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Probability analysis of annual and monthly rainfall in Mizoram, India : Evaluating goodness of fit and identifying best probability distributions

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सार – यह अध्ययन पूर्वोत्तर भारत के राज्य मिजोरम में 1986 से 2021 तक 18 संभाव्यता वितरणों द्वारा वर्षा डेटा के संभाव्यता वितरण का व्यापक विश्लेषण प्रस्तुत करता है। इस अध्ययन का उद्देश्य मिजोरम की वार्षिक और मासिक वर्षा के सबसे उपयुक्त संभाव्यता वितरण की पहचान करना है। प्रत्येक वितरण के लिए उपयुक्तता निर्धारित करने हेतु कोलमोगोरोव-स्मिरनोव, एंडरसन-डार्लिंग और ची-स्क्वायर परीक्षण आयोजित किए गए। इसके अतिरिक्त, तीनों परीक्षणों से प्राप्त कुल स्कोर के आधार पर, उच्चतम स्कोर वाले संभाव्यता वितरण को चौथे वितरण के रूप में शामिल किया गया। संबंधित परीक्षणों से तीन सर्वोत्तम-उपयुक्त वितरणों की पहचान करने के बाद, विश्लेषण की प्रत्येक अवधि के लिए यादृच्छिक संख्या उत्पन्न करने के लिए प्राचलों का उपयोग किया गया। वास्तविक और अनुमानित मूल्यों के बीच न्यूनतम निरपेक्ष विचलन के आधार पर सबसे उपयुक्त संभाव्यता वितरण निर्धारित किया गया। नतीजे दर्शाते हैं कि जनरल एक्सट्रीम वैल्यू वितरण 12 में से 5 महीनों के लिए सबसे उपयुक्त पाया गया, इसके बाद लॉग पियर्सन 3 को 12 में से 2 महीनों के लिए सबसे उपयुक्त पाया गया। मिजोरम की वार्षिक वर्षा के लिए गामा (3पी) वितरण सबसे उपयुक्त पाया गया। इसके अतिरिक्त, अगस्त का महीना 16.8% के साथ सबसे अधिक वार्षिक वर्षा का योगदान देता है जबकि जनवरी का महीना 0.4% के साथ सबसे कम योगदान देता है। ये निष्कर्ष रैखिक प्रवृत्ति, चक्रीय प्रवृत्ति और यादृच्छिक घटकों को ध्यान में रखते हुए वर्षा केअनुमान के लिए विभिन्न महीनों के लिए उचित संभाव्यता वितरण कार्य को अपनाने में उपयोगी हो सकते हैं।

ABSTRACT. This study presents a comprehensive analysis of the probability distribution of rainfall data in Mizoram, a state in Northeast India, from 1986 to 2021 by 18 probability distributions. The objective of this study is to identified the best-fit probability distribution of annual and monthly rainfall of Mizoram. The Kolmogorov-Smirnov, Anderson-Darling, and Chi-Square tests were conducted to determine the goodness of fit for each distribution. Additionally, based on the total score obtained from all three tests, the probability distribution with the highest score was included as a fourth distribution. After identifying the three best-fitting distributions from the respective tests, the parameters were used to generate random numbers for each period of analysis. The best-fit probability distribution was determined based on the minimum absolute deviation between actual and estimated values. The results show that the General Extreme Value distribution was found to be the best fit for 5 out of 12 months, followed by Log Pearson 3 for 2 out of 12 months. Gamma (3P) distribution was found to be the best fit for the annual rainfall of Mizoram. Additionally, the month of August contributes the highest annual rainfall with 16.8% while January contributes the lowest with 0.4%. These findings can be useful to adopt appropriate probability distribution function against different month for rainfall prediction taking into account linear trend, cyclic trend and random components.

Key words – Rainfall, Probability of rainfall occurrences, Probability distribution, Goodness of fit.

