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Probability Analysis of Rainfall at Udaipur

C. M. PRADEEP, YASMIN AND ASHOK KUMAR SINHA

College of Technology & Engineering, M. P. University & Technology
Udaipur 313001, India
E-mail : pradeep0393@gmail.com

Abstract

Daily rainfall data of Udaipur was obtained from Agro-Meteorological Observatory of CTAE, Udaipur and were analyzed for fitting one day maximum rainfall, maximum weekly rainfall, maximum monthly rainfall and annual rainfall data, using different distributions like Normal, Log-normal, Exponential, Log-dearson Type III, Gumbel (minima), Gumbel (maxima), Frechet (minima), Frechet (maxima 2P), Frechet (maxima 3P), Weibull (maxima), Weibull (maxima 2P), and Weibull (minima 3p) to determine the best fit distribution. It proved useful for design of any water harvesting and soil conservation structures. From the rainfall analysis over the study area, Gumbel (minima), Log-normal, and Log-Pearson Type III distributions were identified for the reliable estimation of one day maximum rainfall with minimum D-index value i. e. 0.17, 0.24 and 0.26 respectively. Weibull (minima 3p), Log-Pearson Type III, Log-normal and Frechet (maxima 2P) distributions were identified for the reliable estimation of Maximum weekly rainfall with minimum D-index values of 0.23, 0.25, 0.27 and 0.28 respectively. Log-Pearson Type III, Weibull (minima 3p), Gumbel (maxima), Log-normal, and Frechet (maxima 2P) distributions were identified for fit condition for maximum monthly rainfall with minimum D-index values i. e. 0.15, 0.15, 0.19, 0.20 and 0.20 respectively. Log-normal, Log-Pearson Type III, Weibull (minima) 3p), Gumbel (maxima), Normal, Weibull (minima 2p), and Frechet (maxima 2P) distributions are identified for the reliable estimation of annual rainfall with minimum D-index values i. e. 0.12, 0.12, 0.12, 0.14, 0.18, 0.20 and 0.24 respectively. However, all 12 distributions viz., Normal, Log-normal, Exponential, Log-Pearson Type III, Gumbel (minima), Gumbel (maxima), Frechet (minima), Frechet (maxima 2P), Frechet (maxima 3P), Weibull (maxima), Weibull (minima 2p), and Weibull (minima 3p), D-index values gave relatively low with Log Pearson Type III distribution, and this is the best fitting distribution for Maximum monthly and annual rainfall, also normal fit for one day maximum and maximum weekly rainfall analysis.
Key words : Rainfall, Probability distributions, Maximum rainfall, Annual rainfalls.

In the present study, Udaipur district is selected as a study area , which is situated in southern part of the largest and driest state Rajasthan of India. It lies between $23^0 45'$ to $25^0 10'$ North latitude and $73^0 0'$ to $74^0 35'$ East longitude encompassing a geographical area of about 12,698 km^2. The climate of Udaipur is tropical, semi-arid with mercury staying between a maximum of 42.3 C and a minimum of 28.8C during summers. Winters are cold with the maximum temperature rising to 28.8C and the minimum dipping to 2.5C. January is the coldest month and May is the hottest month. The mean annual evapotranspiration in the study area is 1, 380 mm. The mean annual rainfall is 625mm, precipitating more than 80% during June through September. The rainy season (i.e., wet season) usually starts from mid-June and lasts for about four months up to the end of October. November to May is characterized as the dry period. Rainfall is one of the most important natural resource input to crop production in the tropical region. Out of 189.54 million ha (1996-97) gross cropped area (including area sown more than once) of the country, 61.3% (116.26 million ha) falls under rainfed farming. In India, the gross irrigated area has been rapidly increasing from 28 million ha in 1960-61 to 72.8 million ha in 1997-98. Despite this progress, marginal and small farmers constituting 80% of agricultural income group, still depend on rainfed farming. The early or delay in onset of monsoon, early or late withdrawal of monsoon, breaks in monsoon period, unusual heavy or no rainfall during the critical phenol-phase of crops may disturb the normal crop growth and development. To exploit the available rainfall effectively, crop planning and management practices must be followed based on the rainfall amount and distribution at a place. Probability analysis can be used for prediction of occurrence of future events from available records of rainfall with the help of statistical methods (1). Based on theoretical probability distributions, it would be possible to forecast the rainfall of various magnitudes of different return periods. Several distributions have been used for hydrological data analysis as given by Chow (2) by various investigations. The primary need of water resource development in any area depends on the estimation of rainfall at different probabilities for efficient planning and design of irrigation and drainage systems, command area development, soil and water conservation programs and the optimum utilization of water resources in various agricultural production systems. Most of the watershed planning activities include the estimation of runoff volume, design of water storage structures and erosion control structure and efficient utilization of runoff for irrigation of different duration like one day, monthly and annual is important for better-planning and management of water resource.

