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Deciphering rainfall patterns in Haryana, India : a comprehensive analysis of optimal probability distributions

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सार – **इस शोध का उद्देश्य अत्यधिक वर्षा की घटनाओं की प्रवृत्तियों की जांच करना और हरियाणा राज्य में वर्षा के लिए सबसे उपयुक्त संभाव्यता वितरण निर्धारित करना था, जिसे दो कृषि जलवायु क्षेत्रों में विभाजित किया गया है: पूर्वी और पश्चिमी। इस विश्लेषण के लिए राज्य भर से पांच स्टेशन (अंबाला, करनाल, हिसार, सिरसा और बावल) चुने गए थे। अध्ययन ने अधिकतम एक दिवसीय और पांच दिवसीय वर्षा, साथ ही मानसून और कुल वर्षा की पहचान करने के लिए प्रत्येक स्टेशन से** 36 **वर्षों** (1985-2020) **के दैनिक वर्षा डेटा को संसाधित और विश्लेषित किया। इन घटनाओं में प्रवृत्तियों का आकलन करने के लिए मान-कंडल परीक्षण और सेन के ढलान अनुमानक का उपयोग किया गया था। वर्षा विश्लेषण के लिए दस संभाव्यता वितरण चुने गए, इसके बाद सर्वश्रेष्ठ-फिट संभाव्यता वितरण का चयन करने के लिए** 0.01 **स्तर के महत्व पर कोलमोगोरोव-स्मिरनोव परीक्षण, एंडरसन डार्लिंग और ची-स्क्वायर परीक्षण जैसे फिट-की-फिट परीक्षण किए गए। उल्लेखनीय रूप से, बावल (दक्षिणी हरियाणा) में एक दिन में अधिकतम वर्षा में** 0.95 **मिमी/वर्ष की दर से उल्लेखनीय वृद्धि हुई। पांच दिन में सबसे अधिक वर्षा अंबाला (**560.8 **मिमी) में और सबसे कम हिसार (**29.6 **मिमी) में हुई। मानसून की बारिश औसत वार्षिक वर्षा का** 78% **थी, जो** 373.6 **मिमी (सिरसा में) से लेकर** 843.5 **मिमी (अंबाला में) तक थी। संभाव्यता विश्लेषणों ने संकेत दिया कि अधिकांश स्थानों पर अधिकांश वर्षा की घटनाओं के लिए सामान्य चरम मान फ़ंक्शन एक अच्छा फिट था। हालांकि, वर्षा चर के आधार पर, हरियाणा में एक दिवसीय अधिकतम वर्षा की घटनाओं के वितरण की व्याख्या करते समय लॉगनॉर्मल (**3P**) फ़ंक्शन अधिकांश स्थानों के लिए सबसे उपयुक्त था। पांच दिवसीय अधिकतम वर्षा की घटनाओं के साथ-साथ मानसूनी वर्षा के लिए, सामान्य चरम मान फ़ंक्शन सबसे उपयुक्त था; और वार्षिक वर्षा की घटनाओं के लिए, सामान्य चरम मान और सामान्य फ़ंक्शन दोनों ने अच्छा प्रदर्शन किया।**

ABSTRACT. This research aimed to examine the trends of extreme rainfall events and determine the most suitable probability distribution for rainfall in Haryana state, which is divided into two agroclimatic zones: eastern and western. Five stations (Ambala, Karnal, Hisar, Sirsa and Bawal) were selected from across the state for this analysis. The study processed and analyzed 36 years (1985-2020) of daily rainfall data from each station to identify the maximum one-day and five-day rainfall, as well as monsoonal and total rainfall. The Man-Kandal test and Sen's slope estimator were used to assess trends in these events. Ten probability distributions were chosen for the rainfall analysis, followed by goodness-of-fit tests such as the Kolmogorov-Smirnov test, Anderson Darling and the chi-square test at a 0.01 level of significance to select the best-fit probability distribution. The study found that one-day maximum rainfall in the state varied significantly, ranging from 23 mm (at Hisar) to 203 mm (at Sirsa). Notably, there was a significant increasing trend in one-day maximum rainfall at Bawal (southern Haryana) at a rate of 0.95mm/year. The maximum five-day rainfall was highest at Ambala (560.8 mm) and lowest at Hisar (29.6 mm). Monsoon rain accounted for 78% of the mean annual rainfall, which ranged from 373.6 mm (at Sirsa) to 843.5 mm (at Ambala). The probability analyses indicated that the General Extreme Value function was a good fit for most rainfall events at most locations. However, based on rainfall variables, the Lognormal (3P) function was the best fit for most locations when explaining the distribution of one-day maximum rainfall events in Haryana. For five-day maximum rainfall events as well as monsoonal rainfall, the Gen. Extreme Value function was the best fit; and for annual rainfall events, both the Gen. Extreme Value and Normal functions performed well.

Key words – One-day maximum rainfall, Probability distribution functions, Man-Kandal test, Kolmogorov-smirnov test, Agroclimatic zones Haryana.

1. Introduction

Effectiveness of rainfall strongly depends on its distribution pattern over time and space and substantially influence the agricultural production. Rainfall is a random variable, meaning it can take on a range of values with varying probabilities. A probability distribution function for rainfall data describes the likelihood of different amounts of rainfall occurring. It provides a complete description of the random variable if every possible value of rainfall is considered. It has long been a topic of interest in the fields of climatology to find a probability distribution that provides a good fit to daily rainfall as well as other rainfall entities like annual, seasonal *etc*. Several studies have been conducted in India and abroad on rainfall analysis and best fit probability distribution function as the probability distribution functions are an essential tool in analyzing rainfall patterns. They help us understand the likelihood of different amounts of rainfall occurring over a given period. These studies have identified various distributions such as normal, log-normal, Gumbel, Weibull, and Pearson type distributions. The choice of the distribution depends on the specific characteristics of the rainfall data being analyzed. For example, the lognormal and gamma distributions have been found to be the best fit for annual and monsoon season rainfall data respectively at a location in Uttarakhand, (Sharma & Singh, 2010). The useof probability distribution functions allows meteorologists and researchers to make informed predictions and better understand the behavior of rainfall patterns. The shape of the probability distribution function can tell us a lot about the rainfall in a particular area. For instance, peaks at low rainfall amounts that tails off as the amounts increase might suggest a dry climate.