1. Introduction

Understanding rainfall patterns and distribution is crucial for various activities, including agriculture, industry, domestic water supply, and hydroelectric power generation. Rainfall patterns can affect crop production, water availability, and electricity generation. Probability and frequency analysis of rainfall data can help us understand the likelihood of different rainfall events occurring and their expected intensity (Bhakar *et al*., 2008). This information is essential for designing irrigation systems, managing water resources, and planning for potential flood or drought situations (Gado *et al*., 2021). Moreover, the knowledge of rainfall patterns can help in developing an appropriate strategy for exchanging agriculture products as it can help in predicting the weather conditions during transportation, which can help in reducing the damage and loss of products. Overall, studying rainfall patterns and distribution is crucial for various fields, and probability and frequency analysis of rainfall data can help in determining the expected rainfall at different chances, enabling better planning and management of water resources and other activities. These are some of the studies that have investigated the suitability of different probability distributions to model rainfall data in various regions. The Gamma distribution was found to be the best fit for the south west and north east monsoon season in India by Mooley (1973) and for the Libya region by Sen and Eljadid (1999). Phien and Ajirajah (1984) observed that the Log Pearson 3 was applicable for various rainfall and stream flow variables. Duan *et al*. (1995) compared five probability distributions and found that the Weibull and Gamma (2P) distributions were the best fit for daily rainfall in the Western Cascades of Oregon. Tao *et al.* (2002) compared nine probability distributions for multiple rainguage stations in southern Quebec region and found the General Extreme Value distribution to be the most accurate. Salami (2004) conducted research on the annual flow pattern of the Asa River by utilizing probability distribution models and reported that the Log Pearson 3 distribution was the best fit model for the maximum flow, while the Gumbel distribution was the best fit model for the minimum flow. This suggests that the flow regime in the Asa River may exhibit different characteristics at different flow levels. Bhakar *et al*. (2006) found that the Gamma distribution was the best fit for Banswara, Rajasthan, India, while Bhakar (2008) reported that the Gumbel distribution was the best fit for Kota, Rajasthan, India. This could be due to differences in the hydrological regime and topography of the two regions. Kwaku and Duke (2007) concluded that Log Normal distribution was suitable for examined five consecutive day's maximum rainfall for Accra, Ghana. This finding suggests that the distribution of rainfall in this region can be well represented by the Log Normal distribution. Olofintoye *et al.* (2009) discovered that the Log Pearson 3 distribution was the most common distribution among the stations in Nigeria, followed by Pearson 3 distribution and Log Gumbel distribution. This suggests that the Log Pearson 3 distribution is a good fit for a large portion of the hydrological data in Nigeria. Mahdavi *et al*. (2010) analysed the daily rainfall data of 37 years of Pantnagar, India using 16 probability distributions and found that the best fit probability distribution varied by month for daily rainfall data. This highlights the need to consider seasonality in hydrological analysis and to select an appropriate distribution model for each time period being analysed. Kumar and Singh (2011) evaluated the daily rainfall data of 20 years of Ajamgarh, Uttar Pradesh and revealed Log Normal distribution was the best fit distribution for this region. Singh *et al.* (2012) identified that the Log Pearson 3 distribution was the best fit probability distribution to predict annual one day maximum rainfall of Jhalarapatan, Rajasthan. According to Amin *et al.* (2016) Log Pearson 3 was the most suitable distribution for the northern regions of Pakistan. Kumar *et al.* (2017) compared 10 probability distributions for 13 districts of Uttarakhand and found that the Weibull distribution performed the best among the tested distributions. Alam *et al.* (2018) utilized 30 years of data from 35 locations in Bangladesh and identified General Extreme Value as the best fit for 36% of the stations. Ahuchaogu (2019) conducted a study on determining the most suitable probability distribution for a watershed in Nigeria and found Lognormal was suitable for this area. Mudashiru *et al.* (2023) study revealed that Log Pearson 3 probability distribution was the best fit distribution for Pulau Pinang, Malaysia. The goodness of best fit was tested by Kolmogorov-Smirnov test, Anderson-Darling test and Chi-Squared test (Khudri and Sadia, 2013). Each study has found a different distribution to be the best fit, indicating that the choice of distribution may depend on the specific characteristics of the rainfall data. This suggests that it is important to analyse rainfall data on a case-by-case basis and the selection of an appropriate distribution relies on the characteristics of the available rainfall data specific to each site. Therefore, it becomes necessary to evaluate multiple available distributions in order to identify the best fit distribution that can represent rainfall events. There has been no previous, study on the comparison of probability distributions for rainfall analysis in Mizoram. Consequently, the main objective of this study is to address this gap by comparing the performances of commonly used probability distributions. The aim is to identified the best fit distribution for monthly rainfall in Mizoram. Prediction of rainfall depends upon overall linear trend, cyclic trend and random components. In the present study, we have made an attempt to predict rainfall against the random components applying the probability theory. The occurrences of rainfall are assumed here as a random experiment. The range of rainfall has been divided into finite number of intervals. Here, the rainfall occurrence to fall in certain interval is assumed as an event. The prediction of rainfall is estimated by multiplying the probability of rainfall to fall in particular interval with the mean of the interval. In this connection, the environmental time series of rainfall observation at particular location may have a different nature to follow different trend. Therefore, there is a need to identify the best probability distribution function for predicting rainfall for different months.