Indian agriculture is subject to vagaries of weather in which rainfall is the main factor. Variability of rainfall, in particular the uncertainty of the amount distribution in any given season, forms the greatest source of risk to crop yields, floods. The effects of rainfall and climatic changes are felt most in the dry land farming areas of the semi-arid tropics and thus keeping tracks of rainfall in both the amount and distribution is important, as it influences many sectors in the economy. Agriculture, transportation, power generation and its use, availability of drinking water, industry and several other domestic activities are related to the annual and seasonal changes of rainfall. Hence, there is a need to analyze and forecast its phenomenon for the purpose of agriculture, industrial and hydrological planning.

The variability of rainfall has long been recognized as an important factor related to water resource. In the past, these variables had lead to an extensive study of rainfall especially with respect to their dependence on a large number of climatic and physiographic factors. In India, the agricultural scenario is closely linked with the rainfall distribution, the major part of which is received during the monsoon months (June to September). Knowledge of its distribution and probability is helpful for agriculture planning especially in dry land areas with the principle that water is the limiting factor and one needs to maximize the efficiency of rain water for agricultural production and its economic implications of rain-sensitive operations.

The saying that the farmers learn to live with the limitation of their local climatic conditions and past experiences is no more reliable in modern agriculture though it provides them with broad information on rainfall, flood and drought prone areas. Thus, the need for a scientific approach towards rainfed agriculture was felt with increasing realization that the failure of rainfall or occurrence of drought is more or less inevitable. Hence, it is essential that one must have a proper knowledge of short period rainfall distributions for timely operations in order to derive maximum benefit from rain fed agriculture. A number of irrigation projects had been executed to negotiate with the varying pattern of rainfall, the fact still remains is a challenge that a large that a large portion of the land completely depends on rainfall for a number of activities and the agricultural production in particular. Many new techniques have been developed with a view to make the dry land agriculture a risk-free occupation to the extent possible by adopting scientifically viable and practical methods in which rainfall analysis in its various facets acts as one of the basic technological input information. It is essential to build up each and every aspect of such a technological know-how on firm scientific basis so that little is left for chance (3).

Methods

The daily rainfall data were collected from Agro-Meteorological Observatory of CTAE, Udaipur. The area comes under the semi-arid south eastern region of the agro-climatic zone IV of the Rajasthan state, and is situated between $23^0 45'$ to $25^0 10'$ north latitude and $73^0 0'$ to $74^0 35'$ east longitute encompassing a geographical area of about 12698 km^2 and 598 m above mean sea level. The daily rainfall data for a period of 37 years (1973-2009) were converted into weekly , monthly and annual rainfall.

Theoretical Consideration of Probability Distributions

The theory of different probability distributions, are given as under. A computer software package VTFIT was used to fit the probability distributions.

Probability Distributions

One of the important problems in hydrology deals wit interpreting a past record of rainfall events, in terms of future probabilities of occurrences. There are many probability distributions that have been found to be useful for hydrologic frequency analysis. These can be summarized as belows.

Normal Distribution

This is a symmetrical, bell shaped, continuous distribution, theoretically representing the distribution of accidental errors about their mean, or the so called law of errors. The probability density function is expressed as

$$P(X) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma}}$$

Where, x = variable; μ = mean value of variable;and σ = the standard deviation. In this distribution mean, mode and median are same. The total area under distribution is equal to unity.

Log Normal Distribution

This is a transformed normal distribution in which the variable is replaced by its logarithmic value. Its probability density function is

$$P(X) = \frac{1}{X\sqrt{2\pi^{\sigma 2}}} e^{\frac{-(\ln x-\mu)^2}{2\sigma^2}}$$

Where, x = a variable; μ = mean; and σ = standard deviation.

This is a skewed distribution of unlimited range in both directions.