There are several types of probability distributions that can be used to model rainfall data, such as the Exponential, Gamma and Normal distributions. The Normal distribution, also known as the Gaussian distribution, is often used due to its simplicity and the central limit theorem. Pearson III distribution is flexible and can handle both skewed and symmetric data and Log-Pearson III distribution is a three-parameter distribution used for frequency analysis in hydrology (Mudashiru *et al.,* 2023). The choice of distribution often depends on the characteristics of the rainfall data and the specific requirements of the analysis. These studies highlight the importance of probability distribution models, such as the Normal, Weibull, Gamma distribution and others, in understanding and analyzing rainfall patterns. The Gamma distribution for example, is a two-parameter distribution that provides a flexible framework for analyzing rainfall data. It has been used in various studies to analyze rainfall patterns and estimate the probability of different amounts of rainfall occurring over a given period (Mooley, 1973).The Gumbel distribution is related to extreme value theory and is likely to be useful if the underlying sample data follows a normal or exponential distribution. The Log-Pearson Type III distribution can be used calculate statistical information such as mean values, standard deviations, skewness and recurrence intervals using peak events data and it can take on many forms (like normal distribution, log-normal distribution *etc*.) according to the equations used to carry out the statistical analyses (Derron Coles., 2023). A study conducted in Northeastern Brazil analyzed the fit of different probability distribution models to monthly precipitation data from 293 rainfall stations. The results showed that the Gamma distribution provided one of the best fits for the data (Ximenes *et al.*, 2021). Another study focused on explaining why temporally averaged distributions, including the Gamma distribution, tend to have a gamma-like shape (Martinez V & Neelin, 2019). The Lognormal (3P) is general skew distribution and useful model for many natural phenomena where negative values are not possible, such as rainfall amounts (Sangal *et al.*, 1970). On the other hand, the numerous studies in literature revealed that there is no standard or common method to find out maximum rainfall probability levels (Singh *et al.*, 2004; Eitzinger *et al*., 2009; Bemal *et al.*, 2012). Each parameter has its own pros and cons and one can’t fit on all locations. Therefore, it becomes important to examine and select a best method for any study area or location on earth because of their different climatological and geographical settings. This study focuses on the rainfall analysis in Haryana, a state in India known for its agricultural significance. The state’s unique position in the semi-arid region of Northwest India is the reason in this analysis. The geographical area of Haryana state is probably more susceptible for climate change and variability (Singh *et al*., 2010) as being situated in a transition zone from cool climate in its North-eastern margins (Siwalik hills) to hot and dry climate of Thar desert in south-western margins. Therefore, this study is designed to examine rainfall and their trends at well distributed five different locations in Haryana state (India), as the bulk of state’s agricultural production is heavily influenced by the unpredictability of the monsoon (*kharif*) season. Winter (*rabi* season) rainfall, although significantly lower than monsoon rainfall, is caused by western disturbances and is crucial for the growth of wheat crops. The region experiences significant variations in rainfall, both spatially and temporally, which impact the *rabi* and *kharif* crops, and in turn, the state’s economy. For in-depth understanding the pattern of rainfall, the present study focus on finding the best fit probability distribution function at well distributed five different locations in the state encompassing the two agroclimatic zones as shown in Fig. 1. The findings of this study will be beneficial for policy makers as well as researchers in improving the prediction/statistical models for better judgements on rainfall events and trends *etc*.using these location specific best probability functions. These can also be used by government agencies in formulatingstrategies and improving agricultural management, such as irrigation management, flood control, drainage dynamics, erosion and even the development of crop varieties specific to the location *etc*.

2. Material and methods

2.1. *Study area*

The present study corresponds to a landlocked state of India *i.e.*Haryana, lying between 27°39' to 30°35' N latitudes and 74°28' to 77°36' E longitudes. Comprising 22 smaller administrative units as districts, the study area spread over an area of 44,212 km^2, covering 1.3% of the total area of the country. Without having any its own perineal river, the state is bordered by Yamuna in the east and *Ghaggar* (seasonal river) in the northwest sides. Haryana bears a continental type climate in most of parts where server hot & dry summers and cool short winters forms its climate characteristics. Mainly, the climate of Haryana is hot and dry, with temperatures ranging from 5°C in winter to 45°C in summer. The state experiences monsoon rains from July to September that amounts to 78% of its annual average rainfall (613 mm). The state is divided equally into two agroclimatic zones (Fig. 1),*i.e.*, eastern and western zones (Singh *et al*., 2010).

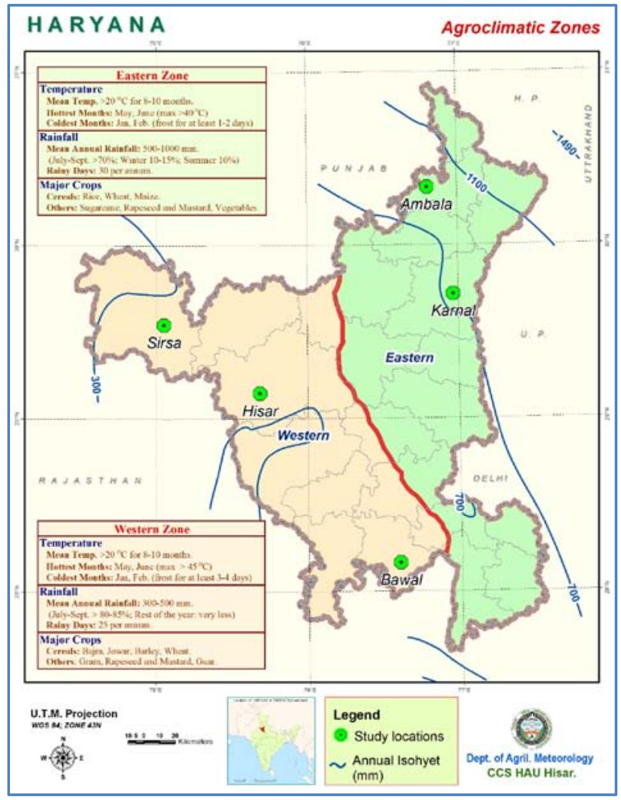


Fig. 1. Study Locations and Agroclimatic zones in Haryana

Haryana is an agricultural state in India and most of the area in under cultivation.The cropping pattern in the state has undergone significant changes over the years due to increased irrigation facilities and agricultural developments. The state has two main cropping seasons, namely Kharif and Rabi. The Kharif season extends from April-May to October whereas the Rabi season starts after monsoon withdrawal or start of winter *i.e*. from October that ends in March - April. The kharif crops includes rice, cotton, jawar, bajra, maize and dominant *rabi* crops are wheat and mustard.

2.2. *Data sources*

The rainfall database for long period, *i.e*., 36 years (1985-2020) recorded from agrometeorological observatories of CCS Haryana Agricultural University at Hisar and Bawal (Rewari) locations is maintained in Dept. of Agricultural Meteorology, CCS HAU Hisar. The other three locations, *i.e*., Karnal (CSSRI), Sirsa (ICAR-CICR) and Ambala (IMD-AMFU) database available in the department was accessed for analysing the extreme rainfall events, their trends, best fit probability distribution for the Haryana state. The selected five locations, *viz*., Ambala, Karnal, Hisar, Sirsa and Bawal that are widely distributed in the state as shown in Fig. 1. The first two locations, *i.e*., Ambala and Karnal corresponds to eastern agroclimatic zone and rest of the three fall in western agroclimatic region.

2.3. *Data processing*

The data was firstly complied in MS Excel and extreme events (one day and five days cumulative rainfall) was derived out using *RClimDex* software (developed by ETCCDI group climate change indices). Non parametric Mann-Kendall test (MK test) was opted to find statistical significance of trends in the climatic indices and computed using *MAKESENS* (an excel template) developed by Salami *et al.* (2002). This test had been employed widely for time series analysis of weather data. Probability distribution functions analysis was done using *Easyfit 5.6* software. Without delving into intricate mathematics, the study also suggested the utilization of software or packages to compute the distributions, as the mathematical principles underlying these distributions are readily accessible in existing literature.

2.3.1. *Rainfall analysis*

The RClimDex software is widely used national as well as internationally for studies on extreme rainfall events. In the present study, set of four indices related to rainfall were computed as (*i*) one day maximum rainfall, (*ii*) five days maximum rainfall, (*iii*) monsoon rainfall and (*iv*) annual rainfall.

2.3.2. *Probability analysis*

The rainfall data for each index was analysed to find the best fit probability distribution for all the five stations. A total of 10 probability distributions were selected for the purpose. These are (*i*) General Extreme Value, (*ii*) General Gamma, (*iii*) General Gamma (4P), (*iv*) Gumbel Max, (*v*) Log-Pearson 3, (*vi*) Lognormal, (*vii*) Lognormal (3P), (*viii*) Normal, (*ix*) Weibull and (*x*) Weibull (3P). The goodness of fit test measures the compatibility of the random sample with the theoretical probability distribution, therefore, the goodness-of-fit tests, *viz*., *Kolmogorov-Smirnov test*, *Anderson Darling and the chi-square* test at α (0.01) level of significance were performed for the selection of the best fit probability distribution. The goodness of fit tests mentioned above were fitted to the various rainfall data (*viz*. one day and five days max., total and monsoonal rainfall) treating as different data sets. The test statistic of each test was computed and tested at (α=0.05) level of significance. Accordingly, the ranking of different probability distributions was marked from 1 to 10 based on the minimum test statistic value. The distribution holding the first rank was selected as the best distribution and the probability distribution having the minimum score by combining all ranks (in all three tests) was considered as the best probability distribution for the said rainfall parameter.

