Statistical Examination of Rainfall Variability and Trends in India from 1901 to 2022

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***Abstract*—This paper presents the application of different statistical methods on Indian Meteorological Department rainfall data by conducting an extensive analysis of historic rainfall trends and shifts across 28 states of India from 1901 to 2022. In this study different statistical methods that include mean, standard deviation and rainfall quantification are performed for analyzing the deviation and extremities.Statistical tests such as Mann-Kendell and Pettitt Test are performed. The findings from the Mann-Kendell test reveals no significant monotonic increase or decrease in rainfall trend neither for a larger or smaller time frame. Whereas, using the Pettitt test significant abrupt shifts in rainfall patterns were uncovered, which emphasize the presence of abrupt shifts rather than trends. Additionally, analysis of decadal rainfall patterns, identification of years and decades with exceptional rainfall level are also conducted. The research also identifies states that receive rainfall through southwest and northeast monsoons. While the dataset used in this study lacks granularity, it is still crucial in determining the significance of the different methods employed in this study. This study can be extended to conduct more region-specific analysis, including districts, taluks to obtain a deeper understanding of rainfall dynamics at a specific region wise in the context of climate change.**

***Index Terms*—Statistical rainfall analysis, extreme rainfall events, abrupt shifts in rainfall, climate change, machine learning**

I. Introduction

In this rapidly changing climate, it is crucial to understand the shifts in weather patterns. Shifts in rainfall pattern remains a central concern, as major disasters, ecosystems and agriculture are tied to it. In recent years, rainfall in India has become more erratic, leading to devastating floods and severe droughts. This research is a step towards unravelling the complex patterns in rainfall changes on the face of climate change in India. Thereby providing vital information to government bodies and disaster management authorities, thus enabling them to develop effective strategies to climate-induced challenges. The motivation behind this research is the 2018 Kerala floods, which prompted the urgency to understand the effects of climate change on rainfall patterns in India. This catastrophic event highlighted the urgent need to analyze the Indian historical rainfall data in order to quantify shifts in its distribution, intensity, and seasonality. The challenges identified during the research include the unavailability of quality data, presence of non-linear trends, urbanization, and climate change-induced data non-stationarity, which underscore the complexities in addressing this critical issue. Previous studies employing statistical tests and machine learning techniques on rainfall trends in India underscored the challenges involved in relying on historical data and model uncertainties [2]. Another study which investigated the impact of climate change on extreme rainfall events and flood risks in India focused only on extreme rainfall events from 1901 to 2011 [3]. Research on flood forecasting using satellite, Machine Learning (ML) and Deep Learning (DL) techniques emphasized issues in data quality and the need for real time systems [4], [5], [7], [10]. The majority of the past studies focused on analysing specific regions than encompassing the whole country [6], [8], [11]. The scope of the study was limited to a short span of time focusing mainly on extreme rainfall events or flood prone regions [3].However, these studies have shed light on aspects of India's rainfall, crucial knowledge gaps persist. This paper aims to conduct exhaustive investigation spanning 122 years of nationwide Indian Meteorological Data rainfall records, thereby facilitating a comprehensive analysis of rainfall trends throughout India. The primary objectives involve detailed analyses such as line plots and utilizing advanced statistical methods such as the Pettitt test for detecting abrupt changes and the Mann-Kendall test and Sen slope for trend analysis.

II. Data

The Indian Meteorological Department provides rainfall data in netCDF(network Common Data Form) which is widely used to store multidimensional scientific data, enabling efficient storage and extraction of large datasets [12]. In this study, data spanning for a period of 12 years from 1901 to 2022 is utilized

III. Software Tools

In our research specialized tools were used to analyse rainfall patterns for around multiple states of India over a period of 122 years (1901-2022). The central platform we have made use for data exploration, preprocessing and visualisation is Jupyter Notebook which enabled efficient and iterative analysis of the data. Python supported by the essential libraries including Numpy, Pandas, Matplotlib and Xarray enabled extensive manipulation, visualisation and analysis of