Exponential Distribution

The exponential distribution occurs naturally when describing the lengths of the inter-arrival times in a homogenus Poisson process. Its probability density function is

$$P(X) = \frac{1}{\sigma} e^{-(x-\mu)/\sigma}$$

Where, x = variable; μ = mean value of variable ; and σ = standard deviation.

Log Pearson Type III

The general and basic equation defined the probability density of a Pearson distribution is described below

$$P(X) = P_o \left(1 - \frac{x}{a}\right)^{c} e^{-\left(\frac{x}{2}\right)}$$

Where,

$$c = \left({}^{4}/_{\beta}\right) - 1, \quad a = \left({}^{c}/_{2}\right) \left(\mu_3/\mu_2\right),$$

$$\beta = \frac{\mu^2_3}{\mu^2_2}$$

$$Mean: \log x = \left\{ (\Sigma \log x)/n \right\}$$

μ_2 = *Variance*

μ_3 = *third moment about mean* $= \sigma^2 g$

Where, g = skew co-efficint, σ =standard deviation.

Log-Pearson type III distribution to convert the data series to logarithms and adopted by US water Resources Council (1967) was employed in the present analysis.

$$\sigma_{\log x} = \sqrt{\frac{\Sigma (\log x - \overline{\log x})^2}{n-1}}$$

$$skew \; g = \frac{n \Sigma (\log x - \overline{\log x})^3}{(n-1)(n-2)(\sigma_{\log x})^3}$$

The values of x for various recurrence intervals are computed from,

$\log x = \log x + K \log x$

The K-values at different probability exceedence are taken from standard table.

Gumbel (Maxima)

This distribution results from any initial distribution of exponential type, which converts to an exponential function, as x increases. The examples of such initial distributions are normal, chi-square and log normal distributions. The probability density function of type I distribution is

$$P(X) = \frac{e^{-(x-\gamma)/\beta} \; e^{-e(x-\gamma)/\beta}}{\beta}$$

Where, X = variable; α = Shape parameter; β = Scale parameter ; and γ = Location parameter.

Gumbel (Minima)

This distribution results from any initial distribution of exponential type, which converts to an exponential function,as x increases. The examples of such initial distributions are normal, chi-square and log normal distributions. The probability density function of type I distribution is

$$P(X) = \frac{e^{-(\gamma - x)/\beta} \; e^{-e^{-(\gamma - x)/\beta}}}{\beta}$$

Frechet (Minima)

The Frechet is a special case of the generalized extreme value distribution. Its probability density function is

$$P(X) = \frac{\alpha}{\beta}\left(\frac{\beta}{\gamma - X}\right)^{a+1} e^{-\left(\frac{\beta}{y-x}\right)^{a}}$$

Frechet (Maxima Two Parameter)

MauriceFrechet (1878-1973) was a French mathematician who had identified one possible limit distribution for the largest order stattistic in 1927. The Frechet distribution, also known as the Extreme Value Type II distribution, is defined as

$$P(X) = \frac{\alpha}{\beta}\left(\frac{\beta}{X}\right)^{\alpha+1} e^{-\left(\frac{\beta}{\xi}\right)^{\alpha}}$$

Frechet (Maxima Three Parameter)

Its probability density function is

$$P(X) = \frac{a}{\beta}\left(\frac{\beta}{X-\gamma}\right)^{a+1} e^{\left(\frac{\beta}{X-\gamma}\right)^{a}}$$

Weibull (maxima)

Waloddi Weibull (1887-1979) was a Swedish engineer and scientist well-known for his work on strength of materials and fatigue analysis. The Weibull distribution, also known as the Extreme Value Type III distribution, first appeared in his papers in 1939. Its probability density function is

$$P(X) = \frac{\alpha}{\beta}\left(\frac{\gamma - X}{\beta}\right)^{\alpha-1} e^{-\left(\frac{\gamma - x}{\beta}\right)^{\alpha}}$$

Weibull (Minima Two Parameter)

The two-parameter version of this distribution has the density function

$$P(X) = \frac{\alpha}{\beta}\left(\frac{X}{\beta}\right)^{a-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}$$

Weibull (Minima three Parameter)

Its probability density function is

$$P(X) = \frac{\alpha}{\beta}\left(\frac{X-\gamma}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}}$$

Where, X = variable; α = Shape parameter ; β =Scale parameter and γ = Location parameter.