2. Materials and methods

2.1. *Study area*

Mizoram is among the seven Northeast state of India, which lies between latitudes 21° 58' N to 24° 35' N and longitudes 92° 15' E to 93° 29' E. It has a total area of 21,081 square km out of which 86.27% are very dense forest, and the rest are moderately dense and open forest but unfortunately it keeps decreasing due to shifting cultivation and other developmental activities. Majority of the people of Mizoram depends on agricultures. It is bounded by two international borders namely Myanmar (404 square km) and Bangladesh (318 square km). It also shares borders with three of the Northeast state namely, Assam (123 square km), Tripura (66 square km) and Manipur (95 square km). The area's dependence on agriculture also highlights the importance of understanding its rainfall patterns for local farmers and their crops. The impact of climate change on rainfall patterns in Mizoram is a growing concern, as rising temperature can lead to changes in precipitation and affect water availability for both agricultural and domestic use. Monitoring and analysing rainfall data in Mizoram over time can help to identify any shifts or trends in rainfall patterns and better inform local decision-making related to water management and crop planning. The temperatures in Mizoram have been exceeding 30 degrees Celsius, while during winter, the temperature ranges from 7 to 22 degrees Celsius and it has a mild climate, with relatively cool temperatures during summer ranging from 20 to 29 degrees Celsius. Its annual rainfall is 2056.8 mm. Fig. 1 display the study area.

Historical and monthly and annual rainfall data for 36 years period (1980-2021) of Mizoram, are obtained from the State Meteorological Centre, Directorate of Science and Technology, Government of Mizoram.

2.2. *Probability analysis*

Let us consider the observed rainfall for M months for the N years and its matrix form may be represented as follows:

$$< X_{i,j} >_{NM} = \begin{bmatrix} X_{11} & X_{12} & X_{13} & \dots & X_{1M} \\ X_{21} & X_{22} & X_{23} & \cdots & X_{2M} \\ X_{31} & X_{32} & X_{33} & \cdots & X_{3M} \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ X_{N1} & X_{n2} & X_{N3} & \dots & X_{NM} \end{bmatrix} \quad (1)$$

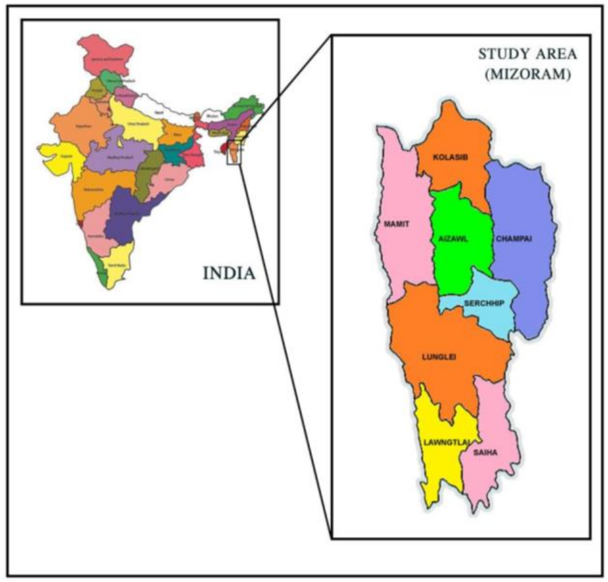

Fig. 1. Location of Study Area

The above matrix can be referred as data matrix and each element X_{ij} in the data matrix represents the total rainfall observed during ith year and jth month.

Now, let us proceed to use the concepts of probability theory to identify the random experiment or trial, event, random variable, sample space and probability *etc*. In fact, we do not see here any experiment or trial as the rainfall occurrence in particular month of certain year is a natural phenomenon. There may or may not be rainfall in the month. Further, if rainfall occurs, it may be any measure. Hence, we may assume the event of rainfall in a certain range of measure is an event of random phenomenon. Thus, if the maximum value of the observed rainfall in the entire period of observation considered for forecast falls within the interval $(n\text{-}1) I \leq X_n < nI$ where I is the length of interval considered for each event of the random phenomenon and each column of the rainfall observation may be divided into $\boldsymbol{n}$ number of events, $E_1, E_2, E_3, \dots, E_n$ as follows:

