988	21	***27.71***	29.31	28.84	27.75	28.32
SA 125	524	42.450000	17.133333	1981 - 2018	38	***7.79***	8.73	14.28	15.53	15.08
SA 126	525	42.883333	17.450000	1966 - 2018	53	26.92	23.90	24.89	24.4	***23.69***
SA 129	528	42.900000	17.166667	1969 - 1987	19	35.32	***24.50***	27.72	26.59	27.17
SA 132	529	42.783333	17.016667	1997 - 2016	20	85.54	27.73	8.80	***6.79***	7.91
SA 135	530	43.233333	16.800000	1990 - 2009	20	12.55	11.68	11.46	***9.85***	10.76
SA 136	531	43.133333	16.683333	1978 - 2013	36	23.46	***16.84***	16.99	17.03	16.95
SA 140	535	43.033333	17.316667	1998 - 2018	21	13.49	13.09	13.17	***12.29***	13.39
SA 143	537	43.133333	16.900000	1971 - 1996	26	29.70	17.00	15.94	***14.90***	15.69
SA 144	538	42.250000	18.166667	1971 - 2000	45	37.62	27.19	***22.73***	25.30	23.95
SA 145	539	42.800000	17.616667	1997 - 2017	21	19.81	15.98	15.69	***14.64***	15.44

Table 3. The number of stations affiliated with each distribution.

Distribution Type	**The number of stations**
GEV	9
Log-Pearson III	8
Gumbel type I	4
Log-normal	3
Pearson type III	1

Table 4. Rainfall forecasting based on the best distribution at different return periods.

Station symbol	Station number	Distribution	Return Period (Tr)								
			2	5	10	15	20	25	50	100	200
A 104	19	GEV	27.24	41.64	53.73	61.14	66.52	70.77	84.31	98.31	112.71
A 106	21	Log-Pearson III	39.03	58.78	68.62	73.14	75.92	77.88	82.97	86.89	89.93
A 118	28	Log-Pearson III	68.36	81.24	82.52	82.70	82.76	82.78	82.81	82.81	82.81
A 121	31	Log-Pearson III	39.47	61.49	76.66	85.33	91.44	96.17	110.84	125.57	140.40
SA 001	496	Gumbel type I	34.52	54.19	67.21	74.55	79.70	83.66	95.87	107.98	120.05
SA 002	497	GEV	20.18	37.52	52.07	60.98	67.47	72.58	88.88	105.73	123.07
SA 101	502	Log-Pearson III	42.02	63.42	74.34	79.45	82.63	84.88	90.82	95.50	99.22
SA 102	503	Gumbel type I	27.48	42.99	53.26	59.05	63.11	66.23	75.86	85.41	94.93
SA 104	505	Log-Pearson III	56.86	64.55	65.47	65.62	65.68	65.70	65.73	65.74	65.74
SA 106	507	GEV	33.16	47.74	59.97	67.47	72.92	77.22	90.92	105.09	119.67
SA 107	508	Gumbel type I	40.74	59.54	71.99	79.02	83.93	87.72	99.39	110.98	122.52
SA 108	509	Log-normal	38.65	52.94	62.41	67.75	71.49	74.38	83.30	92.24	101.26
SA 110	511	GEV	46.57	61.10	73.29	80.76	86.20	90.48	104.13	118.25	132.78
SA 111	512	Log-Pearson III	51.48	70.26	82.61	89.55	94.40	98.14	109.67	121.16	132.72
SA 116	516	Log-normal	46.63	68.10	83.00	91.61	97.74	102.50	117.47	132.80	148.57
SA 125	524	Log-normal	24.88	43.49	58.23	67.36	74.11	79.50	97.21	116.49	137.47
SA 126	525	Gumbel type I	40.59	64.58	80.47	89.44	95.71	100.55	115.44	130.22	144.95
SA 129	528	Log-Pearson III	49.11	70.34	80.14	84.44	87.02	88.79	93.28	96.57	99.01
SA 132	529	GEV	25.25	42.17	56.37	65.07	71.40	76.39	92.29	108.74	125.65
SA 135	530	GEV	39.19	51.01	60.93	67.01	71.43	74.92	86.03	97.52	109.34
SA 136	531	Log-Pearson III	42.18	62.27	73.26	78.68	82.16	84.69	91.69	97.60	102.65
SA 140	535	GEV	44.99	53.92	61.42	66.01	69.35	71.99	80.38	89.06	97.99
SA 143	537	GEV	43.79	56.55	67.26	73.82	78.59	82.36	94.35	106.75	119.51
SA 144	538	Pearson type III	44.09	66.97	79.81	86.44	90.87	94.17	103.82	112.76	121.15
SA 145	539	GEV	40.01	54.86	67.32	74.96	80.51	84.89	98.85	113.28	128.13

