Best Distribution and Plotting Positions of Annual Rainfall in the Catchment of Holy Karbala in Iraq

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Abstract

The research data analysis of annual rainfall in the Catchment of holy Karbala for the purpose of finding the appropriate frequency distribution of the data.Seven were applied theory of probability distributions,namely Normal, Log-Normal, Log-Normal Type III, Gamma, Pearson Type III, Log-Pearson Type III and Weibull Type III distributions were investigated as distributions for modeling at-site annual rainfall using several plotting positions formulas at Euphrates river basin in Kerbala.Frequency curves based on each of these distributions are derived. Goodness of fit tests, namely Chi-square, Anderson-Darling and Kolmnogorov-Smirnove are applied to fit the theoretical distributions for the observed data. The study shows that Gamma distribution is one of the best models for annual rainfall in the Catchment of holy Karbala.The annual rainfall (mm) in the Catchment of holy Karbala, for different return periods (10, 25, 50, 100), were calculated.

Keywords: plotting position**,** rainfall frequency analysis.

الخلاصة

تناول البحث تحليل بيانات المطر السنوية في جابية كربلاء المقدسة وذلك لغرض إيجاد التوزيع التكراري الملائم للبيانات. وتم تطبيق سبعة من توزيعات الاحتمال النظرية وهي التوزيع الطبيعي و التوزيع اللوغارتمي الطبيعي و التوزيع اللوغارتمي الطبيعي النوع الثالث وتوزيع كاما وتوزيع بيرسون النوع الثالث وتوزيع بيرسون اللوغارتمي النوع الثالث وتوزيع ويبل النوع الثالث وقد تم بحث التوزيعات لصياغة نماذج الأمطار السنوية باستعمال عدة صيغ لتعين المواقع في حوض نهر الفرات في كربلاء. وتم أيجاد منحنيات التكرار بالاعتماد على ذلك. وتم تطبيق فحص مربع كأي و اندرسن- دالينك وفحص كولموكروف- سميرنوف لغرض مقارنة التوزيعات النظرية مع نتائج التوزيعات ألميدانية وقد أظهرت الدراسة بأن توزيع كاما من أحسن توزيعات المطر السنوية في جابية كربلاء المقدسة، وتم إيجاد الأمطار السنوية لفترات عوده ١٠ و٢٥ و٥٠ و١٠٠ فيها.

الكلمات المفتاحية : بالتآمر الموقف، تحليل التردد هطول الأمطار

Introduction

Analysis of rainfall data strongly depends on its distribution pattern. It has long been a topic of interest in the fields of meteorology in establishing a probability distribution that provides a good fit to annual rainfall depths. No previous study especially in Karbala Catchment on Statistics rainfall at all, but there are some papers related to my studies. Lee (2005) indicated that log-Pearson type III distribution fits for 50% of total station number for the rainfall distribution characteristics of Chia-Nan plain area. Kwaku *et al*., (2007) revealed that the log-normal distribution was the best fit probability distribution for one to five consecutive days maximum rainfall for Accra, Ghana. Hanson *et al*., (2008) analysis indicated that Pearson type III distribution fits the full record of daily precipitation data and Kappa distribution best describes the observed distribution of wet-day daily rainfall. Olofintoye *et al*., (2009) examined that 50% of the total station number in Nigeria follows log-Pearson type III distribution for peak daily rainfall. Sharma *et al*., (2010) studied statistical distribution of rainfall in India and Gamma distribution has been fitted to rainfall data. Mehdi, (2011) revealed that Gringorton and Weibul plotting position formula are appropriate for the Normal (Log-normal), the Pearson III (Log-pearson III) distributions, respectively. Yahaya *et al*., (2012) carried out a comparative study of the best probability plotting position for predicting parameters of the Weibull Distribution and concluded that, the Gringorten formula performs the best for all sample sizes.

The study area

Karbala Catchment shown in Figure (1a), located between latitudes 32°36'31"N and longitudes 44°01'32"E in central region of Iraq on the eastern edge of the plateau's western desert Euphrates River on the edge of the desert in the middle of the region sedimentary from Iraq. The Karbala city is located 108 km away to the south-west of the Iraqi capital Baghdad, on the edge of the desert in the west of the Euphrates. The conservative climate in general hot summer, cold in winter and tends to moderation in the eastern part of the terms of the temperature and distribution of rain and humidity, especially in the section is located within the area of the plateau. The catchment covers an area of approximately 5034 km^2 and is situated on a plateau of 48 meters above sea level. The area receives one cycle of rainfall that extends from October of the previous year and ends in May of the following year; wherein the dry season runs from June to September.

Validity of distributions based on statistical data standards

Using Table (1) and Figure (1b) the sample estimates of the population skewness and kurtosis for the annual rainfall depths series data are 0.5192 and 1.2723 respectively.Since the parameters are neither close to zero nor to 3, the Normal distribution could not be accepted.

For Lognormal type II distribution the skewness computed from the Eq. $C_s=3C_v+C_v^3$= 1.5142 is different to [C_s= 0.5192]. Furthermore, skewness of logarithm [C_{sy}=-0.1033] is so differ that it can be remote to zero and Kurtosis of logarithm [C_{ky}=3.6362] is something remote to 3.0 justify the possible rejectable of Lognormal type distribution.