$E_1 = 0 \leq X_1 < I,$
$E_2 = I \leq X_2 < 2I,$
$E_3 = 2I \leq X_3 < 3I,$
…………………………..
…………………………..
…………………………..
$E_n = (n\text{-}1)\, I \leq X_n < nI.$

Further let n_k be the number of observations fall within the interval $E_k = (k\text{-}1)\ I \leq X_k < kI$ and the total number of observation for each month is N. Therefore, the probability for the event E_k to occur, *i.e.*, the rainfall X_k to fall within the interval (k-1) $I \leq X_k < kI$ in the random phenomenon is

$$P(E_k) = \frac{n_k}{N} = P_k. \quad (2)$$

2.3. *Candidates of Probability Distribution Function*

18 probability distributions were evaluated in selecting the best fit probability distribution for monthly and annual rainfall of Mizoram. These 18 probability distributions are namely Exponential, Exponential (2P), Gamma (2P), Gamma (3P), Generalized Extreme Value, Generalized Gamma (3P), Generalized Gamma (4P), Log Gamma, Lognormal (2P), Lognormal (3P), Log Pearson 3, Normal, Pearson 5 (2P), Pearson 5 (3P), Pearson 6 (3P), Pearson 6(4P), Weibull (2P), Weibull (3P).

2.4. *Testing of Goodness of fit tests*

The goodness of fit test is used to determine how well the distribution fit the observed data. It included Kolmogorov-Smirnov test, Anderson-Darling test and Chi-squared test. The goodness of fit tests was applied in this study to examine the following null hypothesis:

(*i*) H_O: the observed data follows a specified theoretical distribution;

(*ii*) H_A: the observed data does not follow the specified theoretical distribution.

If the calculated test statistic is greater than the critical value obtained from the specified significance level, the null hypothesis is rejected in favour of the alternative hypothesis.

2.4.1. *Kolmogorov-Smirnov test*

Kolmogorov-Smirnov test (D) (Joyner *et al*., 1967) is a non-parametric test used to determine whether a sample of data follows a specified probability distribution. It can be used to compare any continuous distribution with a sample of data. The test is based on the maximum difference between the cumulative distribution function (CDF) of the sample data and the CDF of the specified distribution. The test statistic is calculated as:

$$D = \max\left|F(x) - G(x)\right| \quad (3)$$

where $F(x)$ is the empirical distribution function (EDF) of the sample data and $G(x)$ is the CDF of the specified distribution.

2.4.2. *Anderson-Darling test*

The Anderson-Darling test (A^2) (Stephens, 1974) is a test used to compare the fit of an observed cumulative distribution function to an expected cumulative distribution function.

2.4.3. *Chi-Squared test*

The chi-squared test is used to compare the observed frequencies of a sample with the expected frequencies, taking into account the sample size and the degrees of freedom.

2.5. *Selection of the best fit probability distribution*

The three goodness of fit tests (*i.e*., Kolmogorov-Smirnov test, Anderson-Darling test and Chi-Square test) were applied to the average monthly and annual rainfall of Mizoram. The statistics for each of the tests were calculated, and hypothesis testing was performed at a significant level of 0.05. The selected 18 probability distributions were ranked based on the minimum test statistic value for each of the three tests, with a score of 18 awarded to the distribution that held the first rank, score 17 for second rank and so on and a score of 1 awarded to the distribution that held the 18th rank. The distribution that held the first rank for all three tests was selected as the best fit distribution for the data. Based on the total score obtained from all three tests, the probability distribution with the highest score was included as a fourth distribution along with the distribution obtained from the previous test.

Among the result of the four probability distributions, the best fit distribution was selected by the following procedure:

2.5.1. *Generating random variables*

Random variables were generated using the parameters obtained from the selected probability distribution from the previous four test.

2.5.2. *Residuals (R)*

Residuals (R) were obtained by comparing the observed value and the expected value derived using the random variables, which is defined by

