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Statical Analysis of Rainfall Trends of Shimla District, Himachal Pradesh

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ABSTRACT: The study faced challenges in dealing with the inherent variability and complexity of rainfall patterns in Shimla District, requiring a meticulous examination of long-term data and the application of various statistical techniques. Additionally, the unpredictability of climatic conditions and the potential impact of climate change posed challenges in projecting accurate future rainfall values.
Despite these challenges, the study contributes significantly to the field. It provides a thorough statistical analysis of 29 years of rainfall data in Shimla District, shedding light on mean, standard deviation, coefficient of variation, skewness, and kurtosis for both monthly and annual rainfall. The identification of an erratic rainfall pattern, particularly highlighted by the coefficient of variation, offers valuable insights for engineering projects and water resource planning.
Furthermore, the study employs various plotting position formulae and probability distribution functions to assess the return period of yearly rainfall. The adoption of the Chegodayev technique as the most fitting distribution for yearly rainfall data enhances the accuracy of return period projections. According to this technique, the projected rainfall for return periods of 5, 10, 50, 100, and 150 years is estimated at 1040.25 mm, 1112.57 mm, 1691.16 mm, 2414.40 mm and 3137.64 mm respectively. These estimated rainfall values for different return periods provide crucial information for designing resilient engineering structures and facilitating informed decision-making for water resource planners, farmers and urban planners. This comprehensive analysis contributes to a better understanding of rainfall dynamics in Shimla District, offering practical implications for infrastructure development and water management in the region.

Keywords: Statistical Analysis, Shimla (H.P), Return Period, Rainfall Data.

INTRODUCTION

Shimla District lies in between the longitude 77º-0″ and 78º-19″ East and latitude 30º-45″ and 31º-44″ North. The district's elevation ranges from 300 to 6000 meters, featuring peaks like Jakhoo, Siah, Churdhar, Chanshal, Hatto and Shali. The terrain is characterized by rugged, steep valleys with high peaks and dense forests. While the soil is generally young and thin, it becomes denser and relatively acidic with increasing altitude. The majority of the district falls under Zone IV (High Risk Zone) based on India's Earthquake hazard zoning. Landslides are also a growing concern, especially after heavy rains, owing to the challenging and rugged topography.

Shimla district is drained by streams/rivers forming part of the drainage basins of the Sutlej, the Yamuna, the Pabbar and Tons rivers. However, major part of the district is drained by tributaries of Sutlej River. Shimla experiences four distinct seasons, including a severe winter from December to March, a scorching summer from April to June, monsoon rains from July to mid-September and a post-monsoon season lasting up to November. The local terrain significantly influences temperature variations, with rising temperatures from March to June and a subsequent fall with the onset of monsoons in late June. January is the coolest month, with mean maximum and minimum temperatures of 8.9°C and 1.7°C, respectively (https://www.emerginghimachal.hp.gov.)

In the context of changing seasonal patterns, the increased frequency of cloudburst-induced extreme rainfall during the monsoon is anticipated. Such alterations in rainfall patterns are expected to intensify in the future due to global warming in the Shimla district of the Indian Himalayan state. These changes could exacerbate adverse impacts on food security, health, agricultural production, and hydrological regimes as highlighted in various studies (Kumar *et al.* 2010; Sharma *et al.*, 2023).