The skewness coefficient is greater than zero and the kurtosis is computed from the Eq. $C_k=3+1.5(Cs)^2$ = 3.4044 is quite different to the kurtosis is that computed from the data [C_k=1.2723] , so Lognormal type III distribution could not be accepted.

Since C_{sy} = -0.1033<0.0 then The Log-Pearson type III distribution cannot be used successfully.

The sample estimates of the population skewness and kurtosis for the annual rainfall depths series data are 0.5192 and 1.2723 respectively. Since the parameters are neither close to 1.14 nor to 5.4, then the Gumbel distribution could not be accepted.

Parameters estimationof distribution functions

The frequency analysis requires estimation of parameters of distribution functions. Parameter estimation is to fit a probability distribution to a set of data. Moments method was recommended by Sharma *et al*, (2010) and Yahaya *et al*, (2008) to estimate the parameters of the different distributions. A new program is written in Matlab version 7.12.0.635. This program is used to compute the parameters of each user distribution here.The parameters values are given in Table 2.

Graphical Comparison of Fits

There is no right answer to the question of which distribution is best for the annual rainfall depths (mm) at the province of holy Karbala in Iraq. However, all the distributions may be fitted and plotted cumulative density function on the normal, lognormal or Gumbel probability papers may give an answer to such a question. The probabilities of exceedence of the annual rainfall depths (mm) were determined using the seven plotting positions cited in (Sooyoung *et al.*, 2012).

Having selected a distribution and estimated its parameters. Chow (Chow, 1964) proposed a general equation (Eq.1) to use this distribution in frequency analysis.

$$X_T = \mu + K_T\sigma \quad \text{Eq.1}$$

Where X_T is the event magnitude at a given return period T; μ is the population mean of hydrological data such as rainfall depth ; is the standard deviation, respectively and K_T is the frequency factor, a function of the return period and probability distribution. A measure of variability of the resulting event magnitudes is the standard error of estimate. The standard error S_T, corresponding to any return period T can be computed from the method of moments using the skewness coefficient γ and the frequency factor K_T belonging to the given return period T. To identify the equations and tables related to these variables can refer to the Eq.2 (McCuen, 2004) and (Haan, 2002).

$$S_T = \delta_T \frac{\sigma}{\sqrt{n}} z_{\left(1-\alpha/2\right)} \quad \text{Eq.2}$$

Where S_T is the standard error, corresponding to any return period T; δ_T is the parameter depending on the values the skewness coefficient γ and the return period T; σ is the standard deviation; $\frac{\sigma}{\sqrt{n}}$ is the standard error of the mean; z denotes a standard normal random variable, α = is the probability a confidence interval will not include the population parameter, 1 - α = the probability the population parameter will be in the interval. We divide α by 2 to reflect the fact that the true value of the parameter can be either greater than or less than the range covered by the confidence interval.

Fundamentally, Ayad (2007), introduce the concept for calculating these variables namely K_T, S_T , δ_T, Upper and Lower limit (Eq.3A and Eq.3B) depending on the equations for every user distribution here. Since then this procedure has been used for annual rainfall frequency analysis here. A new program is written in Matlab version 7.12.0.635 is used. The resulting plots are shown in figures (2) through (8) and the Gamma distribution by Weibll plotting position best fit for the annual rainfall depths (mm) at the province of holy Karbala in Iraq, with 95% confidence intervals. This distribution will explain [R^2 = 98.87%] and would be selected as "best".

Upper limit= $X_T + S_T$ Eq.3A

Lower limit= $X_T - S_T$ Eq.3B

Goodness of Fits

All distributions are fitted for the data and tested by Goodness of fit tests, namely Chi-square, Anderson - Darling and Kolmnogorov – Smirnove. The results are given in Table 3.

When certain measures are used such as Root Mean Square Error **(RMSE)**, the smallest values of this measure lead to the best fit. The results are given in Tables (4a) through (4d).From these Tables, it can be said that, The Log-Normal Type III Distribution when matched with Weibull plotting position had the minimum RMSE=4.072, hence it had the highest fit using this plotting position.

Annual rainfall depths (mm) for various return periods

The magnitudes of the annual rainfall depths (mm) for various return periods are given in Table (5a) through (5d). Because the Log-Normal Type III Distribution by Weibull's plotting position is one of the best models for rainfall depths (mm) at the province of holy Karbala in Iraq, then the magnitudes of rainfall depths (mm) for various return periods are given in Table (6).

Conclusions

The following conclusions were drawn from the study:

- The annual rainfall depths for for holy Karbala catchment vary in magnitude ranging from 12.7mm to 223.7mm within between 1965 through 2012.
- All the seven distributions had the highest coefficient of determination using Weibull plotting position.
- Also, the normal, lognormal, Gamma and Weibull distributions had minimum RMSE when matched with Weibull plotting positions while the other distributions, namely, Log-Normal type III, Pearson type III and Log-Pearson type III distributions had minimum RMSE when matched with Chegodajev plotting positions.
- According to the Chi-square and Klomogorov-Smirnov goodness of fit tests of seven models of the annual rainfall depths data, had concluded that the Gamma distribution is the best models whereas can be said that the Pearson Type III distribution is one of the best models by using Anderson Darling test.
- Thus, predicted rainfall depths with a return period of 10-year, 25-year, 50-year and 100-year, are 138.92,147.68,234.90 and 526.26mm respectively.