Selection of Probability Distribution Function

It is necessary to test the goodness of fit of a probability distribution for selection, to extrapolate a data series. The D-index test was carried out to test the goodness of fit of the probability distributions employed in the study. The test statistic was calculated from the relationship.

D-Index. D-Index was adopted for comparison of relative fitness of fit of different distributions. It is one the non-parametric statistical methods like chi-square test. It is used to assess the absolute mean deviation from an arbitrary number to know the absolute deviation between observed and estimated values. It is also a measure of dispersion, from which the ratio of minimum deviation between observed and estimated value to arithmetic mean can be found out. It can also be a unit frame measure like percentage and it is used for all variables without frequency limit. Though this statistical technique is not commonly employed, it is a good as chi-square test. In chi-square test, limitation of frequency restriction is imposed but the D-index can be employed without any frequency number restrictins. Some authors have successfully employed this technique for analysis of hydrological parameters earlier (4). Hence this relatively simple non-parametric method (D-index) is aopted for verifying fitness rainfall probability distributions.

$$D\text{-}index = \sum_{i=1}^{n} \frac{\left| x_i\ Observed - x_i\ Estimated \right|}{\bar{x}}$$

Where $\overline{X}$ = mean of the observed rainfall, mm

Table 1. One day maximum rainfall. The parentheses represent the deviation of observed and estimated rainfall.

Probability exceedance (%)		10	25	50	75	90	mean	D-index	Fitting condition
Observed rainfall (mm)		43.46	57.45	69.80	92.45	111.51	74.91		
		28.58	52.85	79.81	106.11	131.04	79.68	0.84	Unfit
	Normal	(14.78)	(4.6)	(-10.01)	(-13.66)	(-19.53)			
Estimated		44.20	56.11	73.14	95.34	121.03	77.96	0.24	Fit
rainfall (mm)	Log normal	(-0.84)	(1.34)	(-3.34)	(-2.89)	(-9.52)			
at different		8.41	22.96	55.32	110.64	183.77	76.22	2.33	Unfit
distributions	Exponential	(34.95)	(34.49)	(14.48)	(-18.19)	(-72.26)			
	Log Pearson type	46.41	54.91	69.19	91.72	123.82	77.21	0.26	Fit
	III	(-3.05)	(2.54)	(0.61)	(0.73)	(-12.31)			
		45.40	57.19	73.30	93.74	117.08	77.34	0.17	Best fit
	Gumbel (minima)	(-2.04)	(0.26)	(-3.5)	(-1.29)	(-5.57)			
		-40.10	24.28	80.64	125.06	157.58	85.53	2.75	Unfit
	Gumbel (minima)	(83.46)	(33.17)	(-10.84)	(-32.61)	(-46.07)			
		-18.75	17.80	48.71	72.37	89.31	49.39	2.20	Unfit
	Frechet (minima 2 P)	(62.11)	(39.56)	(21.09)	(20.08)	(22.2)			
		46.79	55.14	69.00	91.70	126.90	77.91	0.30	Unfit
		(-3.43)	(2.31)	(0.80)	(0.75)	(-15.39)			
	Frechet (maxima 3 P)	42.42	45.61	55.60	93.21	249.96	97.36	2.22	Unfit
		(0.94)	(11.84)	(14.20)	(-0.76)	(-138.45)			
		72.18	89.11	111.75	139.65	170.42	116.62	2.78	Unfit
	Weibull (maxima)	(-28.82)	(-31.66)	(-41.95)	(-47.2)	(-58.91)			
		30.85	49.83	75.83	105.57	134.51	79.32	0.83	Unfit
	Weibull (minima 2P)	(12.51)	(7.62)	(-6.03)	(-13.12)	(-23.00)			
		43.51	50.93	67.51	95.51	132.59	77.99	0.44	Unfit
	Weibull (minima 3P)	(-0.15)	(6.52)	(2.39)	(-3.09)	(-21.08)			

i = Series of rainfall amounts at 10, 25, 5, 75 and 90 per cent probabilities of exceedance.

The D-Index value of less than 0.20 is considered as a best fit , 0.20 to 0.30 is normal fit and above 0.30 will be an unfit distribution as adopted by earlier investigators.