3. Results and discussion

The analysis of rainfall events is summarised under two points, *i.e*., (*i*) rainfall events analysis and (*ii*) probability analysis, as described hereunder:

3.1. *Rainfall events analysis*

3.1.1. *Maximum one-day rainfall*

One day maximum rainfall means highest one-day precipitation in a year and the same was find out for all of the stations during the study period of 36 years. The graph of one day maximum rainfall (as shown for every location in Table 1.1) can provide valuable insights into weather patterns and climate change corresponding to different parts of the state. Here, the One-day maximum rainfall showed a varied pattern in the state. Average of 36 years was highest at Karnal with 92.9 mm followed by Ambala (89.2 mm), Bawal (84.7), Sirsa (77.6) and Hisar (76.2) stations. Range of one day maximum rainfall (*i.e*. comparison of minimum and maximum) shown great variability in entire state, especially in western agroclimatic zone.

An increasing trend in graph could indicate that extreme rainfall events are becoming more frequent, possibly due to climate change. Conversely, a decreasing trend might suggest that such events are becoming less common. The graphs of each location (Table 1.1) revealed an increasing pattern in one day maximum rainfall in the last fifteen year, *i.e*., 2004-05 afterwards up to 2020, however no significant trends in one day maximum rainfall were observed at most of stations as per Man Kendal analysis except for Bawal where significant increasing trends were observed. The Sens' slope estimator exhibited an increasing rainfall rate of 0.95mm/year at this location. Ambala in northern Haryana also exhibited a little increasing trend of one day maximum rainfall events. The two locations having significant increasing trends are located southern and northern parts of state. The higher or increasing values of one day maximum rainfall is indication of high rainfall intensity which can lead to loss of crops due to poor drainage conditions in state due to nearly flat topography.

3.1.2. *Maximum cumulative five-day rainfall*

A cumulative five-day rainfall graph is a representation of the total amount of rainfall accumulated over five consecutive days. Average of 36 years five days cumulative maximum rainfall was highest at Ambala with 172.7 mm followed by Karnal (156.2 mm), Bawal (132.8 mm), Hisar (117.2 mm) and Sirsa (106.7 mm) stations (Table 1.2). Range of five-day maximum rainfall (*i.e*. comparison of minimum and maximum rainfall during a day) shown great variability at all stations. No significant trends were observed over the time period (1985-2020) in five days cumulative rainfall at any of station. The graph for cumulative five-day rainfall can provide valuable insights into weather patterns, particularly in relation to extreme weather events. A sharp increase in the graph could indicate a heavy rain event over a five-day period and such information can be crucial for flood forecasting and water resource management.The Ambala have shown more fluctuation in eastern agroclimatic zone as compared to all other locations.

3.1.3. *Monsoon rainfall (June - September)*

The rainfall in the months of June to September is considered as monsoon rainfall that contributes to 75-80%

TABLE 1.1

Maximum one-day rainfall in Haryana

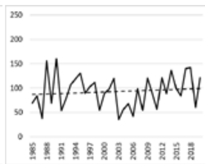
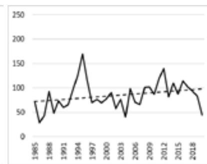
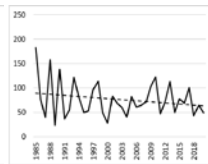
	Ambala	Karnal	Bawal	Hisar	Sirsa
One day rainfall (mm) (normal)	89.2	92.9	84.7	76.2	77.6
(Max. -Min) mm	196.7 – 47.5	159.8 – 35.6	169.6 – 28.8	182.4 – 23.3	203.0 – 24.4
Trends MK	1.74+	-	2.18*	-	-
Sen Slope (S)	-	-	@0.95 mm/year	-	-
250 Rain (mm) 0 (Years) 1985 to 2020					

TABLE 1.2

Maximum cumulative five-day rainfall in Haryana

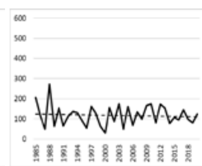
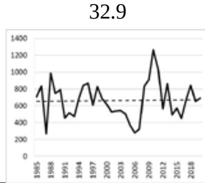
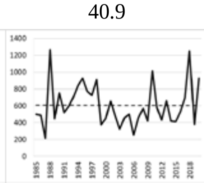
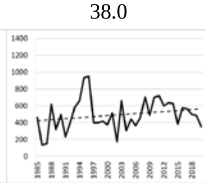
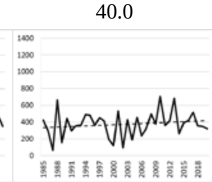
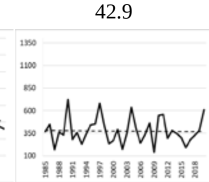
	Ambala	Karnal	Bawal	Hisar	Sirsa
RX5days cumulative rainfall (mm) (normal)	172.7	156.2	132.8	117.2	106.7
(Max. -Min) mm	560.8 – 69.9	316.8 – 68.4	294.4 – 41.3	271.1 – 29.6	274.5 – 30.2
600 Rain (mm) 0 (Years) 1985 to 2020					

TABLE 1.3

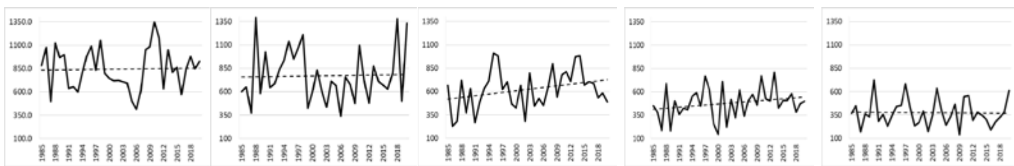
Monsoon rainfall in Haryana

	Ambala	Karnal	Bawal	Hisar	Sirsa
Monsoon precipitation (mm)	662.7	608.6	493.9	375.6	291.2
Range (Max. -Min) mm	268.3 – 1263.8	215.3 – 1265.3	133.7 – 948.9	63.5 – 707.8	52.0 – 583.2
SD	218.0	248.9	187.6	150.4	124.8
CV	32.9	40.9	38.0	40.0	42.9
1400 Rain (mm) 0 (Years) 1985 to 2020					

of annual rainfall in Haryana. Highest average monsoonal rainfall was observed at Ambala with 662.7 mm followed by Karnal (608.6 mm), Bawal (493.9 mm), Hisar (375.6 mm) and Sirsa (291.2 mm) stations (Table 1.3). The coefficient of variation (CV) was highest for Sirsa in western agroclimatic region and for Karnal in eastern region.Although the appearance of graph reveals an increasing pattern of monsoon rainfall at most of locations but no significant treads observed at any location on MK test.

TABLE 1.4

Annual rainfall in Haryana

	Ambala	Karnal	Bawal	Hisar	Sirsa
Annual precipitation (mm)	843.6	771.6	621.5	477.7	373.7
Range (Max. -Min) mm	414.3 – 1347.2	337.2 – 1391.3	288.8 – 1008.7	143.2 – 808.7	137.0 – 722.4
SD	217.1	277.9	205.0	162.5	140.9
CV	25.7	36.0	33.0	34.0	37.7
1400 Rain (mm) 100 (Years) 1985 to 2020					

3.1.4. *Annual rainfall*

It describes total rainfall in a year. The pattern of annual rainfall (as shown in graphs in Table 1.4) is more of less same as of monsoon rainfall because about three fourth of annual rainfall received in Haryana during monsoon period only. In eastern agroclimatic zone Ambala showed highest amount of rainfall (normal) 843.6 mm followed by Karnal (771.6 mm) whereas in western zone, Bawal had highest rainfall of 621.5 mm followed by Hisar (477.7 mm) and Sirsa (373.7mm). The CV was again highest for Karnal and Sirsa while the least was at Ambala. No significant increasing or decreasing trends were observed at any of location on annual rainfall events during the period 1985-2020 in the state (Table 1.4).