In recent years, numerous studies have focused on interpreting global trends, particularly in mean temperature and rainfall – crucial hydrological parameters significantly impacted by climate change and global warming (Shadmani *et al.*, 2012; Sridhgar and Raviraj 2017; Alhaji *et al.*, 2018; Nourani *et al.*, 2018). Gocic and Trajkovic (2013) conducted a comprehensive analysis of annual and seasonal trends in seven meteorological variables across twelve weather stations in Serbia from 1980 to 2010, utilizing the Mann-Kendall test and Sen's slope estimator. Shanomae Eastman and Basheer Khan (2022) conducted a study at the Botanical Gardens rain gauge in Georgetown and analyzed 30 years of rainfall data for engineering projects, revealing unpredictability, a bi-modal pattern and projections of return periods. Similarly, Mondal *et al*. (2012) employed the same statistical tests to study the northeast part of Cuttack, India, analysing rainfall data spanning from 1971 to 2010. Over the past few decades, several studies have scrutinized the hydrological trends in different regions of India, shedding light on the impacts of climate change. Yadav *et al.* (2014) delved into the precipitation and temperature trends in thirteen districts of Uttarakhand from 1971 to 2011. Their comprehensive trend analysis suggested that the changes observed in the studied area were statistically insignificant.

Similarly, Chinchorkar *et al.* (2015) conducted an examination of hydrological parameters in Anand district, India, spanning the period 1970-2011. Their findings revealed an increasing trend in mean maximum temperature, coupled with a decreasing trend in total monthly rainfall, highlighting the dynamic nature of these critical climatic variables.

Furthermore, Shaikh and Lodha (2020) extended their analysis to the Hathmati river basin in India, covering the years 1966-2015. Their results painted a clear picture of positive trends in hydrological parameters, providing compelling evidence of climate change. These findings underscore the potential severe consequences of climate change on hydrological parameters, emphasizing the urgency of addressing these environmental shifts for sustainable water resource management in India. Bhan (2011) conducted a study on total precipitation and snowfall data for Shimla (Himachal Pradesh) during the winter season (December to March) and concluded that it exhibits a decreasing tendency.

Several studies examining the changing pattern of rainfall over India have observed that there is no clear trend of increase or decrease in average rainfall across the country (Mooley and Parthasarthy 1984; Thapliyal and Kulshrestha 1991; Lal 2001; Sinha Ray and De 2003; Kumar and Jain 2010). Despite the absence of a significant trend in all-India monsoon rainfall over a long period, some studies have identified pockets of substantial long-term rainfall changes on a regional scale (Jagannathan and Parthasarathy 1973; Raghavendra, 1974; Chaudhary and Abhyankar 1979; Singh and Sen Roy 2002; Kumar *et al*., 2005; Goswami *et al.*, 2006; Guhathakurta and Rajeevan, 2006; Dash *et al*., 2007; Singh *et al*., 2008). Using high-resolution gridded rainfall data (1951-2003), Goswami *et al*. (2006) observed an increase in the frequency and magnitude of extreme rainfall events during the monsoon season over central India. Dash *et al.* (2007) identified a decreasing trend in monsoon and an increasing trend in pre-monsoon and post-monsoon rainfall during 1871-2002. Singh *et al.* (2008) found an increasing trend in annual rainfall in nine river basins of northwest and central India. Based on high-resolution daily gridded rainfall data from 1901-2004, Rajeevan *et al.* (2008) concluded that the frequency of extreme rainfall events exhibits significant inter-annual and inter-decadal variations. There is a significant amount of research yet to be done in the selected study area to understand the rainfall pattern.

The main aim of the present study is to analyse the trends of precipitation of Shimla district of Himachal Pradesh (India) from 1994 to 2022.

Study Area: Shimla District lies between the longitude 77º-0″ and 78º-19″ east and latitude 30º-45″ and 31º-44″ north (refer to Fig. 1). This research focuses on a 30-year period spanning from 1994 to 2022, utilizing rainfall data as a consistent timeframe for analysis. Through the examination of this observed data, the study aims to furnish comprehensive insights into the anticipated maximum rainfall for various return periods.

Source: (https://www.emerginghimachal.hp.gov.in)

Fig. 1. Location map of Shimla District.