Results and Discussion

A great deal of hydrological data is required in the design of water-related structures. In most cases, the available data are limited which may also contain some gap in the series. When it is decided to carry out a water resources project in a hydrological region, it is first necessary to collect all the information related to the region and then to analyze the collected data. A frequency analysis of the data is the most commonly applied method. Some of the most common and important probability distributions used in the study are the Normal, Log-normal, Exponential, Log-Pearson III Type, Gumbel (minima), Gumbel (maxima), Frechet (minima), Frechet (maxima 2P), Frechet (maxima 3P), Weibull (maxima), Weibull (minima 2P), and Weibull (minima 3P), These distributions are normally used to calculate the annual flows of rivers, hydrological variables such as rainfall, runoff and frequency analysis of floods.

The distribution of rainfall varies over space and time hence it is important to analyze the data covering long periods to obtain reliable information. Further, these data needs to be analyzed in different ways depending on the problem under consideration. The analysis of daily rainfall is more relevant for drainage design of agricultural lands, whereas analysis of weekly rainfall data is more useful for planning cropping pattern and water management practices. Monthly and annual rainfall prediction is more useful for watershed development, command area development and the design of water storage structures like

Table 2. Weekly maximum rainfall. The parentheses represent the deviation of observed and estimated rainfall.

Probability of exceedance (%)		10	25	50	75	90	mean	D-index	Fitting condition
Observed rainfall (mm)		78.76	95.10	113.90	165.65	216.14	133.91		
Estimated rainfall (mm) at different distributions	Normal	65.77	97.60	132.97	168.33	200.16	132.97	0.40	Unfit
		(12.99)	(-2.5)	(-19.07)	(-2.68)	(15.98)			
	Log normal	77.09	96.53	123.93	159.11	199.24	131.18	0.27	Fit
		(1.67)	(-1.43)	(-10.03)	(6.54)	(16.9)			
	Exponential	14.00	38.25	92.17	184.33	306.17	126.98	1.88	Unfit
		(64.76)	(56.85)	(21.73)	(-18.68)	(-90.03)			
	Log Pearson type III	76.92	95.67	122.76	158.70	201.25	131.06	0.25	Fit
		(1.84)	(-0.57)	(-8.86)	(6.95)	(14.89)			
	Gumbel (minima)	14.36	80.16	137.77	183.17	216.41	126.37	0.90	Unfit
		(64.4)	(14.94)	(-23.87)	(-17.52)	(-0.27)			
	Gumbel (maxima)	77.83	97.23	123.74	157.38	195.80	130.40	0.31	Unfit
		(0.93)	(-2.13)	(-9.84)	(8.27)	(20.34)			
	Frechet (minima)	-68.98	21.82	85.68	127.60	154.28	91.67	2.61	Unfit
		(147.74)	(73.28)	(28.22)	(38.05)	(61.86)			
	Frechet (maxima 2P)	82.45	95.46	116.61	150.32	200.90	129.15	0.28	Fit
		(-3.69)	(-0.36)	(-2.71)	(15.33)	(15.24)			
	Frechet (maxima 3P)	67.05	76.77	97.37	143.82	249.24	126.85	0.76	Unfit
		(11.71)	(18.33)	(16.53)	(21.83)	(-33.1)			
	Weibull (maxima)	127.26	153.98	185.76	219.37	250.25	187.32	1.99	Unfit
		(-48.5)	(-58.88)	(-71.86)	(-53.72)	(-34.11)			
	Weibull (minima 2P)	64.05	93.57	130.41	169.40	205.15	132.52	0.36	Unfit
		(14.71)	(1.53)	(-16.51)	(-3.75)	(10.99)			
	Weibull (minima 3P)	73.99	92.62	122.74	162.29	205.03	131.33	0.23	Fit
		(4.77)	(2.48)	(-8.84)	(3.36)	(11.11)			

check dam, percolation and farm pond. The analysis of rainfall data for computation of expected rainfall of a given frequency is commonly done by utilizing different probability distributions.

The computation of observed and estimated rainfall at different probabilities of exceedance at one day maximum, maximum weekly, maximum monthly and annual rainfall at different distributions namely Normal, Log-normal, Exponential, Log-Pearson III Type, Gumbel (minima), Gumbel (maxima), Frechet (minima), Frechet (maxima 2p), Frechet (maxima 3P), Weibull (maxima), Weibull (minima 2P), and Weibull (minima 3P), are described below.