Trend statistics revealed that Annual rainfall in the state (on the basis of all locations in the study) is not changing in long period average although having high temporal and spatial variability. Further, the analysis also revealed a fairly increasing trends of rainfall at Bawal location (in south Haryana) as compared to other locations in the state but the values were not statistically significant. The significant increasing trends were observed only in One day maximum rainfall at Ambala and Bawal locations in the state.

3.2. *Probability analysis*

Probability distribution functions (PDFs) are fundamental to the study of statistics and natural phenomena. When applied to rainfall data, they provide a mathematical model that represents the variations in rainfall over a period of time.

Owing to high spatial variability of rainfall at locations analysed in the study, probability analysis was ought to be done to determine the best fit distribution for rainfall variables, *viz*., One day maximum rainfall, five days maximum rainfall, Monsoon season rainfall (June-Sept.) and Annual rainfall of all stations. Reviewing the studies conducted on the theme, ten probability functions were selected in the present study as described below:

3.2.1. *One day maximum rainfall*

The statistical description and parameter estimation of various fitting distributions of one day max. rainfall at all stations is given in the following Tables 2.1 and 2.2 respectively. Table 2.1 Descriptive Statistics for One Day Maximum Rainfall.

Based on these parameters and statistics, the probability distribution for all analyzed stations and test statistics, as per the goodness of fit tests, was ranked (with the minimum being the best and ranked first) as displayed in Table 2.3. Ultimately, the composite rank score derived from all three tests was used to determine the probability distribution with the lowest rank score, which was then considered the best fit for explaining the one-day maximum rainfall distribution at each respective station.

The analysis revealed that the Lognormal (3P) distribution was identified as the best fit for interpreting the one-day maximum rainfall distribution in Haryana, specifically in the Ambala, Bawal and Hisar regions. Conversely, the General Extreme Value and Lognormal distributions emerged as the most suitable functions for the Karnal and Sirsa stations, respectively.

TABLE 2.1

Descriptive statistics for one day maximum rainfall

	Ambala	Bawal	Hisar	Karnal	Sirsa
Sample Size (year)	36	36	36	36	36
Minimum	47.5	28.8	23.3	35.6	24.4
Range	149.2	140.8	159.1	124.2	178.6
Mean	89.242	84.739	76.206	92.894	77.608
Maximum	196.7	169.6	182.4	159.8	203
Variance	896.44	854.9	1334.9	1152.5	1614.6
Std. Deviation	29.941	29.239	36.536	33.948	40.183
Coef. of Variation	0.3355	0.34504	0.47944	0.36545	0.51776
Std. Error	4.9901	4.8731	6.0893	5.6581	6.6971
Skewness	2.1726	0.57611	1.0776	0.14461	1.8206
Excess Kurtosis	5.8275	0.90445	1.0021	-0.8584	3.9065
5%	52.005	38.83	27.55	37.64	30.52
10%	58.97	44.46	38.68	50.06	34.16
25% (Q1)	75.85	66.65	49.325	62.15	54.05
50% (Median)	82.2	82.2	68.85	89.7	69.2
75% (Q3)	94.15	101.63	99.7	120.15	80.75
90%	128.76	121.01	127.14	140.88	130.56
95%	183.01	144.44	161.91	156.57	203

TABLE 2.2

Parameter estimation of various fitting distribution for one day maximum rainfall

S. No.	Probability distribution function	Ambala	Bawal	Hisar	Karnal	Sirsa
1.	Gen. Extreme Value	k=0.22107 σ=15.998 μ=75.582	k=-0.1438 σ=26.578 μ=72.747	k=0.08864 σ=26.503 μ=58.375	k=-0.2233 σ=33.661 μ=79.677	k=0.18776 σ=23.353 μ=58.858
2.	Gen. Gamma	k=1.0593 α=10.159 β=10.045	k=0.9976 α=8.3526 β=10.089	k=1.0276 α=4.5514 β=17.517	k=0.9863 α=7.2728 β=12.406	k=1.0635 α=4.1037 β=20.805
3.	Gen. Gamma (4P)	k=0.56221 α=12.369 β=0.55943 γ=37.186	k=1.7427 α=2.5189 β=48.498 γ=6.1746	k=1.3492 α=1.3562 β=47.796 γ=20.101	k=3.7392 α=0.25192 β=115.79 γ=35.6	k=0.56599 α=9.0873 β=1.2003 γ=13.839
4.	Gumbel Max	σ=23.345 μ=75.767	σ=22.797 μ=71.58	σ=28.487 μ=59.763	σ=26.469 μ=77.616	σ=31.33 μ=59.524
5.	Log-Pearson 3	α=4.5527 β=0.13313 γ=3.8423	α=10.884 β=-0.11164 γ=5.593	α=2528.6 β=-0.00936 γ=27.893	α=14.95 β=-0.10389 γ=6.0117	α=135.03 β=0.03995 γ=-1.1501
6.	Lognormal	σ=0.28009 μ=4.4484	σ=0.36317 μ=4.3779	σ=0.46405 μ=4.2271	σ=0.39606 μ=4.4586	σ=0.45767 μ=4.2435
7.	Lognormal (3P)	σ=0.42892 μ=3.992 γ=29.6	σ=0.17191 μ=5.0992 γ=-81.585	σ=0.4664 μ=4.222 γ=0.30974	σ=0.10925 μ=5.7211 γ=-214.17	σ=0.48576 μ=4.1833 γ=3.6488
8.	Normal	σ=29.941 μ=89.242	σ=29.239 μ=84.739	σ=36.536 μ=76.206	σ=33.948 μ=92.894	σ=40.183 μ=77.608
9.	Weibull	α=4.2819 β=94.704	α=3.2566 β=92.04	α=2.5288 β=82.497	α=2.8839 β=102.35	α=2.5419 β=83.558
10.	Weibull (3P)	α=1.5595 β=48.013 γ=46.151	α=2.3494 β=72.484 γ=20.407	α=1.56 β=61.096 γ=21.273	α=2.2015 β=78.353 γ=23.518	α=1.4442 β=60.17 γ=23.055

TABLE 2.3

Station wise ranked probability distribution using different goodness of fit tests for one day maximum rainfall

Probab. Distributions	Ambala	Rank	Bawal	Rank	Hisar	Rank	Karnal	Rank	Sirsa	Rank
Kolmogorov Smirnov test										
Gen. Extreme Value	0.15067	3	0.07885	2	0.05823	1	0.08586	1	0.18689	9
Gen. Gamma	0.18788	9	0.08493	7	0.09069	9	0.10416	7	0.18539	8
Gen. Gamma (4P)	0.13997	2	0.07913	3	0.07961	5	0.12049	9	0.16515	2
Gumbel Max	0.15591	4	0.07966	4	0.07968	6	0.12294	10	0.17358	6
Log-Pearson 3	0.16156	6	0.08046	5	0.06608	4	0.09282	2	0.1725	5
Lognormal	0.16173	7	0.10332	10	0.06193	3	0.11091	8	0.16097	1
Lognormal (3P)	0.13502	1	0.07279	1	0.06166	2	0.10195	6	0.1663	4
Normal	0.22658	10	0.08303	6	0.14846	10	0.09325	3	0.24414	10
Weibull	0.18044	8	0.0892	9	0.08538	8	0.10003	5	0.17471	7
Weibull (3P)	0.16097	5	0.08757	8	0.0842	7	0.09984	4	0.16567	3
Anderson Darling test										
Gen. Extreme Value	1.0105	2	0.16495	2	0.13624	4	0.2428	1	0.9445	4
Gen. Gamma	1.5907	8	0.20222	6	0.24766	8	0.39773	7	1.1802	8
Gen. Gamma (4P)	1.0317	3	0.16722	3	0.1775	5	4.2851	10	0.96301	5
Gumbel Max	1.3788	6	0.39541	10	0.2003	6	0.82975	9	1.1737	7
Log-Pearson 3	1.2531	5	0.18439	4	0.13424	1	0.29944	3	0.91812	3
Lognormal	1.1537	4	0.37064	9	0.1357	3	0.543	8	0.91456	1
Lognormal (3P)	0.95245	1	0.14702	1	0.13525	2	0.32779	6	0.91649	2
Normal	2.6029	9	0.22451	7	0.89577	10	0.30366	4	2.3241	10
Weibull	2.8699	10	0.24469	8	0.63019	9	0.27135	2	1.693	9
Weibull (3P)	1.4886	7	0.20144	5	0.20236	7	0.32594	5	1.1675	6
Chi-Squared test										
Gen. Extreme Value	7.1914	6	0.36613	2	0.42898	3	0.70709	3	17.877	7
Gen. Gamma	3.7248	2	0.7581	4	0.86621	5	4.4436	9	3.9215	3
Gen. Gamma (4P)	7.1241	4	0.78356	5	1.5618	8	N/A	10	2.5888	1
Gumbel Max	12.276	10	0.45542	3	0.96188	6	4.4307	8	4.3334	4
Log-Pearson 3	8.7683	7	0.79946	6	0.82974	4	3.8101	7	21.78	9
Lognormal	3.8075	3	1.1075	8	0.38507	1	3.6823	6	2.5997	2
Lognormal (3P)	7.1498	5	0.36204	1	0.38577	2	0.9272	4	21.666	8
Normal	9.2041	8	1.1542	9	5.3268	10	0.68014	2	25.169	10
Weibull	3.6724	1	0.99298	7	1.6461	9	0.58911	1	6.5527	5
Weibull (3P)	11.131	9	1.4241	10	1.5348	7	2.1865	5	7.2227	6