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Table (1): Parameters estimation for annual rainfall depths data (mm) in the Catchment of holy Karbala in Iraq.

Parameter	Symbol	Annual rainfall depth data (mm)
Mean	$\bar{x}$	87.994
Standard deviation	S_d	41.367
Coefficient of variation	C_v	0.47011
Skewness Coefficient	C_s	0.5192
Kurtosis Coefficient	C_k	1.2723
Mean of logarithm	$\bar{y}$	5.4720
Standard deviation of logarithm	S_{dy}	0.1712
Skewness of logarithm	C_{sy}	-0.1033
Kurtosis of logarithm	C_{ky}	3.6362

Table(2): Parameters values of the best fitted distributions of annual rainfall depths (in mm) of the province of holy Karbala in Iraq.

Distributions type	Shape parameter	Scale parameter	Location parameter
Normal	--------	σ=41.367	μ=87.994
Log- Normal	γ=0.0	σ= 0.61295	μ= 4.3311
Log- Normal Type III	γ= -211.91	σ= 0.13551	μ= 5.6943
Gamma	α=4.5248	β=19.447	γ=0.0
Pearson Type III	α=96.091	β=37664.0	γ= -308.12
Log-Pearson Type III	α= 1.9764	β= -0.44072	γ= 5.2021
Weibull Type III	α=2.3891	β= 104.58	γ= -4.9083

Table3: Goodness of fit tests of seven models for annual rainfall depth data (mm) in the Catchment of holy Karbala in Iraq.

Distribution Type	Chi-Squared	Anderson Darling	Klomogorov Smirnov
Normal	3.4912	0.32094	0.07281
Lognormal	3.864	1.8971	0.15514
Lognormal Type III	2.1174	0.3152	0.06565
Gamma	0.71902	0.92723	0.0988
Pearson Type III	2.1185	0.3146	0.06629
Log_Pearson Type III	5.4809	4.365	0.09157
Weibull Type III	3.6642	0.42161	0.0798

Table4: Coefficients of Regression Coefficients (R^2), Root Mean Square Errors (RMSE) and Coefficients of Fitting Equation of observed rainfall depths (mm) for different distributions using various plotting position.

Table (4a): Normal Distribution.

Plotting Positions	**R^2 %**	**RMSE mm**	**Coefficients of Fitting Eq.**		
			$y = a + bx + ce^{x}$		
			a	**b**	**c**
Hazen	98.69	4.8348	5.683	0.924	1.257E-78
Weibull	98.92	4.4041	1.135	0.974	8.545E-74
Blom	98.78	4.6717	4.431	0.937	4.118E-77
Cunnane	98.77	4.6995	4.673	0.935	2.178E-77
Gringorton	98.74	4.7495	5.070	0.930	7.306E-78
Chegodajev	98.82	4.5976	3.727	0.945	2.515E-76
California	98.66	4.9019	2.646	0.935	2.211E+02

Table (4b): Log-Normal Distribution.

Plotting Positions	**R^2 %**	**RMSE mm**	**Coefficients of Fitting Eq.**		
			$y = a + be^{x} + c\ln x$		
			a	**b**	**c**
Hazen	98.69	4.8343	-180.127	1.375E-136	61.666
Weibull	98.92	4.4040	-194.778	1.273E-115	65.019
Blom	98.78	4.6725	-184.145	1.246E-129	62.584
Cunnane	98.77	4.6994	-183.371	6.875E-131	62.408
Gringorton	98.74	4.7511	-182.090	4.958E-133	62.115
Chegodajev	98.82	4.5981	-186.410	3.602E-126	63.102
California	98.62	4.9710	-184.139	4.345E-151	62.151

Table (4c): Log-Normal Type III Distribution.

Plotting Positions	**R^2**	**RMSE mm**	**Coefficients of Fitting Eq.**		
			$y = a + be^{x} + \frac{cx}{\ln x}$		
			a	**b**	**c**
Hazen	98.96	4.195	-17.247	$1.360*10^{-78}$	5.352
Weibull	99.02	4.072	-22.154	$9.135*10^{-74}$	5.597
Blom	98.98	4.149	-18.524	$4.439*10^{-77}$	5.415
Cunnane	98.98	4.157	-18.272	$2.349*10^{-77}$	5.403
Gringorton	98.80	4.503	-13.733	$1.378*10^{-73}$	5.263
Chegodajev	98.97	4.071	-17.862	$7.891*10^{-78}$	5.382
California	99.00	4.128	-19.272	$2.706*10^{-76}$	5.453

Table (4d): Gamma Distribution.