Observed Rainfall

To assess the relative suitability of of distributions, computed and observed values were plotted. The different types of observed rainfall was calculated by Weibull's plotting method at 10, 25, 50, 75 and 90% probabilities of exceedance and presented in Tables 1 to 4. This was minimally processed to know the comparative ability of the prediction of various fitted theoretical distributions. This minimally processed observed data by Weibull plotting position is herein referred as "observed rainfall" only.

Maximum One Day Rainfall

The estimated one day maximum rainfall at different probabilities is presented in Table 1. It is seen from this table that the per cent deviations from the probability distributions are more at 90% probability of exceedence. Also, D-Index value was found to be minimum for Gumbel (minima) (0.17) followed by Log-normal distribution (0.24) and Log-Pearson III Type (0.26). Hence, Gumbel (minima) is considered to be best fitted and followed by Log-normal and Log-Pearson III distributions are normal fit for the one day

Table 3. Maximum monthly rainfalls. The parentheses represent the deviation of observed and estimated rainfall.

Probability of exceedance (%)		10	25	50	75	90	mean	D-index	Fitting condition
Observed rainfall (mm)		160.16	188.10	223.20	298.35	392.96	252.55		
		133.19	190.07	253.27	316.47	373.47	253.27	0.38	Unfit
	Normal	(26.97)	(-1.97)	(-30.07)	(-18.12)	(19.61)			
Estimated		156.57	191.30	239.01	298.62	364.87	250.87	0.20	Fit
rainfall (mm)	Log normal	(3.59)	(-3.2)	(-15.81)	(-0.27)	(28.09)			
at different		26.69	72.86	175.56	351.11	583.18	241.88	2.07	Unfit
distributions	Exponential	(133.47)	(115.24)	(47.64)	(-34.64)	(-190.22)			
		160.02	188.79	232.27	293.30	370.31	248.94	0.15	Best
	Log Pearson type III	(0.14)	(-0.69)	(-9.07)	(5.05)	(22.65)			fit
		89.55	189.99	277.93	347.24	397.98	260.54	0.72	Unfit
	Gumbel (minima)	(70.61)	(-1.80	(-54.73)	(-48.89)	(-5.02)			
		150.20	187.25	237.88	302.10	375.46	250.58	0.19	Best
	Gumbel (maxima)	(9.96)	(0.85)	(-14.68)	(-3.75)	(17.5)			fit
		-46.34	78.85	173.89	240.40	284.85	164.87	2.10	Unfit
	Frechet (minima)	(206.5)	(109.25)	(49.31)	(57.95)	(108.11)			
		166.23	189.41	226.39	283.87	367.59	246.70	0.20	Fit
	Frechet (maxima 2P)	(-6.07)	(-1.31)	(-3.19)	(14.48)	(25.37)			
		157.68	178.70	223.62	326.04	561.56	289.52	0.83	Unfit
	Frechet (maxima 3P)	(2.48)	(9.4)	(-0.42)	(-27.69)	(-168.6)			
		239.85	284.34	339.86	402.43	464.42	346.18	1.85	Unfit
	Weibull (maxima)	(-79.69)	(-96.24)	(-116.66)	(-104.08)	(-71.46)			
		125.66	180.90	248.87	320.02	384.69	252.03	039	Unfit
	Weibull (minima 2P)	(34.5)	(7.2)	(-25.67)	(-21.67)	(8.27)	34.5		
		154.61	183.77	233.54	301.90	378.36	250.44	0.15	Best
	Weibull (minima 3P)	(5.55)	((4.33)	(-10.34)	(-3.55)	(14.6)	5.55		fit

maximum rainfall. The all other distributions are unfit for the one day maximum rainfall.

It was found that the maximum one day rainfall occurred highest in the year 1983 i. e. 262.2 mm and lowest was occurred in the year 1999 i.e. 39.2 mm.

Maximum Weekly Rainfall

The estimated maximum weekly rainfall at different probabilities is presented in Table 2. It was observed that the percent deviations were identified at more in 10% probability of exceedance. Also, the D-Index was found to be minimum in Weibull (minima 3P) (0.23), followed by Log-Pearson Type III (0.25), Log-normal (0.27) and Frechet (maxima 2P) (0.28) distributions are considered to be fit for maximum weekly rainfall. All other distributions are unfit for the maximum weekly rainfall. It was found that the annual rainfall occurred highest in the year 1983 i.e. 307.3 mm and lowest was occurred in 1987 i.e. 55.1 mm.