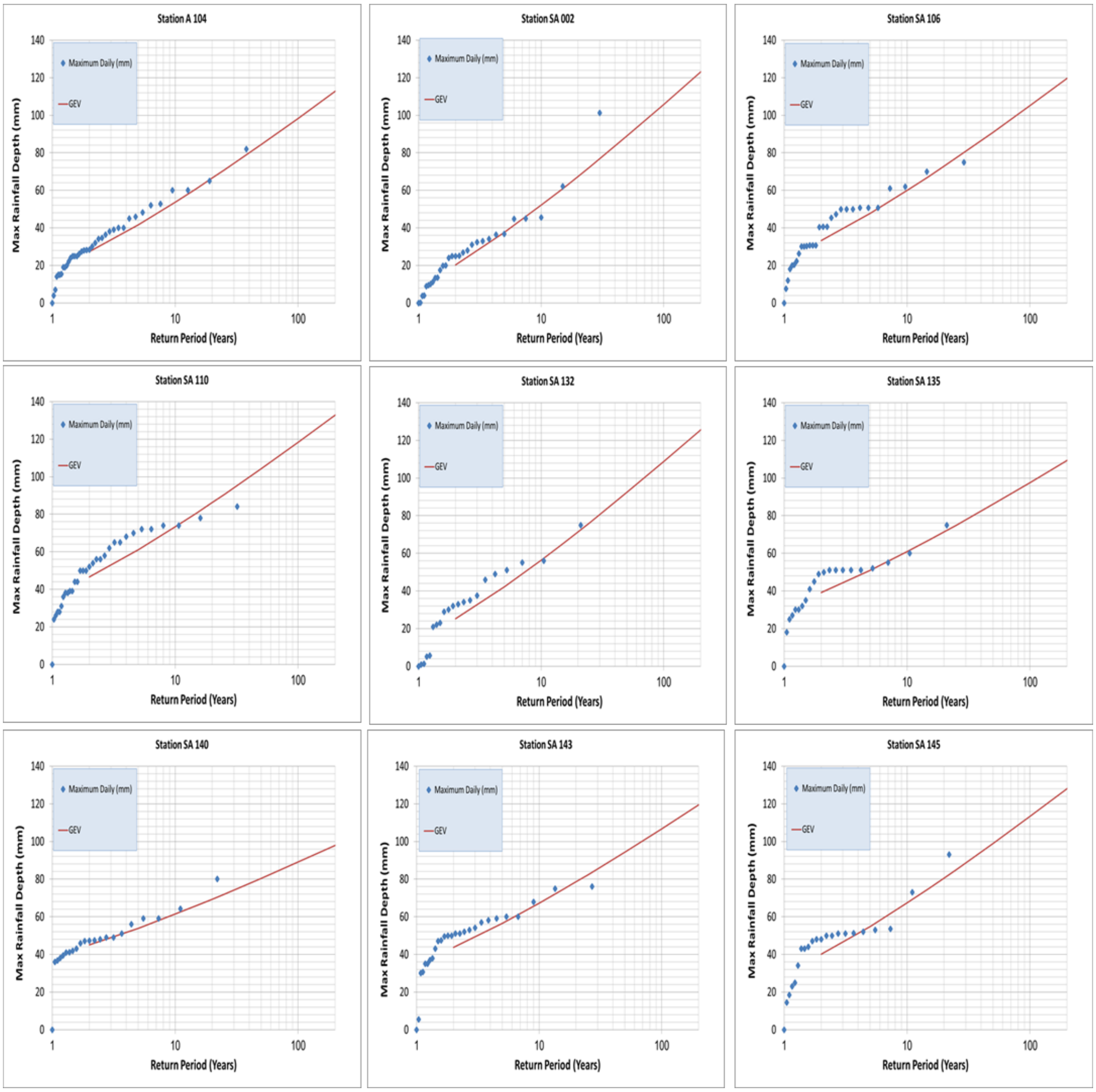

Figure 3. Relationships between maximum daily rainfall depth (mm) and return period (years) of 9 rainfall stations in the Jazan Province (A104, SA002, SA106, SA110, SA132, SA135, SA140, SA143, and SA145) depending upon the best probability distributions.

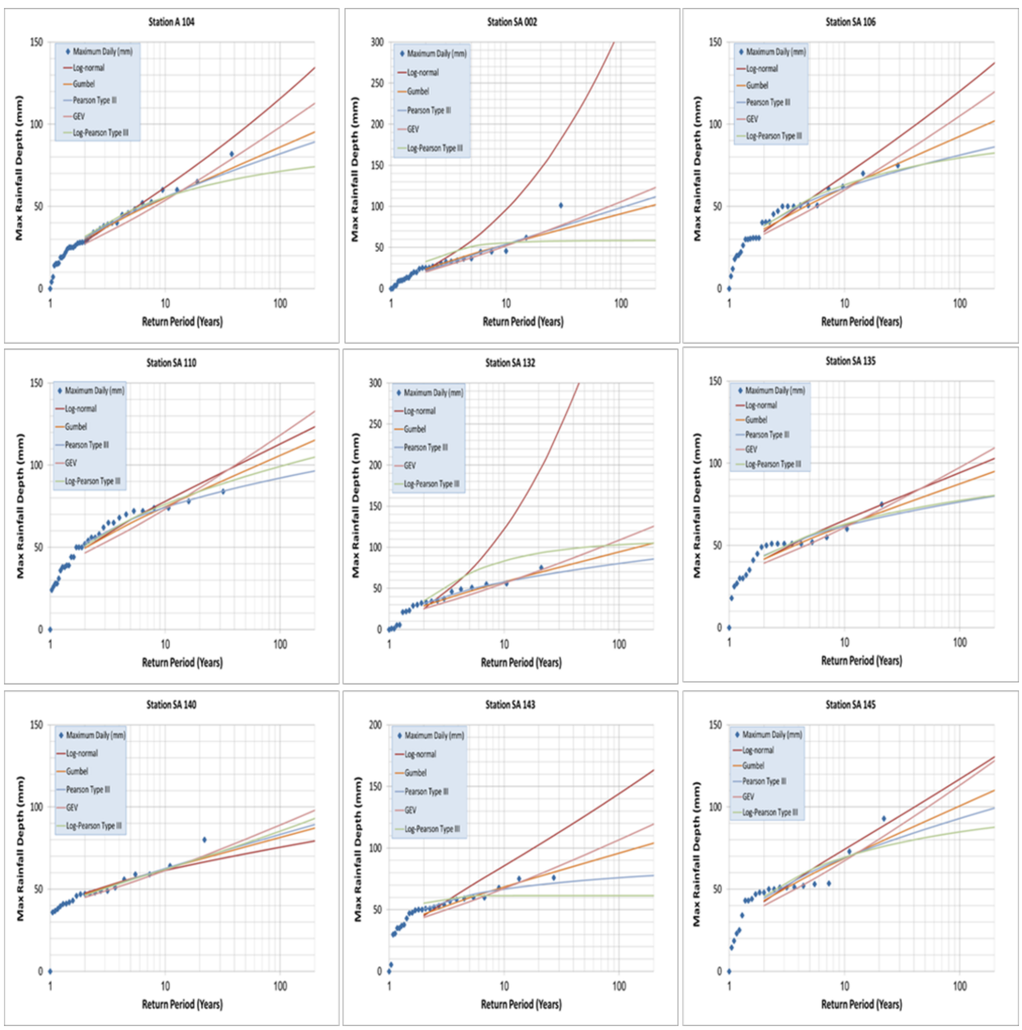

Figure 4. GEV distribution is the best probability distribution for 9 rainfall stations in the Jazan Province (A104, SA002, SA106, SA110, SA132, SA135, SA140, SA143, and SA145).