MATERIAL AND METHOD

Over a span of 29 years (1994-2022), monthly and annual precipitation data were acquired from various sources, including Jal Shakti Vibhag Shimla, Met Centre Shimla and IMD Pune, specifically for the rain gauge stations situated in the district. To assess the long-term variability and trend in the region's rainfall pattern, a set of statistical techniques—mean, standard deviation, skewness, kurtosis, and coefficient of variation were applied to analyze this dataset. Additionally, the return period of yearly rainfall was examined using diverse plotting position formulas, including California, Hazen, Weibull, Chegodayev, Blom, and Gringorten.

It is commonly recommended to consider return periods ranging from 5 to 100 years for activities such as soil and water conservation measures, dam construction, irrigation, and drainage works. Consequently, the estimated rainfall was computed for return periods of 5, 10, 50, 100, and 150 years to facilitate informed decision-making in these critical areas.

A. Plotting Position Methods

Table 1 displays the plotting position methods employed in this study. These empirical equations, identified as the most widely utilized by Subramanya (2013) for determining probability P, have been selected for their common applicability. It is worth noting that while these methods generally yield satisfactory results for minor extrapolations, errors tend to escalate with an increase in the number of extrapolations.

In the determination of the return period, the rainfall data underwent ranking in descending order, and diverse plotting positions along with probabilistic methods were applied. The equations derived from the graphs, specific to various plotting position methods, were then utilized to ascertain the rainfall magnitudes corresponding to different return periods.

Table 1: Plotting Position Methods.

Plotting Position Method	Equation for P
California	$\frac{m}{N}$
Weibull	$\frac{m}{(N+1)}$
Hazen	$\frac{(m-0.5)}{(N)}$
Chegodayev	$\frac{m-0.3}{(N+0.4)}$
Blom	$\frac{(m-3/8)}{(N+1/4)}$
Gringorten	$\frac{(m-0.44)}{(N+0.12)}$

where, m is rank of the data, and N=number of the sample (no. of years) (Source-Subramanya (2013).

RESULTS AND DISCUSSION

A. Yearly Rainfall Analysis

The analysis of Shimla district's annual rainfall distribution spans a 29-year period from 1994 to 2022, as illustrated in Fig. 2. This depiction includes both the annual rainfall values and their averages. Notably, the highest recorded rainfall of 1392.90 mm occurred in 2022, closely followed by 1286.83 mm in 1995. Conversely, the minimum rainfall of 737.72 mm was noted in 2004, with the second-lowest amount (749.90 mm) observed in 2007. The calculated average annual rainfall over this 29-year duration is 1035.30 mm.

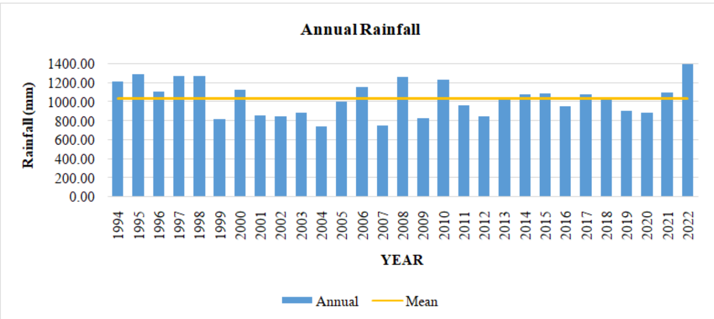

Fig. 2. Annual Rainfall of Shimla District.

Examining the specific details of 2022, it is noteworthy that July received the highest monthly rainfall, reaching 350.10 mm out of the total 1392.90 mm.

Table 2 provides a breakdown of descriptive parameters for annual rainfall covering the years 1994 to 2022. The relatively elevated standard deviation value of 179.84 implies a substantial variability in the annual rainfall data. The coefficient of variation, a measure of how dispersed data points are from the mean, attests to the erratic nature of the rainfall, with a value of 17.37%. The skewness, indicating the asymmetry of the annual precipitation around the mean, is calculated at 0.12, suggesting a rightward skew in the distribution. Furthermore, the kurtosis, reflecting the peakedness or flatness of a frequency distribution, approaches zero with a value of (-)0.99, indicating a mesokurtic distribution.