Maximum Monthly Rainfall

The estimated monthly rainfall is furnished in Table 3. It is inferred from the table that the percent deviations were registered maximum (from 0.14 to 206.5 at 10% probability of exceedance. Also D-Index was observed to be minimum for Log-Pearson Type III (0.15) is considered to be best fitted distribution followed by Weibull (minima 3P) (0.15), and Gumbel (maxima) distributions. Log-normal distribution (0.20) and Frechet (maxima 2p) are considered as normal fit for the maximum monthly rainfall and gave the reliable results for the selected study region. And all other distributions are unfit for the maximum monthly rainfall.

It was found that the maximum monthly rainfall occurred highest in the year 2006 i. e. 593.8 mm and lowest was occurred in the year 1999 i.e. 128.9 mm.

Annual Rainfall

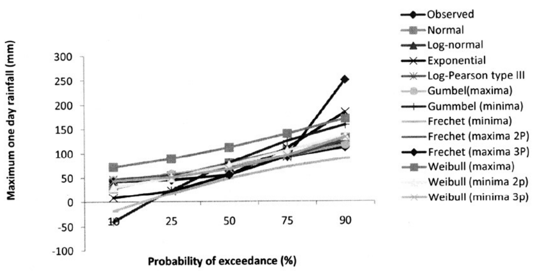

Figure 1. Observed and estimated maximum one day rainfall.

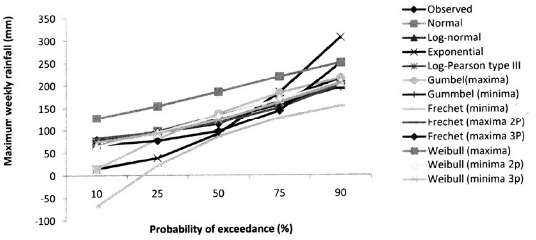

Figure 2. Observed and estimated maximum weekly rainfall.

The estimated annual rainfall at different probabilities is presented in Table 4. It was observed that the percent deviations were identified at more in all the percent (10, 25, 50, 75 and 90% probability of exceedance. The percent deviation values ranged from 106.5 to 776.13 (Frechet (minima), -137.46 to -511.64 (Exponential) distributions at different probability exceedance. Also, the D-Index was found to be minimum in Log-normal (0.12), Log-pearson Type III and Weibull (minima 3P) distributions. From the results, it could be inferred that the five distributions namely Log-normal, Log-Pearson Type III, Weibull (minima 3P), Gumbel (maxima) and Normal distributions were best fitted for annual rainfall to give the reliable esti-

Table 4. Annual rainfall. The parentheses represent the deviation of observed and estimated rainfall.

Probability of Exceedance (%)		10	25	50	75	90	mean	D-index	Fitting condition
Observed rainfall (mm)		379.17	479.65	588.30	711.75	898.87	611.55		
Estimated rainfall (mm) at different distributions		374.42	487.24	612.58	737.92	850.73	612.58	0.18	Best fit
	Normal	(4.75)	(-7.59)	(-24.28)	(-26.17)	(48.14)			
		400.96	479.96	586.12	715.76	856.78	607.92	0.12	Best fit
	Log normal	(-21.79)	(-0.31)	(2.18)	(-4.01)	(42.09)			
		64.54	176.23	424.61	849.21	1410.51	585.02	2.34	Unfit
	Exponential	(314.63)	(303.42)	(163.69)	(-137.46)	(-511.64)			
		401.92	478.67	583.43	713.97	859.23	607.44	0.12	Best fit
	Log Pearson type III	(-22.75)	(0.98)	(4.87)	(-2.22)	(39.64)			
		370.25	515.74	643.11	743.51	817.00	617.92	0.35	Unfit
	Gumbel (minima)	(8.92)	(-36.09)	(-54.81)	(-31.76)	(81.87)			
		408.15	481.64	582.04	709.41	854.90	607.23	0.14	Best fit
	Gumbel (maxima)	(-28.98)	(-1.99)	(6.26)	(2.34)	(43.97)			
		-396.96	112.89	423.97	605.25	710.62	449.94	2.62	Unfit
	Frechet (minima)	(776.13)	(366.76)	(164.33)	(106.5)	(188.25)			
		425.11	475.70	558.27	682.96	862.50	600.91	0.24	Fit
	Frechet (maxima 2P)	(-45.94)	(3.95)	(30.03)	(28.79)	(36.37)			
		378.49	408.55	484.27	698.36	1333.92	660.72	1.02	Unfit
	Frechet (maxima 3P)	(0.68)	(71.1)	(104.03)	(13.39)	(-435.05)			
		603.88	709.50	824.38	932.52	1018.85	817.83	1.69	Unfit
	Weibull (maxima)	(-224.71)	(-229.85)	(-236.08	(-220.77)	(-119.98)			
		353.77	473.74	611.74	784.31	867.25	610.96	0.20	Fit
	Weibull (minima 2P)	(25.4)	(5.91)	(-23.44)	(-36.56)	(31.62)			
		390.48	453.32	562.92	716.17	889.94	602.57	0.12	Best fit
	Weibull (minima 3P)	(-11.31)	(26.33)	(25.38)	(-4.42)	(8.93)			