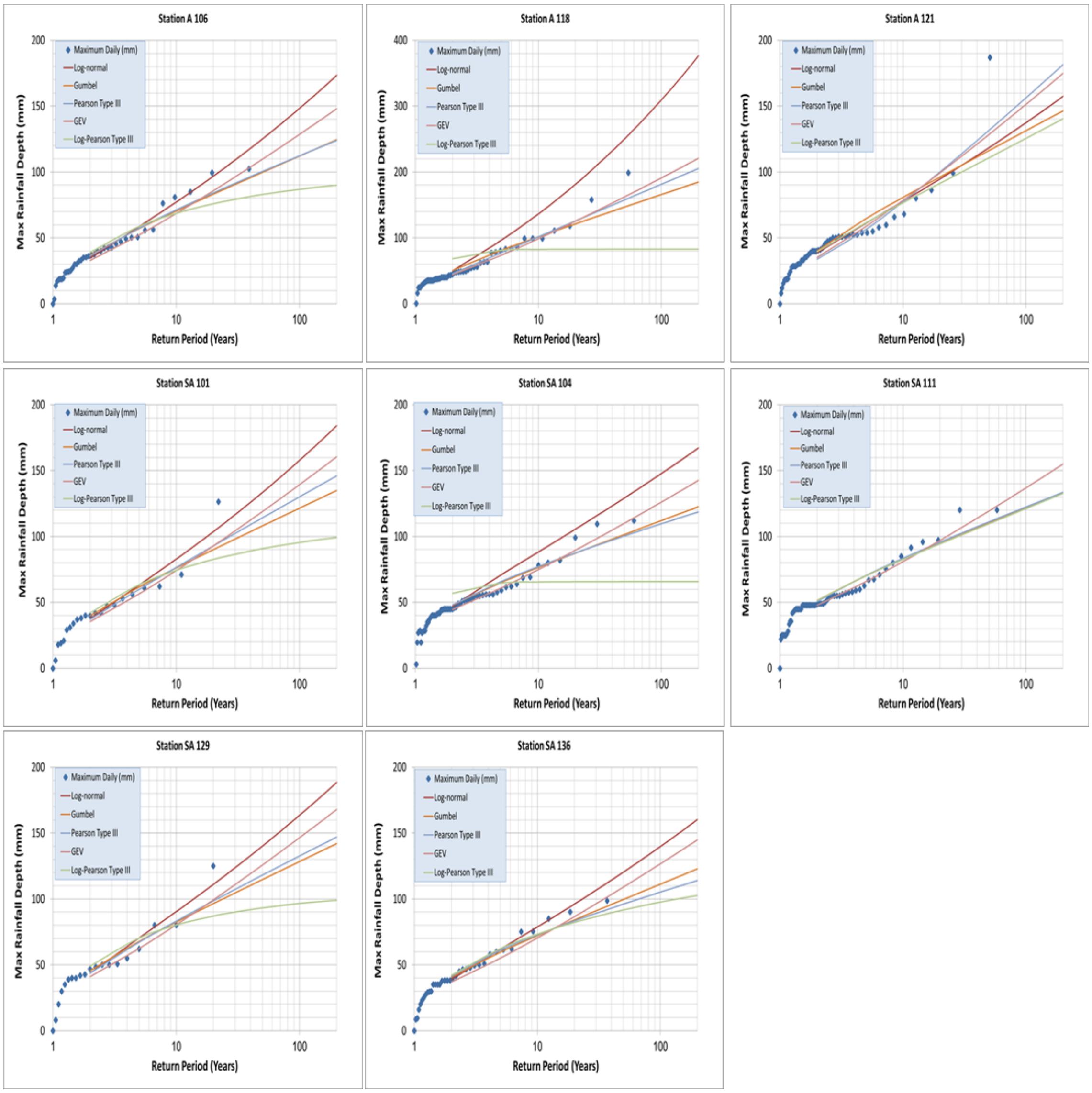

Figure 5. Relationships between maximum daily rainfall depth (mm) and return period (years) of 8 rainfall stations in the Jazan Province (A106, A118, A121, SA101, SA104, SA111, SA129, and SA136) depending upon the best probability distributions.