Plotting Positions	R^2	RMSE mm	Coefficients of Fitting Eq. $y = a + be^x + cx^5 \ln x$		
			a	b	c
Hazen	98.53	5.1357	-20.176	3.322E-85	2.629
Weibull	98.87	4.4939	-26.788	1.719E-78	2.787
Blom	98.44	5.2876	-19.543	1.412E-84	2.616
Cunnane	98.64	4.9322	-21.688	1.837E-83	2.665
Gringorton	98.60	5.0080	-21.104	4.008E-84	2.651
Chegodajev	98.72	4.7793	-23.080	5.654E-82	2.698
California	98.55	5.0875	-23.462	5.950E-97	2.661

Table (4e): Pearson Type III Distribution.

Plotting Positions	R^2	RMSE mm	Coefficients of Fitting Eq. $y = a + bx + ce^x$		
			a	b	c
Hazen	98.69	4.8348	5.683	0.924	1.257E-78
Weibull	98.92	4.4041	1.135	0.974	8.545E-74
Blom	98.78	4.6717	4.431	0.937	4.118E-77
Cunnane	98.77	4.6995	4.673	0.935	2.178E-77
Gringorton	98.74	4.7495	5.070	0.930	7.306E-78
Chegodajev	98.82	4.3976	3.727	0.945	2.515E-76
California	98.66	4.9020	2.646	0.935	2.211E02

Table (4f): Log-Pearson Type III Distribution.

Plotting Positions	R^2	RMSE mm	Coefficients of Fitting Eq. $y = a + be^x + cx^5 \ln x$		
			a	b	c
Hazen	98.81	5.0662	-19.053	4.765E-86	2.787
Weibull	99.04	4.6055	-25.665	1.113E-79	2.945
Blom	98.93	4.8731	-18.427	2.654E-85	2.774
Cunnane	98.89	4.9009	-20.565	2.340E-83	2.823
Gringorton	98.86	4.9509	-19.981	4.876E-88	2.809
Chegodajev	98.94	4.5993	-21.957	7.234E-83	2.856
California	98.78	5.1034	-22.339	6.987E-93	2.819

Table (4g): Weibull Type III Distribution.

Plotting Positions	R^2	RMSE mm	Coefficients of Fitting Eq. $y = a + be^x + cx^5 \ln x$		
			a	b	c
Hazen	98.53	5.1357	-20.176	3.322E-85	2.629
Weibull	98.87	4.4939	-26.788	1.719E-78	2.787
Blom	98.44	5.2876	-19.543	1.630E-85	2.616
Cunnane	98.64	4.9322	-21.688	1.837E-83	2.665
Gringorton	98.60	5.0079	-21.104	4.008E-84	2.651
Chegodajev	98.72	4.7793	-23.080	5.654E-82	2.698
California	98.55	5.0874	-23.462	5.950E-97	2.661

R^2=Correlation coefficients

RMSE =Root Mean Square Errors

Table (5): Predicted rainfall depths (mm) at the province of holy Karbala in Iraq versus return periods for different distributions using various plotting position.

Table (5a)

Plotting Positions	Normal Distribution				Log-Normal Distribution			
	Return Periods(years)				Return Periods(years)			
	10	25	50	100	10	25	50	100
Hazen	138.49	146.82	156.42	237.13	138.49	146.82	156.42	237.13
Weibull	138.92	147.68	234.9	526.25	138.92	147.68	234.9	526.25
Blom	138.59	146.9	165.81	305.49	138.59	146.9	165.81	305.49
Cunnane	138.57	146.88	163.5	290.19	138.57	146.88	163.5	290.19
Gringorton	138.54	146.86	160.28	267.33	138.54	146.86	160.28	267.33
Chegodajev	138.66	146.96	174.23	355.13	138.66	146.96	174.23	355.13
California	139.03	148	241.05	532.15	139.03	148	241.05	532.15

Table (5b)

Plotting Positions	Log-Normal Type III Distribution				Gamma Distribution			
	Return Periods(years)				Return Periods(years)			
	10	25	50	100	10	25	50	100
Hazen	138.49	146.82	156.42	237.13	137.79	142.25	146.64	147.28
Weibull	138.92	147.68	234.90	526.26	138.07	145.79	147.03	151.63
Blom	138.59	146.90	165.81	305.49	137.78	141.99	146.6	147.2
Cunnane	138.57	146.88	163.50	290.19	137.84	142.93	146.73	147.6
Gringorton	138.54	146.86	160.28	267.33	137.82	142.65	146.7	147.46
Chegodajev	138.66	146.96	174.23	355.13	137.89	143.68	146.81	148.03
California	139.03	148.00	241.05	532.15	137.59	140	145.87	146.67

Table (5c)

Plotting Positions	Pearson Type III Distribution				Log-Pearson Type III Distribution			
	Return Periods(years)				Return Periods(years)			
	10	25	50	100	10	25	50	100
Hazen	138.85	148.63	231.55	557.83	138.39	142.65	146.61	147.98
Weibull	139.32	172.92	435.49	652.56	138.67	146.19	146.34	152.33
Blom	138.97	150.93	281.38	577.28	138.38	142.39	146.87	147.92
Cunnane	138.94	150.33	270.62	587.44	138.44	143.33	147.01	148.32
Gringorton	138.91	149.53	254.16	587.21	138.42	143.05	147.03	148.35
Chegodajev	139.03	153.23	315.35	484.68	138.49	144.08	147.11	148.73
California	138.33	147.11	147.3	147.3	138.19	140.40	146.17	147.37