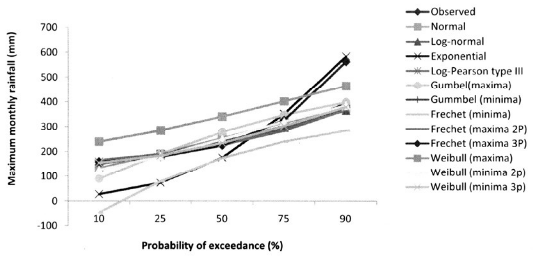

Figure 3. Observed and estimated maximum monthly rainfall.

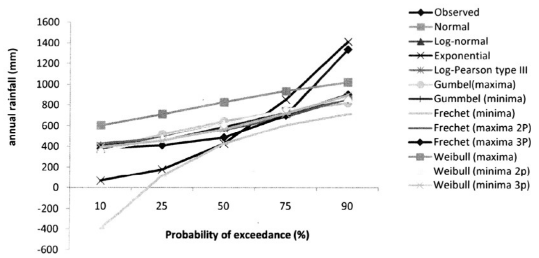

Figure 4. Observed and estimated annual rainfall.

mates in the selected study region and Weibull (minima 2P) and Frechet (maxima 2P) distributions are normally fit for the annual rainfall. And all the other methods are unfit for the annual rainfall.

It was found that the annual rainfall occurred highest in the year 1973 i.e. 1145.3 mm and lowest was occurred in the year 1995 i.e. 333.7 mm.

The observed and estimated rainfall data at different percent of probabilities were also drawn graphically for One day maximum rainfall (Fig.1). Maximum weekly rainfall, (fig. 2), Maximum monthly rainfall (Fig. 3) and Annual rainfall (Fig.4) respectively.

Conculsion

Thirty seven years (1973—2009) daily rainfall data were obtained from the Agro Meteorogical Observatory of CTAE, Udaipur. The data were analyzed for fitting one day maximum rainfall, maximum weekly rainfall, maximum monthly rainfall and annual rainfall through various theoretical distributions; Normal, Log-normal, Exponential, Log-Pearson III Type, Gumbel (minima), Gumbel (maxima), Frechet (minima), Frechet (maxima 2P), Frechet (maxima 3P), Weibull (maxima), Weibull (minima 2P), and Weibull (minima 3P). From the present rainfall analysis of the study area, the following distributions are identified for the reliable estimates of rainfall at different durations considered : Gumbel (minima) followed by Log-normal, and Log-Pearson Type III distributions can be used for the estimation of one day maximum rainfall. Weibull (minima 3P), Log-Pearson Type III, Log-normal and Frechet (maxima 2P) distributions can be used for the estimation of maximum weekly rainfall. Log-Pearson Type III, Weibull (minima 3P), Gumbel (maxima), Log-normal, and Frechet (maxima 2P) distributions can be employed for fitting the maximum monthly rainfall data. Log-normal, Log-Pearson Type III, Weibull (minima 3P), Gumbel (maxima), Normal, Weibull (minima 2P), and Frechet (maxima 2P) distributions serve as the best fit distributions for the annual rainfall data and provide reliable estimates at different probabilities. Log-Pearson Type III distribution is fitted for the all maximum one day, maximum weekly, maximum monthly and annual rainfalls.There is a potential scope to use the above fitted distributions for the design of various structures related to water management and crop planning activities.

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