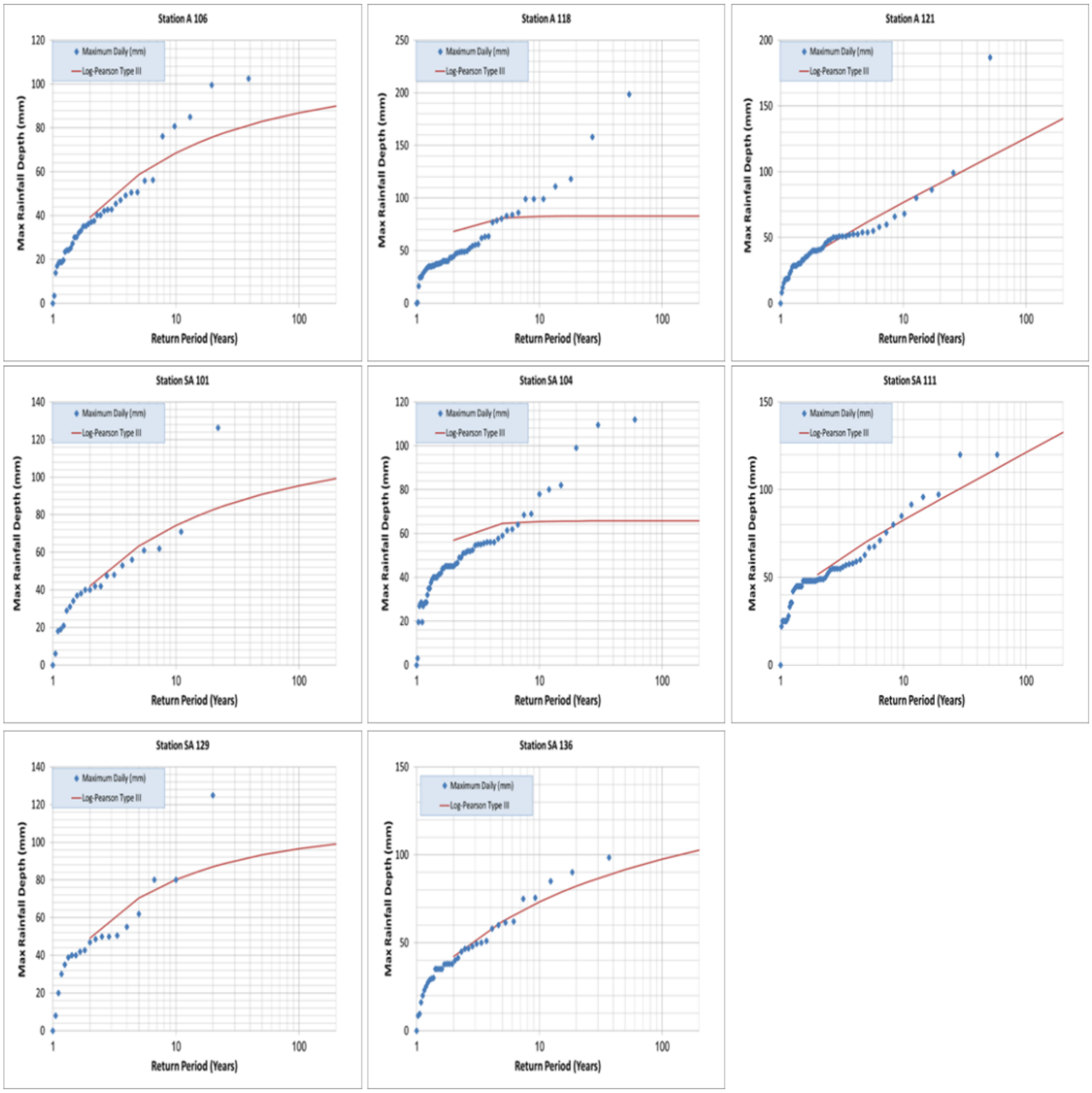

Figure 6. Log-Pearson III distribution is the best probability distribution for 8 rainfall stations in the Jazan Province (A106, A118, A121, SA101, SA104, SA111, SA129, and SA136).

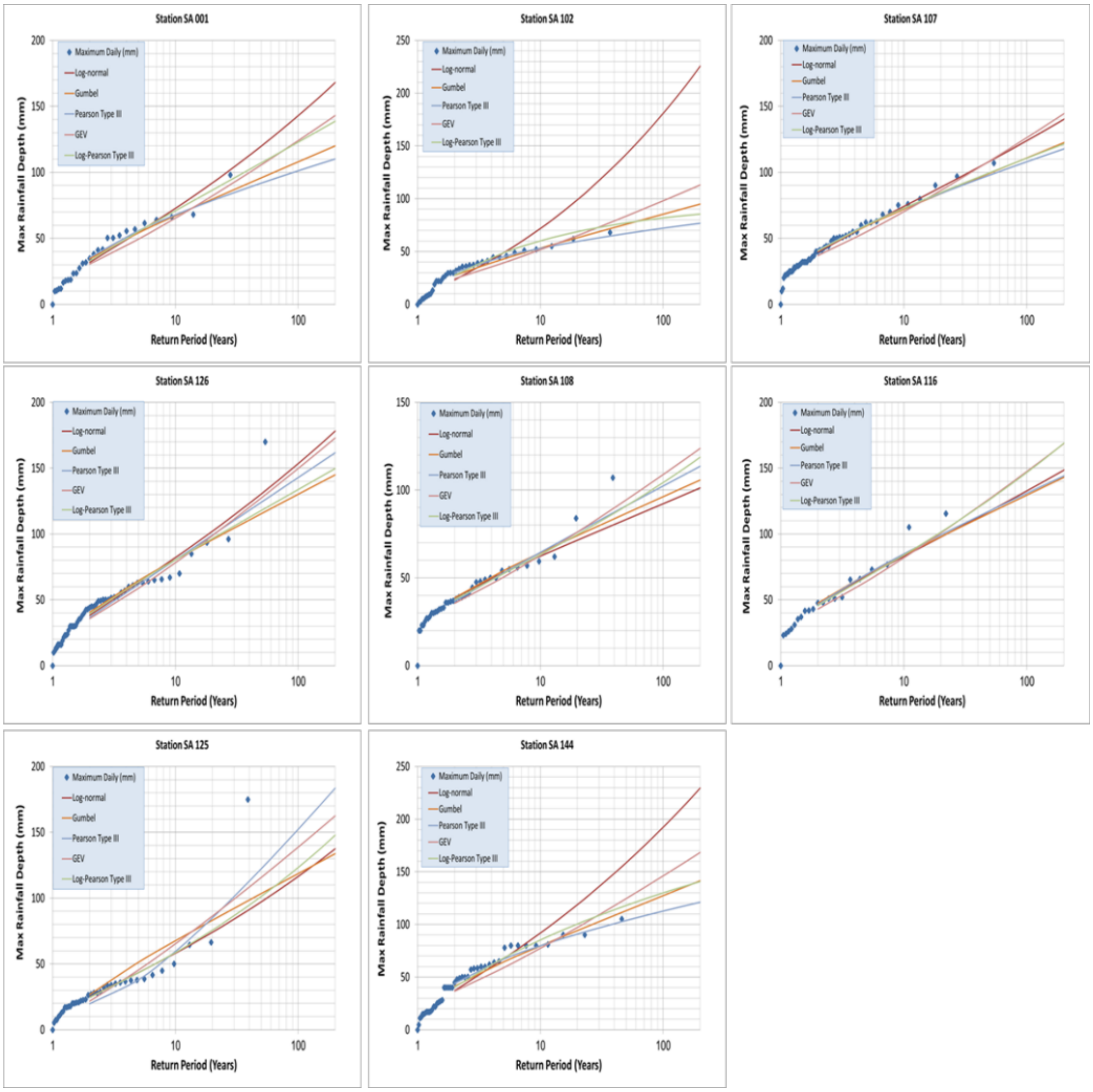

Figure 7. Relationships between maximum daily rainfall depth (mm) and return period (years) of 8 rainfall stations in the Jazan Province (SA001, SA102, SA107, SA126, SA108, SA116, SA125, and SA144) depending upon the best probability distributions.