Composite Ranking (on the basis of all three tests)

	Ambala	Bawal	Hisar	Karnal	Sirsa
Gen. Extreme Value	11	6	8	5	20
Gen. Gamma	19	17	22	23	19
Gen. Gamma (4P)	9	11	18	29	8
Gumbel Max	20	17	18	27	17
Log-Pearson 3	18	15	9	12	17
Lognormal	14	27	7	22	4
Lognormal (3P)	7	3	6	16	14
Normal	27	22	30	9	30
Weibull	19	24	26	8	21
Weibull (3P)	21	23	21	14	15

TABLE 2.13

Best probability functions for rainfall variables at different locations

S. No.	Rainfall variable	Ambala	Bawal	Hisar	Karnal	Sirsa
1.	One day maximum rainfall	Lognormal (3P)	Lognormal (3P)	Lognormal (3P)	Gen. Extreme Value	Lognormal
2.	Five days cumulative maximum rainfall	Lognormal	Gen. Extreme Value	Weibull (3P)	Gen. Extreme Value	Gen. Extreme Value
3.	Annual rainfall	Normal	Lognormal (3P)	Normal	Gen. Extreme Value	Gen. Extreme Value, Lognormal (3P)
4.	Monsoon rainfall	Gen. Extreme Value	Lognormal (3P)	Normal	Gen. Extreme Value, Lognormal	Gen. Extreme Value

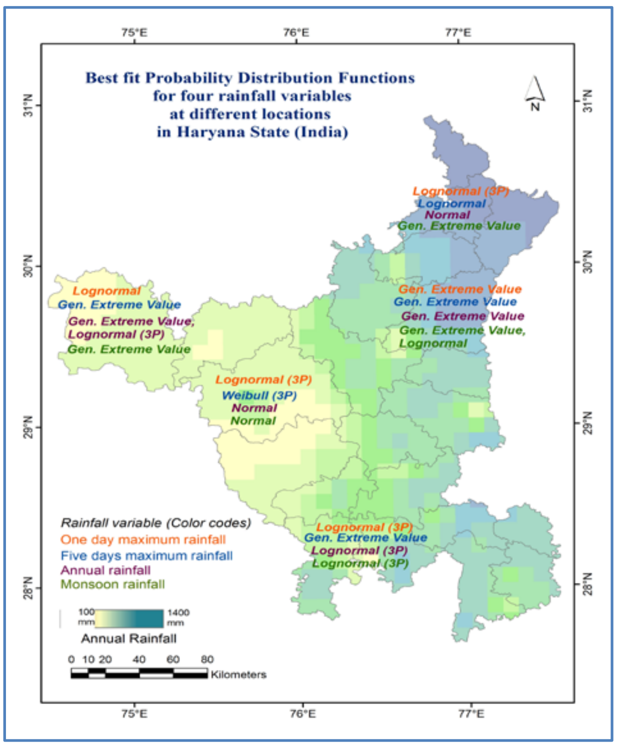


Fig. 2. Location wise Best fit distributions for various rainfall events in Haryana

The examination of the remaining three rainfall variables, *i.e.*, five-day cumulative maximum rainfall, annual rainfall, and monsoon rainfall - for all locations is detailed in Tables 2.4 to 2.12 (**Annexure**). A summary of the best fit distribution function for all rainfall variables, organized by location, is provided in Table 2.13.

4. Conclusion

From the aforementioned tabulation, it can be inferred that the General Extreme Value function appears most frequently in Table 2.13, thus making it the most suitable fit for the majority of rainfall events in Haryana. This distribution is also widely used in various fields such as hydrology, meteorology, environmental science, civil engineering, structural engineering and even finance where modelling of extreme events is necessary. When considering rainfall variables, the Lognormal (3P) distribution was found to be themost effective at the majority of locations for characterizing the distribution of one-day maximum rainfall events in Haryana. Whereas, in the case of five-day maximum rainfall events, theGeneral Extreme Value function proved to be the most effective. For annual rainfall events, both the General Extreme Value and Normal functions performed well. As for monsoon rainfall events,the General Extreme Value function was identified as the best distribution function in Haryana state, as illustrated in Map (Fig. 2).

Distribution functions play a crucial role in analyzing rainfall data. They help model the variability and frequency of rainfall amounts and events across time and space, estimate the likelihood and recurrence intervals of extreme rainfall events such as floods and droughts and analyze the spatial and temporal patterns of rainfall in relation to climate change and variability. Given that Haryana is predominantly an agricultural state, such analyses can assist policymakers in managing resources more precisely, including flood control, drainage, erosion prevention and water storage *etc.*

Rainfall patterns in Haryana exhibit significant spatial and temporal diversity, as evidenced by the substantial variations in all rainfall events (one day, five day, monsoon, and annual) across different locations or agroclimatic zones. The temporal variations are particularly noticeable, with annual and monthly fluctuations (more than 70% of rainfall occurs during the four monsoon months).

The one-day maximum rainfall has shown increasing trends at Bawal and Karnal, indicating higher rainfall intensities that could lead to short-term disasters. Such events may be unmanageable without prior understanding or anticipation of rainfall events that could negatively impact crops. The study also suggests more variations in these events as the annual rainfall has not been found to change over time.

The study can assist in better predicting and analyzing rainfall frequencies and trends using location-specific probability distribution functions. These functions can undoubtedly be beneficial for stochastic rainfall models for each location and can be useful in filling missing records and extending the length and spatial coverage of rainfall data.