Table (5d)

Plotting Positions	Weibull Type III Distribution			
	Return Periods(years)			
	10	25	50	100
Hazen	94.04	126.74	139.17	146.53
Weibull	94.15	127.73	139.76	146.9
Blom	94.04	126.7	139.14	146.48
Cunnane	94.06	126.91	139.27	146.63
Gringorton	94.06	126.84	139.23	146.59
Chegodajev	94.08	127.09	139.38	146.71
California	93.86	126.06	138.62	145

Table (6): Predicted rainfall depths (mm) at the province of holy Karbala in Iraq versus return periods for Log-Normal Type III using Weibull plotting position.

Return Period year	The annual rainfall (mm)
10	138.92
25	147.68
50	234.90
100	526.26

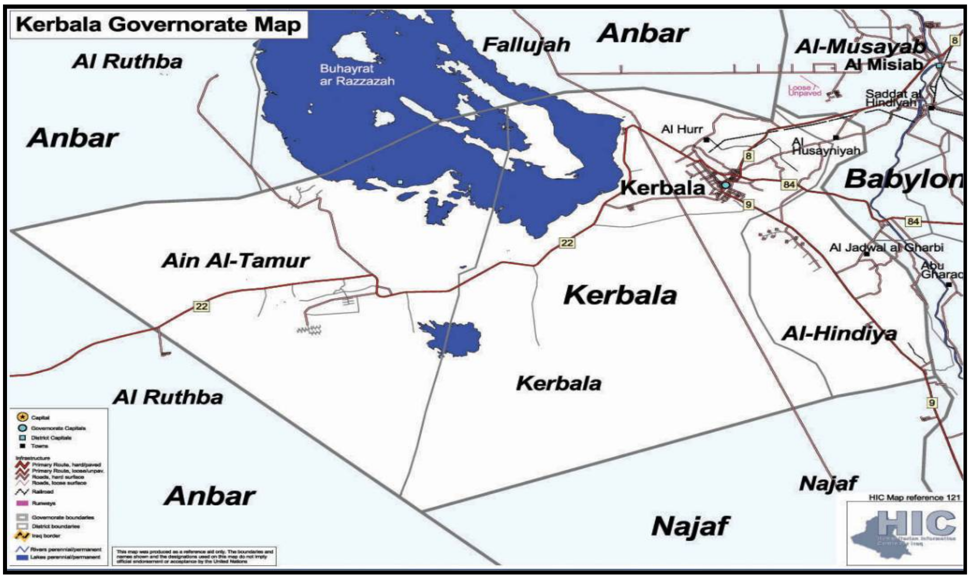

Figure (1a): Catchment of holy Karbala in Iraq.

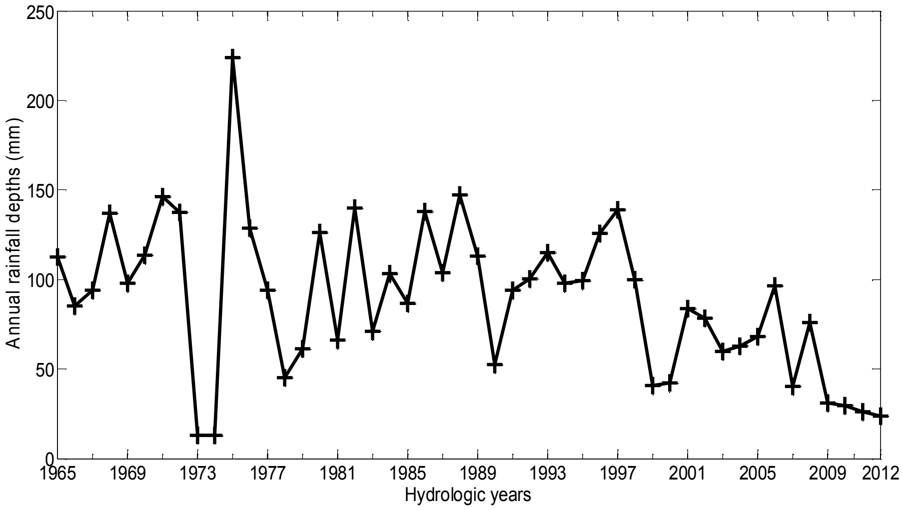

Figure (1b):Time series of the annual rainfall depths (in mm) at catchment of holy Karbala in Iraq.