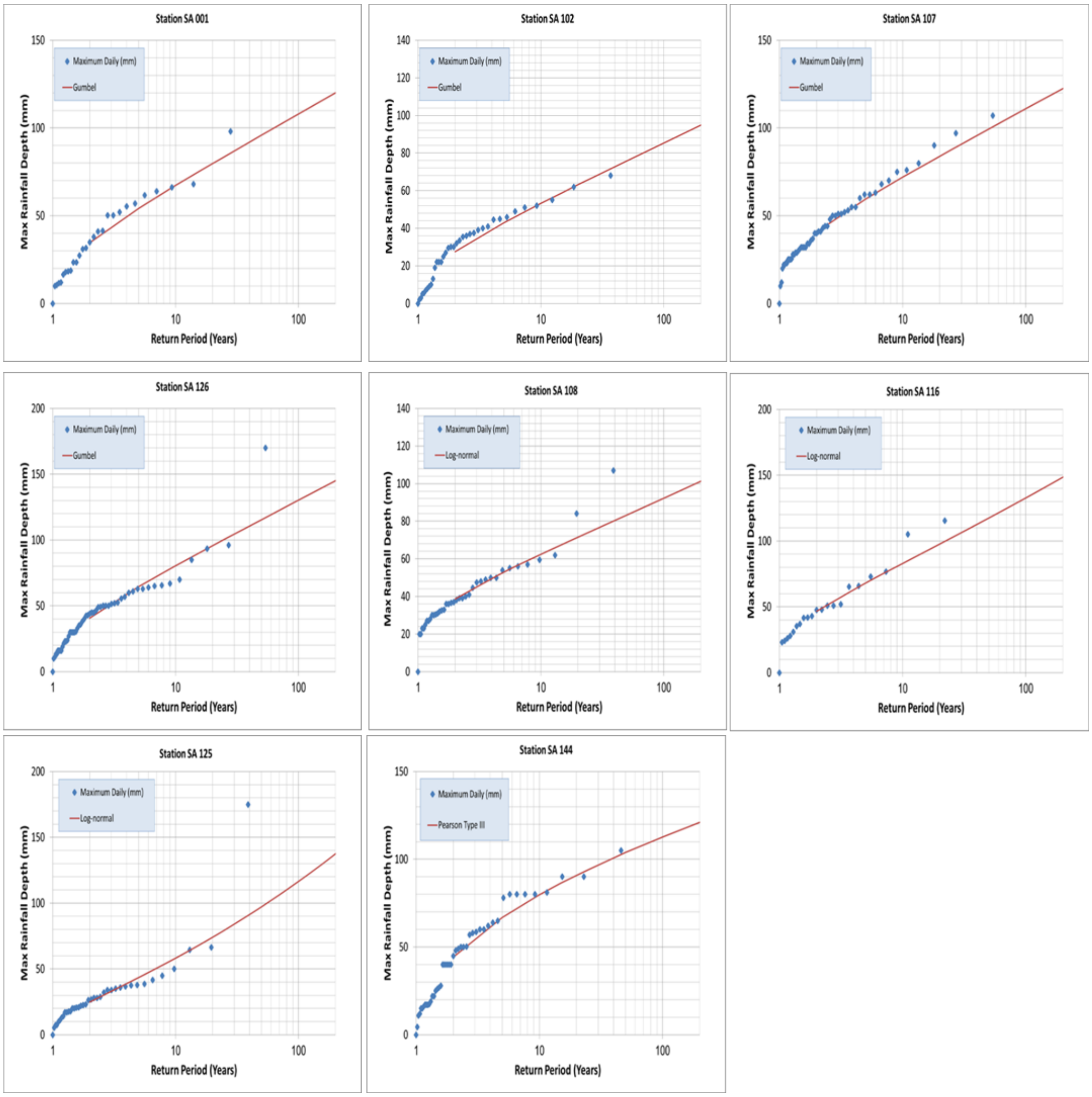

Figure 8. Gumbel type I distribution is the best probability distribution for 4 rainfall stations in the Jazan Province (SA001, SA102, SA107, and SA126), log-normal distribution is the best probability distribution for 3 rainfall stations (SA108, SA116, and SA125), and Pearson type III distribution is the best probability distributions for SA144, respectively.

Table 5 presents the main statistical measures of the data for 25 rainfall stations in the Jazan Province. These statistics are the mean, standard deviation (SD), variance, coefficient of skewness, and coefficient of variation (CV). The arithmetic mean values range from 27.16 to 56.07 mm, with an average of 43.38 mm. While the standard deviation values range between 10.49 to 34.98 mm, with an average of 21.20 mm. As, the variance values range between 110.01 to 1223.25 mm^2. With an average of 476.68 mm^2. It is clear from table 5 that the coefficient of skewness is ranging between -0.70 and 3.92. Skewness values for the SA110, SA135, and SA102 stations are 0.01, 0.02, and 0.07 respectively. It can be said that it is a normal distribution because its values are very close to zero. The skewness value for the SA143 station is equal to -0.7, it is negatively skewed. The remaining stations give positive values; it is positively skewed. Finally, the coefficient of variation (CV) values ranges from 0.22 to 0.89, with an average of 0.5. CV values less than one indicate a low CV, which means that the dispersion of data values is low relative to the mean.