The study additionally recommends the application of advanced statistical methods for a more comprehensive understanding of rainfall frequency, trend analysis and modelling. The probability distribution functions proposed in this study can be utilized for improved prediction

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Disclaimer : The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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Annexure

TABLE 2.4

Descriptive statistics for five day maximum rainfall

	Ambala	Bawal	Hisar	Karnal	Sirsa
Sample Size	36	36	36	36	36
Range	490.9	253.1	241.5	248.4	244.3
Mean	172.67	132.85	117.22	156.15	106.67
Variance	7290.9	2698.0	2634.2	4048.4	2886.1
Std. Deviation	85.387	51.943	51.324	63.627	53.722
Coef. of Variation	0.4945	0.391	0.43785	0.40746	0.50363
Std. Error	14.231	8.6571	8.5541	10.604	8.9537
Skewness	2.8881	1.0327	0.65701	0.48185	1.7304
Excess Kurtosis	11.825	1.8348	0.76055	-0.38834	3.838
Minimum	69.9	41.3	29.6	68.4	30.2
5%	80.78	54.305	46.09	70.27	35.045
10%	96.55	71.1	52.58	74.68	54.73
25% (Q1)	124.78	97.25	77.7	100.28	70.95
50% (Median)	150.7	127.25	111.85	160.25	96.6
75% (Q3)	199.3	152.72	154.57	203.05	119.43
90%	250.8	204.79	173.63	236.52	170.48
95%	359.94	255.21	215.0	281.27	274.5
Maximum	560.8	294.4	271.1	316.8	274.5

TABLE 2.5

Parameter estimation of various fitting distribution for one day maximum rainfall

S. No.	Probability distribution function	Ambala	Bawal	Hisar	Karnal	Sirsa
1.	Gen. Extreme Value	k=0.22052 σ=44.486 μ=134.73	k=-0.00866 σ=41.004 μ=109.53	k=-0.1331 σ=46.576 μ=95.813	k=-0.11238 σ=57.586 μ=128.73	k=0.14679 σ=33.807 μ=81.463
2.	Gen. Gamma	k=1.0983 α=4.7722 β=42.224	k=1.0143 α=6.7281 β=20.309	k=0.99518 α=5.1695 β=22.472	k=1.002 α=6.0459 β=25.926	k=1.0527 α=4.2765 β=27.056
3.	Gen. Gamma (4P)	k=0.53286 α=9.5955 β=1.5827 γ=51.716	k=0.893 α=9.5258 β=11.047 γ=-6.5661	k=2.3439 α=0.69321 β=127.63 γ=25.019	k=2.6102 α=0.2897 β=162.38 γ=68.4	k=0.57142 α=12.624 β=1.1267 γ=6.1927
4.	Gumbel Max	σ=66.576 μ=134.24	σ=40.499 μ=109.47	σ=40.017 μ=94.121	σ=49.61 μ=127.52	σ=41.887 μ=82.492
5.	Log-Pearson 3	α=8.4663 β=0.13591 γ=3.9165	α=22.718 β=-0.08364 γ=6.7155	α=13.918 β=-0.12755 γ=6.438	α=143.46 β=-0.03548 γ=10.056	α=1285.2 β=-0.01306 γ=21.343
6.	Lognormal	σ=0.38993 μ=5.0672	σ=0.39307 μ=4.8153	σ=0.4692 μ=4.6627	σ=0.41899 μ=4.9663	σ=0.4615 μ=4.5629
7.	Lognormal (3P)	σ=0.51131 μ=4.7804 γ=35.993	σ=0.2735 μ=5.1649 γ=-48.883	σ=0.26817 μ=5.2014 γ=-70.912	σ=0.4201 μ=4.9636 γ=0.34657	σ=0.42587 μ=4.642 γ=-7.1443
8.	Normal	σ=85.387 μ=172.67	σ=51.943 μ=132.85	σ=51.324 μ=117.22	σ=63.627 μ=156.15	σ=53.722 μ=106.67
9.	Weibull	α=3.3528 β=179.88	α=3.0184 β=143.96	α=2.5019 β=127.98		α=2.5543 β=114.94
10.	Weibull (3P)	α=1.3644 β=114.55 γ=68.065	α=2.0239 β=112.46 γ=33.053	α=1.9658 β=107.86 γ=21.513		α=1.5658 β=88.342 γ=27.3

TABLE 2.6

Station wise ranked probability distribution using different goodness of fit tests for five day maximum rainfall

Probab. Distributions	Ambala	Rank	Bawal	Rank	Hisar	Rank	Karnal	Rank	Sirsa	Rank
Kolmogorov Smirnov test										
Gen. Extreme Value	0.12431	8	0.086	4	0.08445	2	0.12416	1	0.12416	1
Gen. Gamma	0.12345	7	0.0852	3	0.09076	5	0.13677	3	0.13677	3
Gen. Gamma (4P)	0.11194	4	0.08243	2	0.08726	3	0.23353	10	0.23353	10
Gumbel Max	0.12054	6	0.08766	5	0.10401	9	0.15508	6	0.15508	6
Log-Pearson 3	0.12778	9	0.09026	6	0.08816	4	0.14744	4	0.14744	4
Lognormal	0.09026	1	0.09732	8	0.1042	10	0.15816	7	0.15816	7
Lognormal (3P)	0.10691	3	0.07949	1	0.09246	7	0.15829	8	0.15829	8
Normal	0.16391	10	0.12537	10	0.09114	6	0.15306	5	0.15306	5
Weibull	0.10574	2	0.09333	7	0.10038	8	0.12704	2	0.12704	2
Weibull (3P)	0.11999	5	0.10012	9	0.08427	1	0.16726	9	0.16726	9
Anderson Darling test										
Gen. Extreme Value	0.35472	2	0.28236	2	0.26453	4	0.54259	1	0.35086	1
Gen. Gamma	0.83271	7	0.3114	5	0.29895	5	0.60974	3	0.57125	7
Gen. Gamma (4P)	0.41877	4	0.30586	4	0.24322	1	2.4405	10	0.42809	5
Gumbel Max	1.0713	8	0.2844	3	0.43839	10	0.84221	9	0.56641	6
Log-Pearson 3	0.42478	5	0.3379	6	0.26072	3	0.61487	4	0.40972	4
Lognormal	0.37384	3	0.36518	7	0.43681	9	0.693	6	0.3928	3
Lognormal (3P)	0.34607	1	0.27973	1	0.30198	6	0.69348	7	0.3805	2
Normal	2.1071	9	0.70503	10	0.35898	8	0.62727	5	1.6011	10
Weibull	2.4627	10	0.56554	9	0.32362	7	0.59985	2	0.97025	9
Weibull (3P)	0.78941	6	0.4467	8	0.24919	2	0.71639	8	0.71685	8
Chi-Squared test										
Gen. Extreme Value	0.69079	2	1.0315	3	0.5425	2	5.2884	7	2.1235	3
Gen. Gamma	6.1614	7	2.0928	7	2.0762	9	5.672	9	3.755	7
Gen. Gamma (4P)	2.1158	4	2.094	8	1.3349	6	5.3818	8	3.5355	5
Gumbel Max	7.0659	9	1.032	4	1.3048	5	2.2909	5	4.4845	8
Log-Pearson 3	0.66987	1	2.0856	6	2.0286	8	1.297	2	1.5878	2
Lognormal	1.5998	3	0.28325	1	0.96354	4	1.8085	3	2.248	4
Lognormal (3P)	2.1219	5	2.1099	9	1.9696	7	2.0555	4	1.5715	1
Normal	12.197	10	5.1442	10	2.396	10	1.2569	1	10.446	10
Weibull	6.1738	8	0.72074	2	0.14508	1	4.9539	6	3.5872	6
Weibull (3P)	3.9971	6	2.0646	5	0.60561	3	8.7217	10	4.9097	9

Composite Ranking (on the basis of all three tests)

	Ambala	Bawal	Hisar	Karnal	Sirsa
Gen. Extreme Value	12	**9**	8	**9**	**5**
Gen. Gamma	21	15	19	15	17
Gen. Gamma (4P)	12	14	10	28	20
Gumbel Max	23	12	24	20	20
Log-Pearson 3	15	18	15	10	10
Lognormal	**7**	16	23	16	14
Lognormal (3P)	9	11	20	19	11
Normal	29	30	24	11	25
Weibull	20	18	16	10	17
Weibull (3P)	17	22	**6**	27	26