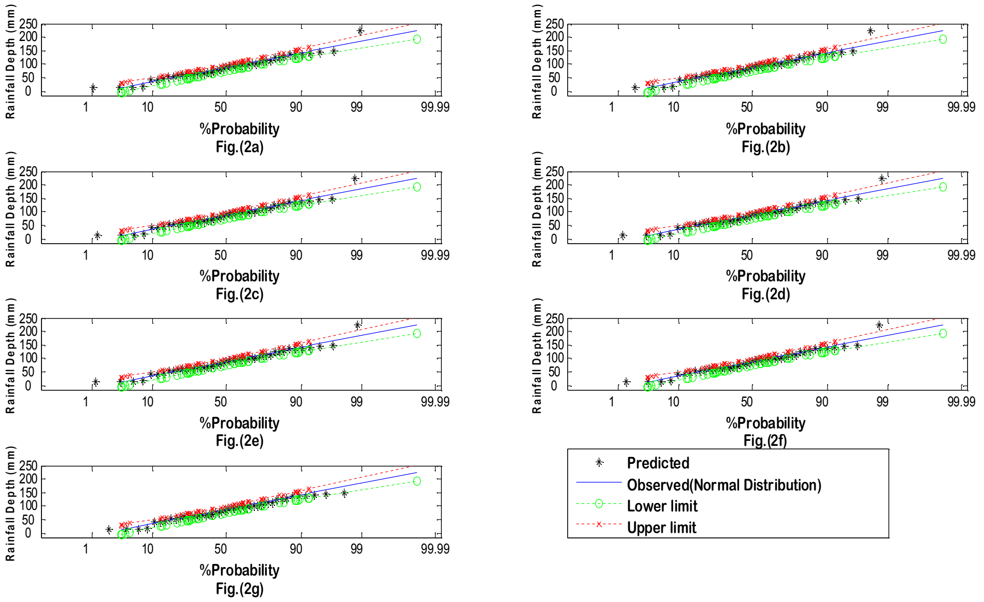

Figure 2. Normal distribution using (a) Hazen's (b) Weibull's (c) Blom's (d) Cunnane's (e) Gringorton's (f) Chegodajev's (g) California's plotting position.

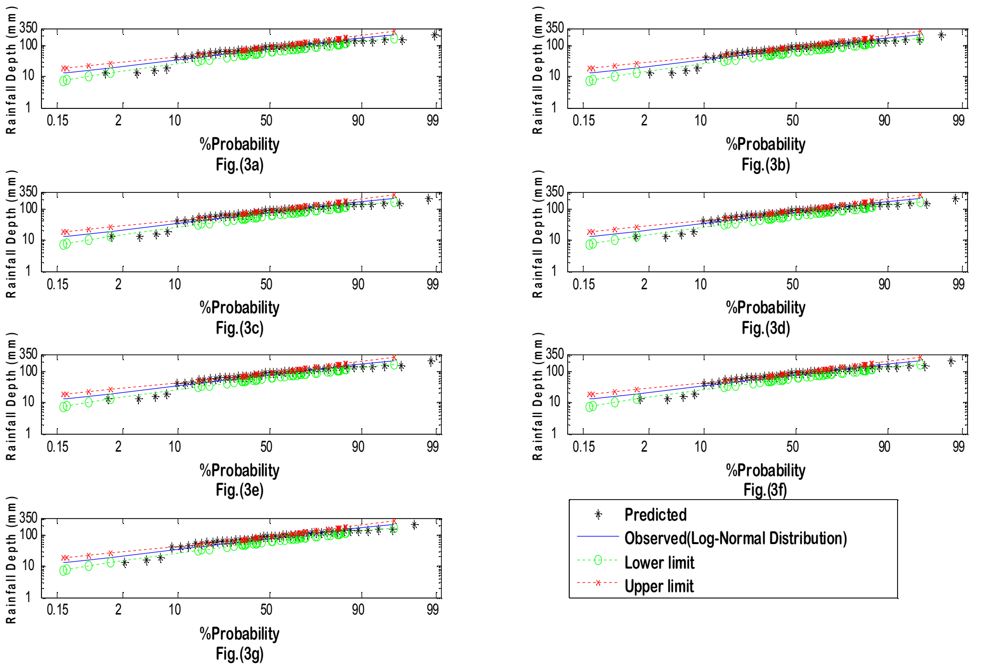

Figure 3. Log-Normal distribution using (a) Hazen's (b) Weibull's (c) Blom's (d) Cunnane's (e) Gringorton's (f) Chegodajev's (g) California's plotting position.