Table 5. Summary of the statistical analysis.

Station symbol	Station number	Mean (mm)	Standard deviation, SD (mm)	Variance (mm^2)	Skew	CV
A 104	19	33.04	16.92	286.12	0.81	0.51
A 106	21	40.72	22.78	518.97	1.19	0.56
A 118	28	56.07	34.98	1223.25	1.96	0.62
A 121	31	44.69	27.64	763.95	2.97	0.62
SA 001	496	38.17	22.26	495.30	0.71	0.58
SA 002	497	27.16	20.36	414.56	1.81	0.75
SA 101	502	43.89	24.76	613.03	1.77	0.56
SA 102	503	30.36	17.55	307.97	0.07	0.58
SA 104	505	51.17	19.42	376.95	0.99	0.38
SA 106	507	39.03	17.12	293.02	0.19	0.44
SA 107	508	44.23	21.28	452.81	0.96	0.48
SA 108	509	41.53	17.46	304.70	1.77	0.42
SA 110	511	52.42	17.06	291.05	0.01	0.33
SA 111	512	55.01	21.23	450.82	1.24	0.39
SA 116	516	51.50	24.90	619.79	1.27	0.48
SA 125	524	31.28	27.86	775.98	3.92	0.89
SA 126	525	45.05	27.15	737.36	2.00	0.60
SA 129	528	49.69	25.10	629.90	1.46	0.51
SA 132	529	32.06	19.87	394.79	0.14	0.62
SA 135	530	43.95	13.88	192.68	0.02	0.32
SA 136	531	44.26	21.36	456.08	0.75	0.48
SA 140	535	48.59	10.49	110.01	1.47	0.22
SA 143	537	48.93	14.98	224.53	-0.70	0.31
SA 144	538	45.59	26.06	679.18	0.35	0.57
SA 145	539	45.99	17.44	304.12	0.52	0.38

Model calibration:

The model was calibrated by the Hyfran Plus program, where the results proved the validity and accuracy of the model. As an example, Figure 9 shows the similarity log-Pearson III distribution pattern for rainfall station in the Jazan Province A118 using the model and the Hyfran Plus program. The same applies to station SA104 bottom Figure 9. And to confirm the validity of what was discussed above about the data of two stations, which gave unrealistic results that the log-Pearson III distribution is the most appropriate distribution for them. And through the comparison in Figures 10 and 11 between the used distributions, it is noted that the log-Pearson III distribution is not appropriate for the data of the two stations. In Figure 10, it is noted that the appropriate distribution for the data of the A118 station is the GEV distribution, while the distribution of Gumbel type I is the most appropriate for the data of the SA104 station, as shown in Figure 11.

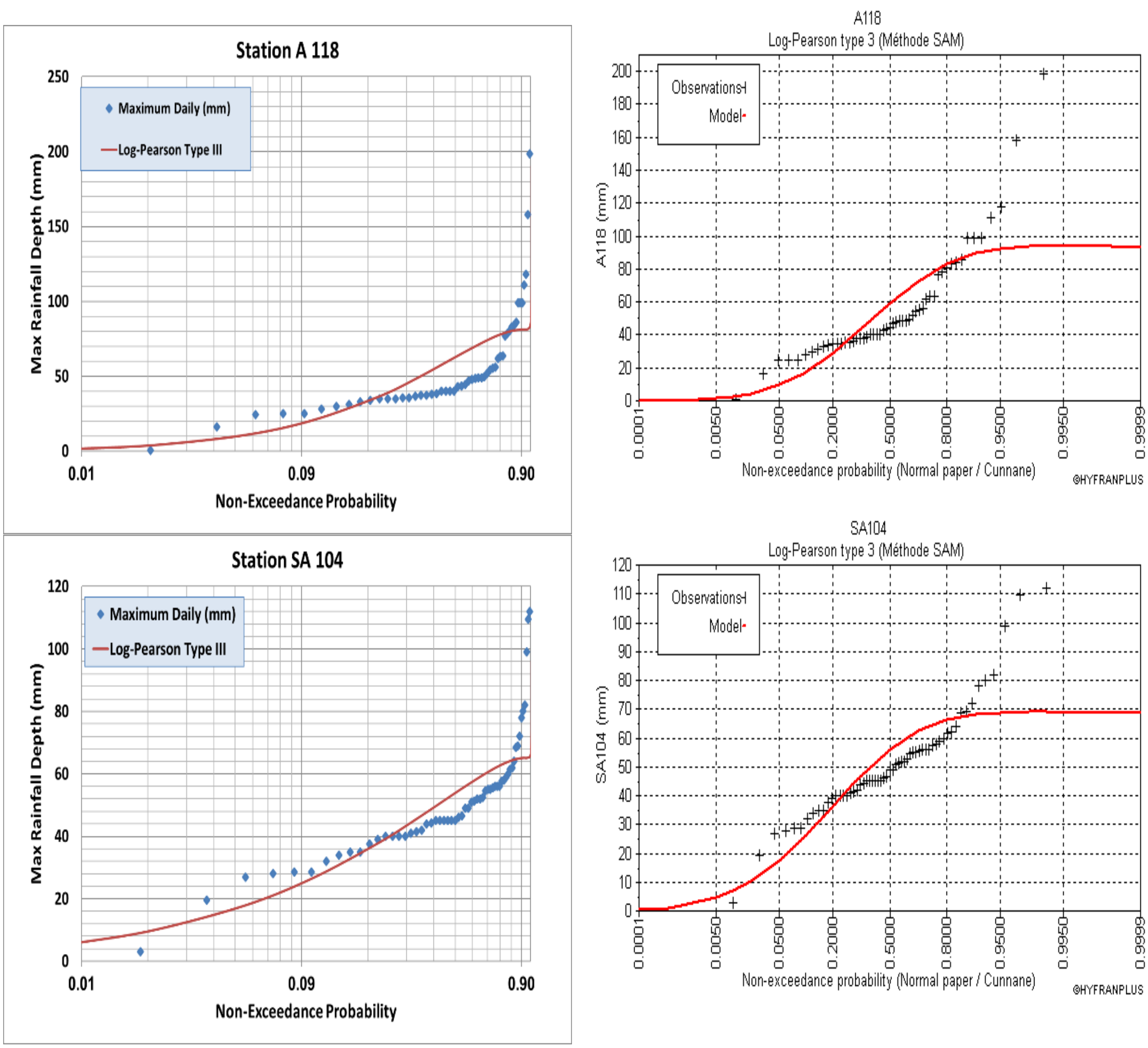

Figure 9. Log-Pearson III distribution for 2 rainfall stations in the Jazan Province A118 (top image), and SA104 (bottom image), using model (left) and Hyfran Plus program (right).