TABLE 2.7

Descriptive statistics for monsoon rainfall

	Ambala	Bawal	Hisar	Karnal	Sirsa
Sample Size	36	36	36	36	36
Range	995.5	815.2	644.3	1050	531.2
Mean	662.72	493.94	375.61	608.63	291.17
Variance	48872.0	36203.0	23256.0	63710.0	16015.0
Std. Deviation	221.07	190.27	152.5	252.41	126.55
Coef. of Variation	0.33358	0.38521	0.40601	0.41471	0.43463
Std. Error	36.845	31.712	25.417	42.068	21.092
Skewness	0.37982	0.29342	0.0472	1.0024	0.55039
Excess Kurtosis	0.26008	0.32668	0.21235	0.74988	0.28682
Minimum	268.3	133.7	63.5	215.3	52
5%	276.46	147.9	87.47	245.81	70.445
10%	350.49	213.69	145.33	359.44	146.35
25% (Q1)	507.1	377.78	297.9	435.97	201.25
50% (Median)	664.15	486.15	371	525.3	293.6
75% (Q3)	837.82	624.08	456.5	745.4	345.78
90%	931.4	709.33	573.48	955.66	492.96
95%	1071.1	936.41	688.5	1254.9	583.2
Maximum	1263.8	948.9	707.8	1265.3	583.2

TABLE 2.8

Parameter estimation of various fitting distribution for monsoon rainfall

S. No.	Probability distribution function	Ambala	Bawal	Hisar	Karnal	Sirsa
1.	Gen. Extreme Value	k=-0.19399 σ=210.56 μ=575.65	k=-0.21469 σ=182.49 μ=421.19	k=-0.31199 σ=153.45 μ=324.32	k=0.08415 σ=183.98 μ=485.82	k=-0.09506 σ=111.06 μ=236.68
2.	Gen. Gamma	k=0.99396 α=8.8621 β=73.744	k=0.97268 α=6.3739 β=73.294	k=0.9419 α=5.4175 β=61.916	k=1.0244 α=6.0877 β=104.68	k=0.97677 α=5.0716 β=55.002
3.	Gen. Gamma (4P)	k=3.4022 α=0.39515 β=686.93 γ=254.15	k=3.1988 α=0.55532 β=579.59 γ=94.54	k=3.7197 α=0.55943 β=504.86 γ=13.691	k=0.74837 α=7.3581 β=33.954 γ=105.07	k=1.3704 α=5.2594 β=118.28 γ=-98.884
4.	Gumbel Max	σ=172.37 μ=563.23	σ=148.35 μ=408.31	σ=118.9 μ=306.97	σ=196.8 μ=495.04	σ=98.67 μ=234.21
5.	Log-Pearson 3	α=12.256 β=-0.10242 γ=7.693	α=3.726 β=-0.23426 γ=6.9888	α=1.8884 β=-0.38701 γ=6.5495	α=5189.8 β=-0.00563 γ=35.553	α=3.1113 β=-0.29002 γ=6.4678
6.	Lognormal	σ=0.35353 μ=6.4378	σ=0.44587 μ=6.116	σ=0.52439 μ=5.8187	σ=0.39995 μ=6.3317	σ=0.50441 μ=5.5654
7.	Lognormal (3P)	σ=0.14061 μ=7.3337 γ=-883.58	σ=0.09486 μ=7.5832 γ=-1479.7	σ=0.04799 μ=8.046 γ=-2748.9	σ=0.3937 μ=6.3474 γ=-8.2269	σ=0.18758 μ=6.4748 γ=-368.9
8.	Normal	σ=221.07 μ=662.72	σ=190.27 μ=493.94	σ=152.5 μ=375.61	σ=252.41 μ=608.63	σ=126.55 μ=291.17
9.	Weibull	α=3.3172 β=720.96	α=2.5551 β=548.02	α=2.1223 β=424.97	α=2.8919 β=662.07	α=2.247 β=324.71
10.	Weibull (3P)	α=2.3423 β=543.08 γ=181.02	α=2.6384 β=519.41 γ=31.868	α=3.1942 β=488.28 γ=-61.985	α=1.7265 β=466.34 γ=192.87	α=2.3473 β=313.02 γ=13.456

TABLE 2.9

Station wise ranked probability distribution using different goodness of fit tests for Monsoon Rainfall

Probab. Distributions	Ambala	Rank	Bawal	Rank	Hisar	Rank	Karnal	Rank	Sirsa	Rank
Kolmogorov Smirnov test										
Gen. Extreme Value	0.07764	2	0.07015	2	0.10123	1	0.08579	3	0.09041	1
Gen. Gamma	0.09055	7	0.09281	7	0.17449	9	0.1067	8	0.09741	3
Gen. Gamma (4P)	0.09715	8	0.09228	6	0.11719	6	0.08645	5	0.09781	4
Gumbel Max	0.11	10	0.09531	8	0.16943	8	0.09264	6	0.10569	6
Log-Pearson 3	0.07805	3	0.08086	5	0.1133	5	0.08499	2	0.12836	9
Lognormal	0.09047	6	0.12062	10	0.19976	10	0.08489	1	0.11908	8
Lognormal (3P)	0.0892	5	0.06299	1	0.11112	3	0.08608	4	0.09484	2
Normal	0.07561	1	0.07483	3	0.10387	2	0.14601	10	0.12917	10
Weibull	0.09767	9	0.10895	9	0.15415	7	0.11446	9	0.10428	5
Weibull (3P)	0.08164	4	0.07655	4	0.11121	4	0.10098	7	0.10795	7
Anderson Darling test										
Gen. Extreme Value	0.22087	1	0.2708	3	0.4762	4	0.26479	1	0.23018	2
Gen. Gamma	0.28673	6	0.50753	8	1.0585	7	0.41786	8	0.3408	6
Gen. Gamma (4P)	0.36904	8	0.38366	5	0.5159	5	0.31089	5	0.24694	3
Gumbel Max	0.57696	10	0.73567	9	1.35	8	0.31261	6	0.31957	4
Log-Pearson 3	0.23261	3	0.39656	6	4.7787	10	0.2908	3	0.53565	9
Lognormal	0.43908	9	0.88914	10	1.6399	9	0.28832	2	0.67529	10
Lognormal (3P)	0.22833	2	0.24074	1	0.41382	2	0.29093	4	0.22877	1
Normal	0.24782	4	0.26084	2	0.39691	1	0.99374	10	0.44862	8
Weibull	0.29111	7	0.42846	7	0.97656	6	0.85461	9	0.43585	7
Weibull (3P)	0.24998	5	0.30197	4	0.45074	3	0.40668	7	0.32034	5
Chi-Squared test										
Gen. Extreme Value	0.4555	2	1.4431	4	0.75016	5	1.2697	2	1.5781	4
Gen. Gamma	1.5623	9	0.55061	2	9.1072	8	3.5363	8	1.0973	2
Gen. Gamma (4P)	0.28992	1	1.1176	3	0.3479	1	1.286	4	4.4692	9
Gumbel Max	0.95891	6	0.50606	1	5.3141	7	1.3973	7	0.48154	1
Log-Pearson 3	0.60996	3	1.6332	7	N/A		1.2972	6	4.1472	7
Lognormal	0.73426	4	2.3435	9	4.7139	6	1.2821	3	1.2812	3
Lognormal (3P)	1.5413	8	1.5887	5	0.5922	4	1.2889	5	4.5136	10
Normal	2.5566	10	1.6159	6	0.50653	2	11.642	10	1.9519	5
Weibull	0.90596	5	1.9503	8	9.8594	9	7.4257	9	4.1581	8
Weibull (3P)	1.4085	7	2.3612	10	0.54103	3	0.41161	1	3.954	6

Composite Ranking (on the basis of all three tests)

	Ambala	Bawal	Hisar	Karnal	Sirsa
Gen. Extreme Value	**5**	9	10	**6**	**7**
Gen. Gamma	22	17	24	24	11
Gen. Gamma (4P)	17	14	12	14	16
Gumbel Max	26	18	23	19	11
Log-Pearson 3	9	18	15	11	25
Lognormal	19	29	25	**6**	21
Lognormal (3P)	15	**7**	9	13	13
Normal	15	11	**5**	30	23
Weibull	21	24	22	27	20
Weibull (3P)	16	18	10	15	18