$$R = \left|\sum_{i=1}^{n} X_i - X_i^{'}\right| \quad (4)$$

where X_i = Observed value

TABLE 1

Summary of Statistics

S. No.	Month	Maximum	Minimum	Mean	Standard Deviation	Coefficient of Skewness	Coefficient of Variation	Maximum Probability	Interval of Maximum probability	Percent contribute to annual rainfall
1.	Jan	68.2	0.0	8.3	15.4	1.5	1.9	0-10	0.7778	0.4
2.	Feb	120.8	0.0	22.4	25.1	0.9	1.1	0-10	0.3889	1.1
3.	Mar	314.3	0.0	64.9	71.3	1	1.1	10-20	0.1389	3.2
4.	Apr	368.3	13.1	148.0	85.9	0.8	0.6	140-150	0.0833	7.2
5.	May	718.0	71.2	278.0	133.9	1	0.5	180-190	0.0833	13.5
6.	Jun	743.5	106.5	323.5	148.5	0.5	0.5	300-310	0.0833	15.7
7.	Jul	539.0	66.9	318.0	100.8	0.1	0.3	370-380	0.1111	15.5
8.	Aug	517.9	156.9	344.7	88.9	-0.3	0.3	350-360	0.1389	16.8
9.	Sep	510.8	131.0	305.1	92.1	0.1	0.3	260-270	0.0833	14.8
10.	Oct	421.0	67.9	179.9	86.9	0.6	0.5	110-120	0.0833	8.7
11.	Nov	250.2	0.0	50.8	57.8	0.9	1.1	0-10	0.3056	2.5
12.	Dec	91.1	0.0	13.1	24.9	1.6	1.9	0-10	0.7500	0.6
13.	Annual	2686.7	1547.7	2056.8	339.7	1.2	16.5	1740-1750	0.0833	100

TABLE 2

Study Period wise first rank probability distribution using goodness of fit tests

S. No.	Month	Kolmogorov-Smirnov		Anderson-Darling		Chi-Squared	
		Distribution	Statistics	Distribution	Statistics	Distribution	Statistics
1.	Jan	Normal	0.29488	Weibull	-6.4606	General Extreme Value	7.8454
2.	Feb	General Extreme Value	0.12207	General Extreme Value	0.68016	General Extreme Value	0.08706
3.	Mar	General Extreme Value	0.07319	General Extreme Value	0.07319	Lognormal	0.13856
4.	Apr	General Gamma (3P)	0.06759	General Extreme Value	0.17325	Log Pearson 3	1.0645
5.	May	Pearson 6 (4P)	0.09542	General Extreme Value	0.25126	Gamma (3P)	0.16945
6.	Jun	General Extreme Value	0.06297	Log Pearson 3	0.14604	Log Gamma	0.30656
7.	Jul	Weibull (3P)	0.0914	Weibull (3P)	0.32718	Pearson 5 (3P)	0.20272
8.	Aug	Log Pearson 3	0.07541	General Extreme Value	0.19265	Pearson 5 (2P)	0.36418
9.	Sep	General Extreme Value	0.06304	General Extreme Value	0.142	Weibull (2P)	0.13315
10.	Oct	Lognormal	0.07445	Weibull (3P)	0.18304	Pearson 6 (3P)	0.26985
11.	Nov	General Extreme Value	0.10438	General Extreme Value	0.47858	General Extreme Value	0.88102
12.	Dec	General Extreme Value	0.3221	Weibull (2P)	-4.8442	General Extreme Value	6.2254
13.	Annual	Gamma (3P)	0.10344	Gamma (3P)	0.10344	Gamma (3P)	0.10344

X'_i = Expected Value

$i = 1, 2, \ldots, n$

The best fit distribution for a given data set was determined based on the minimum value of the residual (R).

Finally, the best fit probability distribution was identified.

3. Results and discussion

3.1. *Summary of statistics*

The process outlined earlier was implemented on the average data over a span of 36 years (1986-2021) rainfall (mm) of Mizoram. The data was classified into 13 data sets, which were January - December and Annual rainfall. The average rainfall of Mizoram during the period 1986-2021 are analysed and the summary of statistics are presented in Table 1. The rainfall data are arranged into

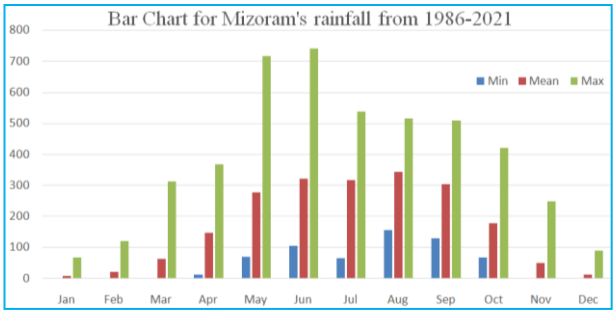

Fig. 2. Bar chart showing maximum, minimum and average rainfall of Mizoram

TABLE 3

Distribution with highest Score

S. No.	Month	Distribution	Score
1.	Jan	General Extreme Value	51
2.	Feb	General Extreme Value	54
3.	Mar	General Extreme Value	52
4.	Apr	General Extreme Value	44
5.	May	Pearson 6 (4P)	49
6.	Jun	Log Pearson 3	44
7.	Jul	Normal and Weibull (3P)	41
8.	Aug	Log Pearson 3 and Normal	46
9.	Sep	General Extreme Value	53
10.	Oct	Lognormal (2P) and Log Pearson 3	45
11.	Nov	General Extreme Value	54
12.	Dec	General Extreme Value	52
13.	Annual	Gamma (3P)	54