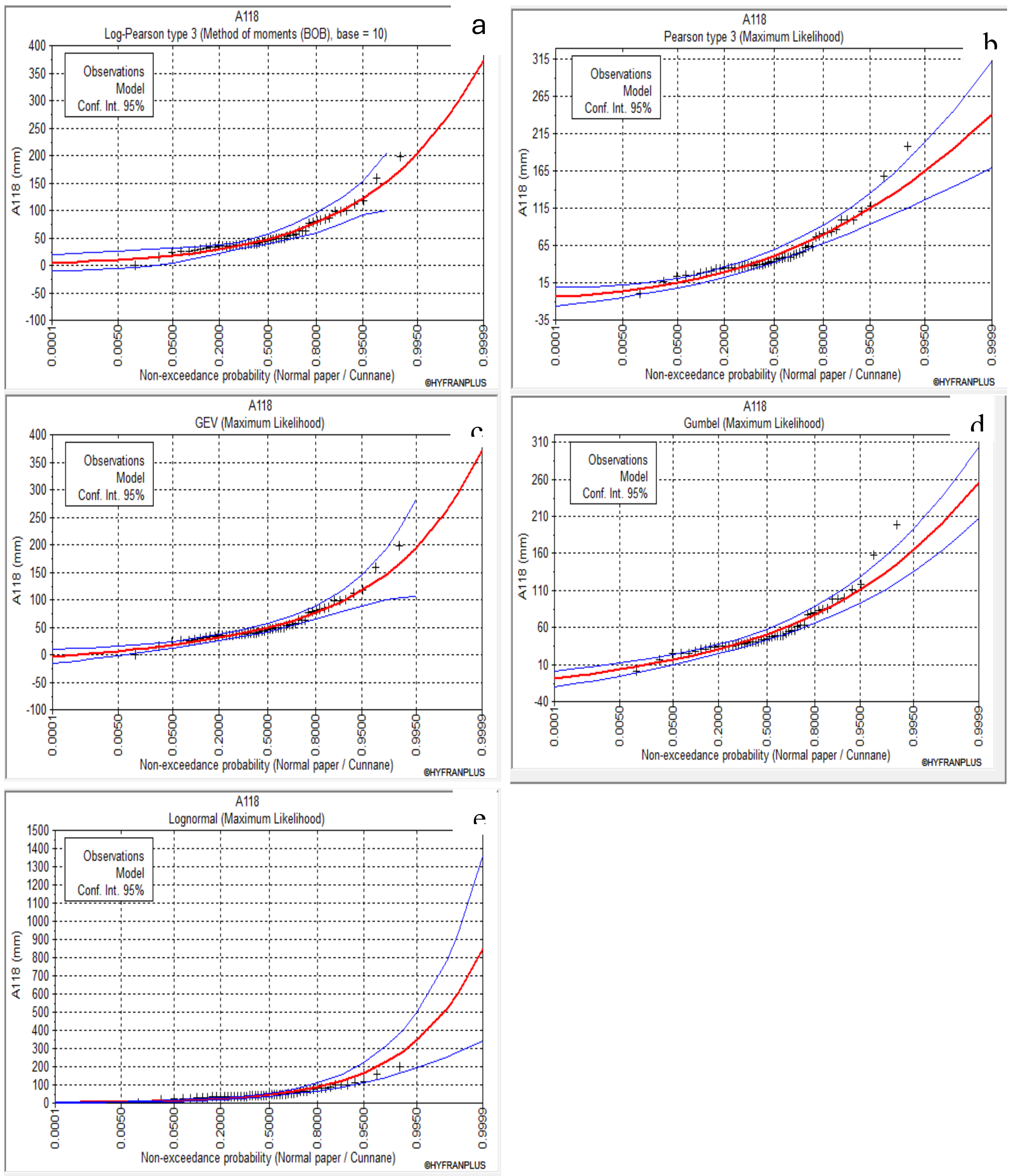

Figure 10. Relationships between maximum daily rainfall depth (mm) and return period (years) of the A118 rainfall station in the Jazan Province based on probability distributions are: (a) log-Pearson III, (b) Pearson type III, (c) GEV, (d) Gumbel type I, and (e) log-normal.