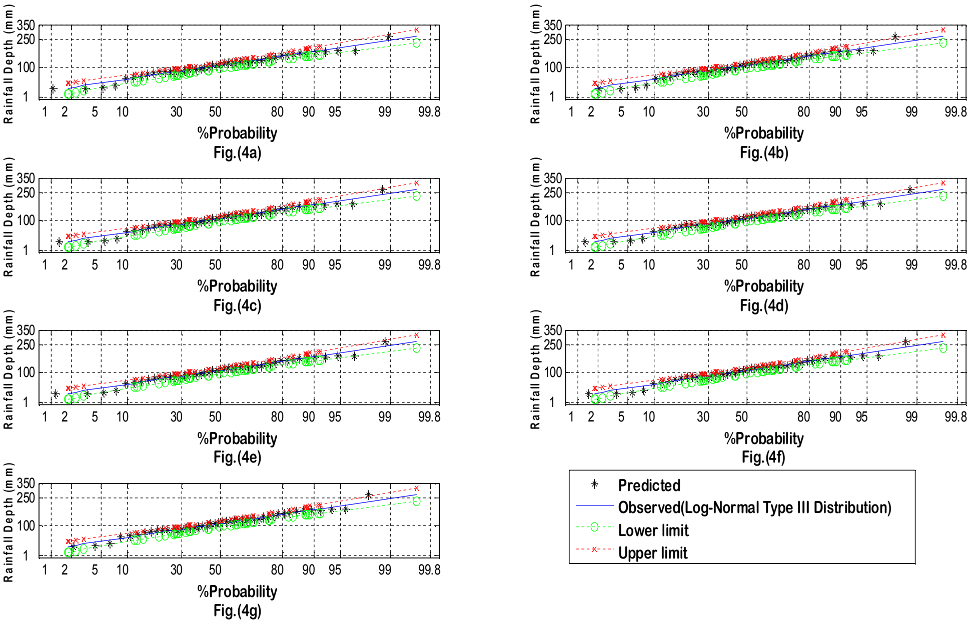

Figure 4. Log-Normal Type III distribution using (a) Hazen's (b) Weibull's (c) Blom's (d) Cunnane's (e) Gringorton's (f) Chegodajev's (g) California's plotting position.

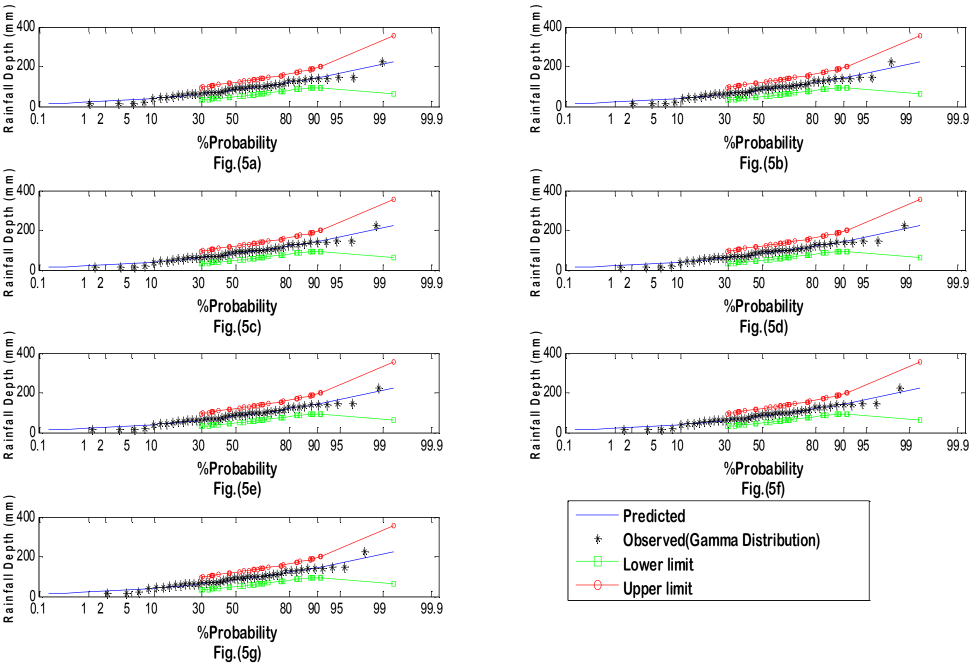

Figure 5. Gamma distribution using (a) Hazen's (b) Weibull's (c) Blom's (d) Cunnane's (e) Gringorton's (f) Chegodajev's (g) California's plotting position.

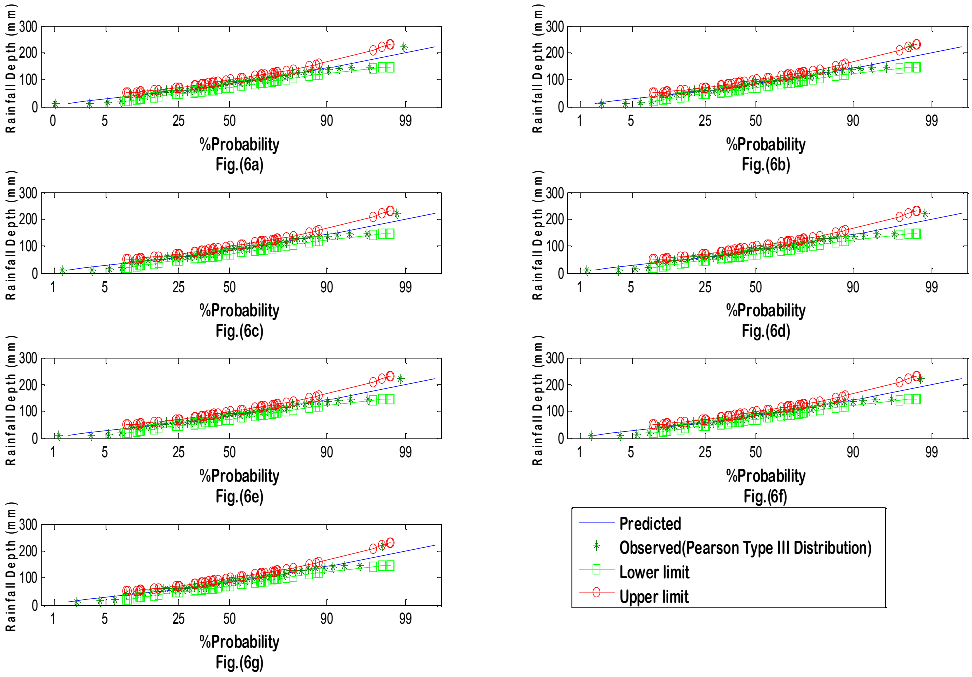

Figure 6. Pearson Type III distribution using (a) Hazen's (b) Weibull's (c) Blom's (d) Cunnane's (e) Gringorton's (f) Chegodajev's (g) California's plotting position.