Table 2: Descriptive Parameters for Annual Rainfall.

Description	Descriptive Statistics
Mean Rainfall(mm)	1035.30
Standard Deviation	179.84
Co-efficient of Variation	17.37%
Skewness	0.12
Kurtosis	(-) 0.99

B. Analysis of Plotting Position Methods

Table 3 presents the annual rainfall corresponding to different return periods for various plotting positions. Notably, the California method yields the highest rainfall values for different return periods, while the Hazen method produces the lowest values, making it less suitable for comprehensive analysis. In contrast to other distribution methods, the Chegodayev approach stands out by providing a maximum rainfall approximately 99.7% of the average maximum rainfall, establishing it as the most fitting distribution for yearly rainfall data. The Chi-square test was employed to evaluate the goodness of fit for these distributions, revealing that the Chegodayev method exhibits the lowest Chi-square value, thus emerging as the most suitable match for the distribution.

The projection of rainfall for any given return period can be achieved using the equation depicted in Fig. 3. Employing the Chegodayev plotting position method, the exceedance probability for the highest recorded rainfall of 1392.90 mm in 2022 is determined to be 2.3%, while the second-highest rainfall of 1286.83 mm in 1995 has an exceedance probability of 5.6%.

Table 3: Maximum Annual Rainfall(mm)-Based on Different Plotting Position Methods.

Method/Return Period	5years (mm)	10years (mm)	50years (mm)	100years (mm)	150years (mm)
Weibull method	1054.56	1161.40	2016.07	3084.42	4152.76
California method	1058.25	1168.77	2052.91	3158.10	4263.28
Hazen method	1032.03	1081.32	1475.56	1968.36	2461.16
Chegodayev Method	1040.25	1112.57	1691.16	2414.40	3137.64
Blom Method	1037.00	1100.65	1609.84	2246.34	2882.83
Gringorten Method	1034.34	1090.50	1539.73	2101.28	2662.82
Average	**1042.74**	**1119.20**	**1730.88**	**2495.48**	**3260.08**

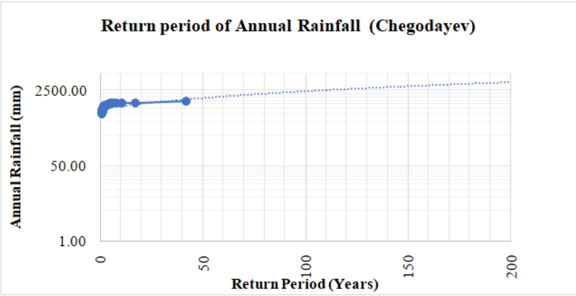

Fig. 3. Return Period of Annual Rainfall of Shimla District.

C. Monthly Rainfall Analysis

The examination of the month-wise mean rainfall distribution in Shimla district spans a period of 29 years, from 1994 to 2022. Fig. 4 illustrates a plot of the mean monthly rainfall data for this entire duration, providing insights into the rainfall pattern of the district. Notably, the month of July exhibits the highest mean rainfall, recording 217.41mm, closely followed by August with 203.15mm. In contrast, the month of November experiences the lowest mean rainfall at 15.96mm, with December being the second-lowest at 18.10mm.

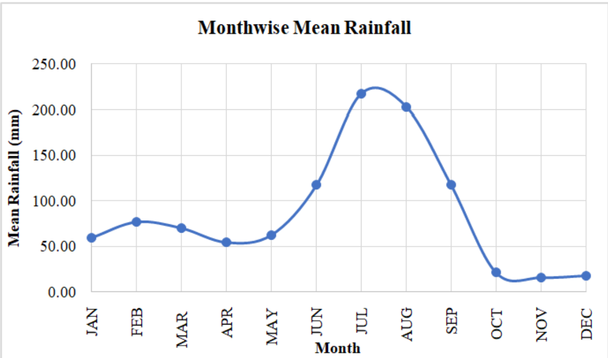

Fig. 4. Mean Monthly Rainfall of Shimla District.