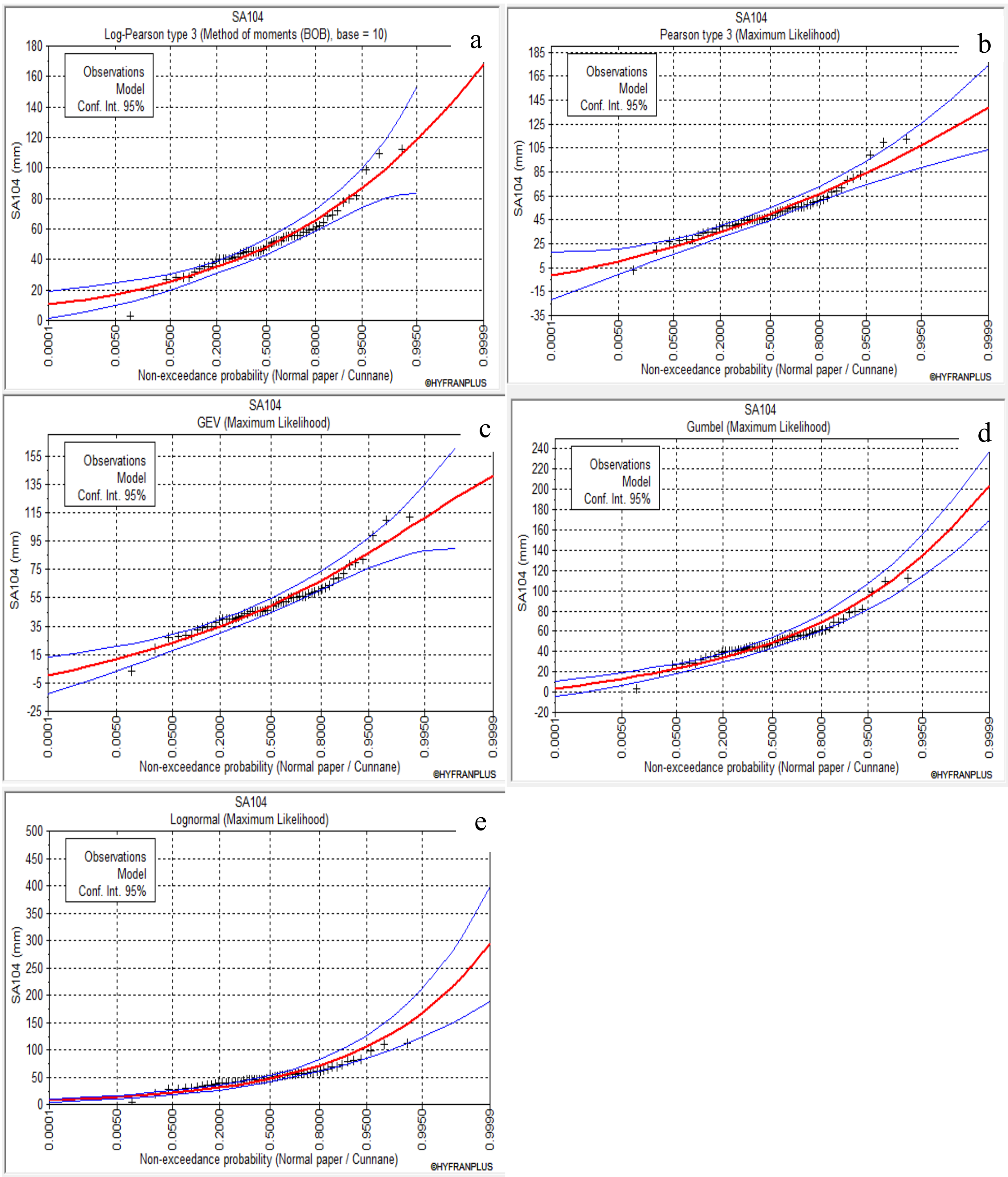

Figure 11. Relationships between maximum daily rainfall depth (mm) and return period (years) of the SA104 rainfall station in the Jazan Province based on probability distributions are: (a) log-Pearson III, (b) Pearson type III, (c) GEV, (d) Gumbel type I, and (e) log-normal.

Conclusions.

The important conclusions from this study can be summarized in the following:

1. Jazan Province is characterized by the highest rainfall in KSA.
2. Based on RMSE, GEV distribution is the best probability distribution for 36% of stations, followed by log-Pearson III, Gumbel type I, log-normal, and, Pearson type III distributions, with percentages of 32%, 16%, 12%, and 4% of the total studied stations, respectively. However, the RMSE criterion gave odd results for stations A118 and SA104 appeared in the fitting which needs further investigation.
3. The developed Excel sheet model prepared for the analysis proved effective and accurate, and its results were validated by the Hyfran Plus program. It is recommended to use the model.
4. It can be said that the SA110, SA135, and SA102 stations are of normal distribution because they have skewness values that can be taken as zero. While the rest of the stations show an asymmetric distribution.
5. The coefficient of variation (CV) values less than one, which means that the dispersion of data values is low relative to the mean.
6. The research provides a database for scientific research that contributes to flood risk assessment studies.

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التحليل التكراري لاقصى مطر يومي لإدارة مخاطر السيول في منطقة جازان بالمملكة العربية السعودية: تطويرنموذج قائم على برنامج Excel

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مستخلص. تعد المملكة العربية السعودية من أكثر الدول جفافاً في العالم، ويكاد يكون هطول الأمطار نادراً باستثناء المنطقة الجنوبية الغربية من المملكة العربية السعودية، حيث تقع منطقة جازان. تهدف الدراسة إلى تحليل توزيع الأمطار لمعرفة التوزيع الانسب لمنطقة جازان من خلال بيانات الأمطار السنوية لمنطقة جازان لتوفير قاعدة بيانات للدراسات الهيدرولوجية وتقييم مخاطر السيول. تم استخدام بيانات 25 محطة هطول الأمطار لفترات تتراوح بين 19 إلى 59 سنة (1960–2018) لمتوسط هطول الأمطار السنوي والحد الأقصى اليومي. تم إعداد برنامج حاسوبي على Excel بالتوزيعات المختلفة وهي (log–normal، Pearson type III، log–Pearson type III، GEV، وGumbel) لتحليل البيانات بناءً على معيار RMSE، أظهرت النتائج أن توزيع GEV هو أفضل توزيع احتمالي لـ 36% من المحطات. تليها التوزيعات log–Pearson III، Gumbel type I، log–normal، وPearson type III بنسب 32%، 16%، 12%، و4% من إجمالي المحطات المدروسة على التوالي. أظهر النموذج فعالية النموذج المطور في التحليل، حيث تم التحقق من صحة نتائجه بواسطة برنامج Hyfran Plus، وينصح باستخدام النموذج المطور لسهوله التعامل معه.

الكلمات المفتاحية: توزيع الأمطار، التوزيعات الاحتمالية، RMSE، منطقة جازان، المملكة العربية السعودية.