several intervals with a range of 10 mm. The maximum monthly rainfall in a year occurs in June with 743.5 mm falling in the interval of 740-750 mm, while the minimum monthly rainfall occurs in the month of January, along with February, March, November and December with 0 mm falling in the interval of 0-10 mm. Additionally, the month with the highest contribution to annual rainfall is August with 16.8% and January contributes the lowest with 0.4%. The expected rainfall for the upcoming year for each month will have a high chance of falling within interval of maximum probability.

3.2. *Goodness of fit test results*

18 probability distribution were evaluated by the three tests, *i.e.*, Kolmogorov - Smirnov test, Anderson-Darling test and Chi-Square test. The probability distribution having the first rank along with their statistic value for each test are presented in Table 2.

TABLE 4

Best Fit probability distribution

S. No.	Month	Distribution
1.	Jan	General Extreme Value
2.	Feb	General Extreme Value
3.	Mar	General Extreme Value
4.	Apr	General Extreme Value
5.	May	Pearson 6 (4P)
6.	Jun	Log Pearson 3
7.	Jul	Normal and Weibull (3P)
8.	Aug	Log Pearson 3 and Normal
9.	Sep	General Extreme Value
10.	Oct	Lognormal (2P) and Log Pearson 3
11.	Nov	General Extreme Value
12.	Dec	General Extreme Value
13.	Annual	Gamma (3P)

The fourth probability distribution was identified by summing up the scores obtained from a three-goodness fit test for each of the 18 probability distributions. The distribution with the highest score was selected, and any probability with the same highest score was selected, and any distributions with the same highest score were also included. The fourth distribution are presented in Table 3.

Random numbers were generated for each data set using the obtained parameter values, and the residuals were calculated by comparing the observed values with the expected values. The probability distribution with the minimum residual or deviation was considered the best-fit for each individual data set. Table 4 shows the best fit probability distribution for each data set.

The General Extreme Value distribution was consistently identified as the best fit for the months of January, February, March, November and December. This suggested that this distribution effectively captured the underlying patterns and characteristics of the data in those months. For April and June, the Log Pearson 3 distribution was determined to be the best fit. These implies that the Log Pearson 3 distribution closely matched the data and provided a suitable representation for those particular months. The Gamma (3P) distribution was found to be the most suitable for May, the Weibull (3P) distribution for July, Normal distribution for August, the Weibull (2P) distribution for September, and the Lognormal distribution for October. Finally, for the annual dataset, the Gamma (3P) distribution was identified as the best fit.

These findings are valuable in understanding the underlying statistical characteristics of the data for each month and the entire year. The selection of the best fit distribution allows for more accurate modelling analysis, and prediction of rainfall, aiding in various applications and decision-making processes.

4. Conclusions

This study addresses the gap in the understanding of probability distributions for rainfall analysis in Mizoram by comparing the performances of commonly used distributions and identifying the best fit distribution for monthly and annual rainfall. The selection of an appropriate distribution for rainfall analysis relies on the characteristics of the available rainfall data specific to each site. Evaluating multiple distributions is necessary to identify the best fit distribution that accurately represents rainfall events. The results of the study suggest that the General Extreme Value distribution was found to be the best distribution for modelling rainfall data in Mizoram for the majority of the monthly data sets, *i.e*., 5 months out of 12 months, followed by the Log Pearson 3 distribution for 2 months out of 12 months. Gamma (3P) distribution, Lognormal distribution, Normal distribution, Weibull (2P) distribution and Weibull (3P) distribution for 1 month out of 12 months. Furthermore, the Gamma (3P) distribution was found to be the best distribution for modelling the annual rainfall data in Mizoram. With the knowledge of the best fit probability distribution for each month's rainfall, it becomes possible to predict rainfall more accurately. The prediction of rainfall is mainly based on three components: linear, cyclic and random. These components help in understanding the underlying patterns and variations in rainfall data. These findings can be useful for various applications, such as water resource management, agriculture planning, by providing a better understanding of the expected rainfall patterns.

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