D. Descriptive Parameters

Table 4 reveals that the months of June, July, August and September receive higher average rainfall values, registering at 117.27mm, 217.41mm, 203.15mm and 117.48mm, respectively. In general, the standard deviation values are lower than the corresponding mean values, with the exception of October, November and December. Among these, November stands out with the largest variation in the distribution of rainfall. The data highlights considerable variability in rainfall for October, November and December, recording percentages of 142.91%, 185.94% and 120.26%, respectively. Conversely, lower variability is observed in rainfall for May, July and August, at percentages of 50.12%, 41.83% and 36.54%, respectively.

Table 4: Descriptive Parameters for Monthly Rainfall Analysis.

Month	Mean Rainfall (mm)	Standard deviation (mm)	Coefficient of Variation (%)	Skewness	Kurtosis	Minimum (mm)	Maximum (mm)
JAN	59.71	37.25	62.39	0.96	2.69	0.00	181.00
FEB	77.17	49.81	64.55	0.39	-1.01	9.92	188.30
MAR	70.37	46.15	65.59	0.17	-1.17	0.00	148.70
APR	54.65	29.10	53.24	0.12	-0.01	0.00	119.58
MAY	62.73	31.44	50.12	0.14	-1.16	5.30	118.90
JUN	117.27	64.19	54.74	1.17	1.31	38.79	291.63
JUL	217.41	90.94	41.83	0.04	-0.77	28.45	368.88
AUG	203.15	74.23	36.54	-0.31	-1.01	57.20	317.62
SEP	117.48	78.01	66.40	0.61	-0.58	9.48	296.86
OCT	21.30	30.43	142.91	2.77	10.34	0.00	147.40
NOV	15.96	29.67	185.94	2.95	10.95	0.00	140.00
DEC	18.10	21.77	120.26	2.05	5.79	0.00	98.16

Upon closer examination, it is evident that the data series are predominantly positively skewed, with the exception of August, which exhibits a slight negative skew. The range of kurtosis for all the data series falls within the spectrum of (-) 1.17 to 10.95. Specifically, negative kurtosis, indicating flat distributions, is observed in the months of February to May and July to September. In contrast, positive kurtosis, signifying peaked distributions, is noticeable in all other months.

CONCLUSIONS

The statistical analysis of the rainfall data from 1994 to 2022 in Shimla District, Himachal Pradesh, aimed to comprehend the rainfall patterns in the region. Key parameters such as mean, standard deviation and coefficient of variation were calculated for both yearly and monthly rainfall to assess variability. The outcomes revealed an erratic rainfall pattern, with the highest recorded rainfall of 1392.90 mm in 2022 and the lowest at 737.72 mm in 2004. The average annual rainfall over the 29-year period amounted to 1035.30 mm. July exhibited the highest mean rainfall at 217.41 mm, while November recorded the least at 15.96 mm.

The analysis identified significant variability in rainfall data, particularly in October, November and December (142.91%, 185.94%, and 120.26%, respectively). In contrast, May, July and August experienced lower variability at 50.12%, 41.83%, and 36.54% respectively.

This analysis holds valuable insights for agricultural engineers, farmers and water resource planners. It aids in assessing water availability and designing suitable storage solutions. Given the unpredictable rainfall pattern, the findings can guide the design of effective drainage systems to prevent flooding, stabilize agriculture, and provide long-term security for farmers investments. Additionally, the study contributes to a better understanding of regional and global climate and rainfall patterns.

The recommendation is made to conduct similar studies for other districts in Himachal Pradesh once adequate data becomes available. Recognizing the impact of short-duration, intense storms versus longer storms with higher constant loading on drainage systems can enhance the precision of future analyses.

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