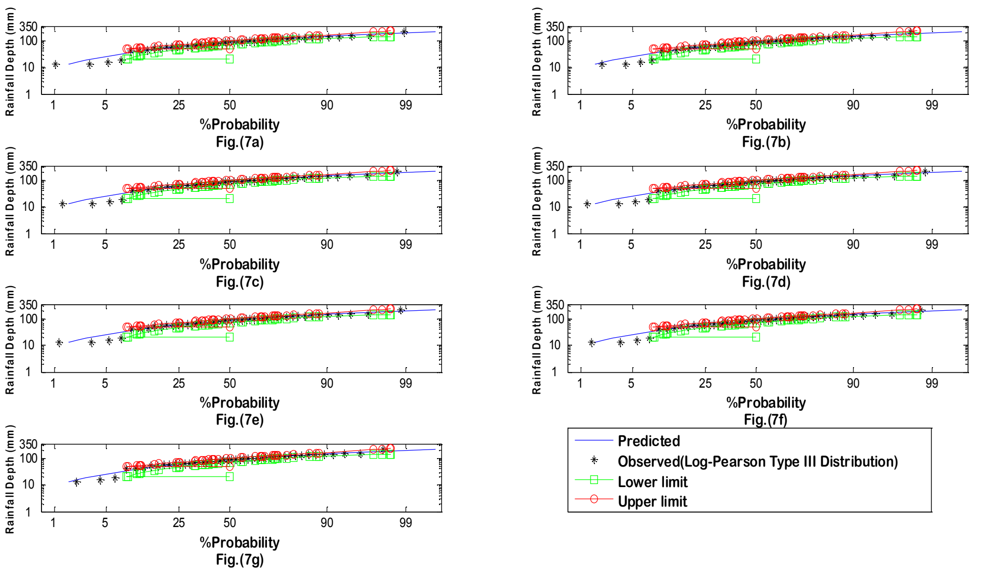

Figure 7. Log-Pearson Type III distribution using (a) Hazen's (b) Weibull's (c) Blom's (d) Cunnane's (e) Gringorton's (f) Chegodajev's (g) California's plotting position.

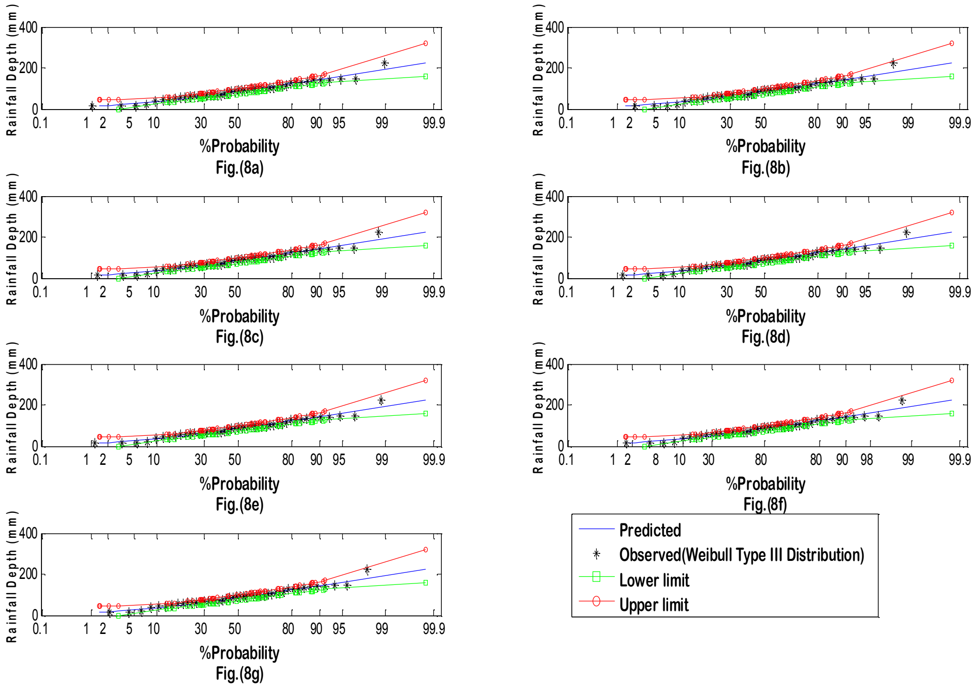

Figure 8.Weibull Type III distribution using (a) Hazen's (b) Weibull's (c) Blom's (d) Cunnane's (e) Gringorton's (f) Chegodajev's (g) California's plotting position.