TABLE 2.10

Descriptive statistics for annual rainfall

	Ambala	Bawal	Hisar	Karnal	Sirsa
Sample Size	36	36	36	36	36
Range	932.9	780.2	665.5	1054.1	585.3
Mean	843.55	621.5	477.69	771.57	373.66
Variance	48467.0	43232.0	27144.0	79430.0	20413.0
Std. Deviation	220.15	207.92	164.75	281.83	142.87
Coef. of Variation	0.26098	0.33455	0.3449	0.36528	0.38236
Std. Error	36.692	34.654	27.459	46.972	23.812
Skewness	0.11403	0.02346	-0.05747	0.71437	0.70524
Excess Kurtosis	-0.57108	-0.44245	-0.14977	-0.1845	0.23616
Minimum	414.3	228.5	143.2	337.2	137.1
5%	484.93	260.71	175.92	367.89	162.52
10%	548.68	280.89	212.79	432.6	184.17
25% (Q1)	664.17	470.73	380.75	597.45	280.17
50% (Median)	839.3	642.6	500.3	694.4	353.4
75% (Q3)	1033.7	715.97	577.37	945.72	447.35
90%	1130.1	975.85	726.51	1246.0	618.83
95%	1205.0	985.92	777.67	1381.9	687.38
Maximum	1347.2	1008.7	808.7	1391.3	722.4

TABLE 2.11

Parameter estimation of various fitting distribution for annual rainfall

S. No.	Probability distribution function	Ambala	Bawal	Hisar	Karnal	Sirsa
1.	Gen. Extreme Value	k=-0.25019 σ=220.94 μ=760.86	k=-0.29059 σ=211.09 μ=548.09	k=-0.31399 σ=167.92 μ=421.78	k=0.01004 σ=226.73 μ=638.42	k=-0.04025 σ=119.47 μ=309.29
2.	Gen. Gamma	k=0.99606 α=14.523 β=57.456	k=0.97862 α=8.5086 β=69.56	k=0.96642 α=7.7998 β=56.823	k=1.0151 α=7.7365 β=102.95	k=1.008 α=6.9501 β=54.629
3.	Gen. Gamma (4P)	k=4.7857 α=0.31345 β=752.64 γ=394.55	k=6.77 α=0.1751 β=744.4 γ=223.1	k=1.0242 α=148.39 β=15.621 γ=-1581.4	k=3.3288 α=0.28029 β=878.08 γ=337.2	k=2.3697 α=0.62182 β=361.23 γ=127.95
4.	Gumbel Max	σ=171.65 μ=744.47	σ=162.12 μ=527.93	σ=128.46 μ=403.55	σ=219.75 μ=644.73	σ=111.4 μ=309.36
5.	Log-Pearson 3	α=19.324 β=-0.06257 γ=7.9115	α=5.9834 β=-0.15507 γ=7.2966	α=3.3118 β=-0.22554 γ=6.8446	α=9657.2 β=-0.0037 γ=42.301	α=43.469 β=-0.05971 γ=8.4466
6.	Lognormal	σ=0.27121 μ=6.7024	σ=0.374 μ=6.3688	σ=0.4047 μ=6.0977	σ=0.35836 μ=6.5848	σ=0.38819 μ=5.8509
7.	Lognormal (3P)	σ=0.06507 μ=8.1101 γ=-2491.0	σ=0.04662 μ=8.3858 γ=-3768.0	σ=0.04238 μ=8.2622 γ=-3399.3	σ=0.37926 μ=6.5278 γ=37.421	σ=0.28711 μ=6.1463 γ=-112.88
8.	Normal	σ=220.15 μ=843.55	σ=207.92 μ=621.5	σ=164.75 μ=477.69	σ=281.83 μ=771.57	σ=142.87 μ=373.66
9.	Weibull	α=4.2972 β=910.26	α=3.0356 β=686.2	α=2.7931 β=530.62	α=3.1961 β=841.47	α=2.9913 β=407.75
10.	Weibull (3P)	α=2.7285 β=610.2 γ=301.2	α=2.9834 β=620.98 γ=67.575	α=3.4491 β=558.79 γ=-24.53	α=1.6885 β=515.4 γ=310.87	α=1.8919 β=290.32 γ=115.67

TABLE 2.12

Station wise ranked probability distribution using different goodness of fit tests for annual rainfall

Probab. Distributions	Ambala	Rank	Bawal	Rank	Hisar	Rank	Karnal	Rank	Sirsa	Rank
Kolmogorov Smirnov test										
Gen. Extreme Value	0.07078	2	0.10813	6	0.08675	4	0.09817	2	0.09302	5
Gen. Gamma	0.09465	8	0.13131	8	0.12683	8	0.12577	7	0.08828	2
Gen. Gamma (4P)	0.05945	1	0.11846	7	0.08953	5	0.13927	8	0.09682	7
Gumbel Max	0.12338	10	0.1537	10	0.15064	10	0.10444	6	0.0968	6
Log-Pearson 3	0.08204	5	0.10305	4	0.09156	6	0.10298	5	0.08966	3
Lognormal	0.09955	9	0.15055	9	0.14915	9	0.10189	3	0.1083	9
Lognormal (3P)	0.08524	6	0.09327	1	0.08632	3	0.0978	1	0.08818	1
Normal	0.07563	3	0.09993	3	0.08066	2	0.16703	10	0.13675	10
Weibull	0.08974	7	0.10638	5	0.1101	7	0.13974	9	0.0989	8
Weibull (3P)	0.08178	4	0.10813	6	0.07927	1	0.10281	4	0.09247	4
Anderson Darling test										
Gen. Extreme Value	0.16213	2	0.32708	2	0.32437	4	0.2453	1	0.25219	1
Gen. Gamma	0.24277	7	0.5604	8	0.73029	8	0.34439	7	0.27117	4
Gen. Gamma (4P)	0.15123	1	0.55481	7	0.32184	3	4.3671	10	0.36926	8
Gumbel Max	0.68899	10	1.1241	10	1.3132	10	0.27527	5	0.28864	5
Log-Pearson 3	0.18203	3	0.35798	5	0.39646	6	0.2513	2	0.26815	3
Lognormal	0.31332	9	0.82123	9	1.1256	9	0.25948	4	0.30781	6
Lognormal (3P)	0.21562	6	0.33739	3	0.31241	2	0.25435	3	0.25807	2
Normal	0.2045	5	0.31856	1	0.29308	1	0.77959	9	0.61942	10
Weibull	0.26743	8	0.38716	6	0.52626	7	0.77021	8	0.5401	9
Weibull (3P)	0.18472	4	0.35584	4	0.32481	5	0.27701	6	0.3193	7
Chi-Squared test										
Gen. Extreme Value	0.96331	6	1.1975	7	2.3672	4	2.4749	1	0.50916	1
Gen. Gamma	1.6882	9	0.56487	3	3.9906	8	4.0131	6	0.57201	3
Gen. Gamma (4P)	1.329	8	2.7481	9	2.5067	5	N/A		1.4556	8
Gumbel Max	2.2675	10	3.0582	10	4.9345	10	2.5445	5	1.357	7
Log-Pearson 3	0.95553	5	0.8427	5	2.8384	6	2.5127	2	0.51407	2
Lognormal	0.9484	4	2.709	8	4.6683	9	2.537	4	2.7153	9
Lognormal (3P)	1.0196	7	0.49099	2	1.3578	2	2.5323	3	0.59765	4
Normal	0.68487	1	0.60663	4	1.411	3	5.365	9	6.7851	10
Weibull	0.86307	2	1.1068	6	3.1015	7	4.5793	7	1.1774	6
Weibull (3P)	0.92355	3	0.44526	1	1.2336	1	5.17	8	0.73772	5

Composite Ranking (on the basis of all three tests)

	Ambala	Bawal	Hisar	Karnal	Sirsa
Gen. Extreme Value	10	15	12	**4**	**7**
Gen. Gamma	24	19	24	20	9
Gen. Gamma (4P)	10	23	13	18	23
Gumbel Max	30	30	30	16	18
Log-Pearson 3	13	14	18	9	8
Lognormal	22	26	27	11	24
Lognormal (3P)	19	**6**	7	7	**7**
Normal	**9**	8	**6**	28	30
Weibull	17	17	21	24	23
Weibull (3P)	11	11	7	18	16