TABLE I
MEAN AND STANDARD DEVIATION OF TOTAL ANNUAL RAINFALL FOR VARIOUS STATES FROM 1901-2022

State	**Mean of Total Annual Rainfall (mm)**	**Standard Deviation of Total Annual Rainfall (mm)**
Andra Pradesh	761.87	233.29
Arunachal Pradesh	2572.49	734.31
Assam	2179.58	383.29
Bihar	1177.19	179.58
Chhattisgarh	1241.81	281.12
Delhi	600.41	53.34
Gujarat	719.21	278.12
Haryana	1030.14	70.41
Himachal Pradesh	1467.60	283.89
Jammu & Kashmir	1159.31	267.65
Jharkhand	1156.95	223.07
Karnataka	757.14	195.58
Kerala	2423.66	392.29
Madhya Pradesh	909.13	261.86
Maharashtra	1082.07	165.77
Manipur	1425.28	406.23
Meghalaya	2186.28	377.26
Mizoram	960.01	585.44
Nagaland	1457.23	413.24
Odisha	1507.96	316.42
Punjab	796.54	60.37
Rajasthan	533.25	157.54
Sikkim	2611.24	524.53
Tamil Nadu	1149.54	336.75
Telangana	1030.51	175.08
Tripura	2131.28	564.89
Uttarakhand	1337.89	87.69
West Bengal	1561.65	181.50

TABLE II
RAINFALL PERCENTILE ANALYSIS FROM 2010-2022

State	**Years above 95th %**	**Years below 5th %**
Andhra Pradesh	2010	2018
Arunachal Pradesh	2012	2010
Assam	2020	2010
Bihar	2011	2015
Chhattisgarh	2022	2010
Delhi	2010	2014
Gujarat	2020	2012
Haryana	2010	2012
Himachal Pradesh	2013	2010
Jammu & Kashmir	2013	2010
Jharkhand	2011	2022
Karnataka	2010	2016
Kerala	2021	2016
Madhya Pradesh	2010	2021
Maharashtra	2013	2018
Manipur	2020	2021
Meghalaya	2020	2010
Mizoram	2017	2010
Nagaland	2020	2021
Odisha	2012	2010
Punjab	2010	2020
Rajasthan	2010	2018
Sikkim	2021	2010
Tamil Nadu	2021	2016
Telangana	2010	2011
Tripura	2017	2010
Uttarakhand	2013	2020
West Bengal	2021	2010

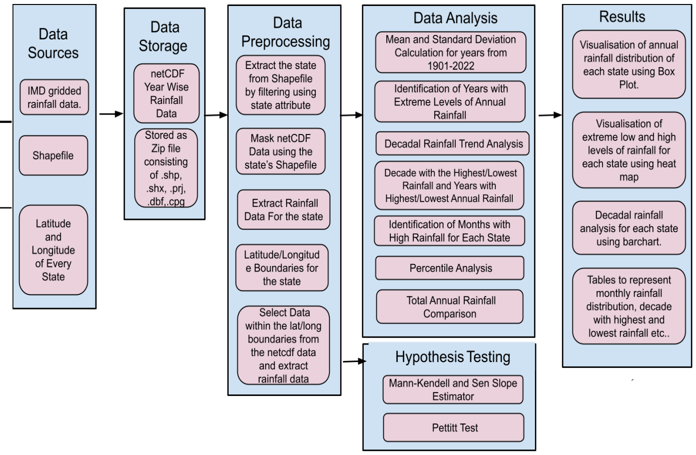

Fig. 1. Block Diagram Representing Various Analysis Carried out in this Study

NetCDF multidimensional data. Additionally, netCDF libraries netCDF4 provide functionality in manipulating and extracting rainfall data programmatically. By using these tools strategically we conduct a comprehensive study to analyse and comprehend the trends and variabilities of the rainfall and analyse the significance of multiple statistical tools that will help in providing valuable information to understand climate change dynamics for every state.

IV. METHODOLOGY

In this section systematic approach employed to analyze rainfall trends, encompassing both graphical exploration and statistical techniques to provide understanding of temporal variations in rainfall trends is presented [Figure: 1.

- *Extraction of State-wise Rainfall Data:* To streamline state-level analysis, shapefiles were utilized to extract data for individual states from the comprehensive netCDF datasets, which encompass daily rainfall records for the entire nation. Shapefiles provide a geospatial representation of geographic features, such as state boundaries, enabling the extraction of specific regions or areas of interest from larger datasets. However, shapefiles never covered the entire extent of the state all the time, hence longitudinal and latitudinal range were explicitly provided during the extraction wherever the shapefile did not bear results.This preprocessing step was essential to tailor the dataset to the scope of our research and ensure relevance to the study objectives.
- *Mean and Standard Deviation Calculation for years from 1901-2022:* Mean and standard deviation of the total annual rainfall across all the years was conducted. This statistical approach helped us to quantify the central tendency and variability of the total annual rainfall over the time period for every state.
- *Identification of Years with Extreme Levels of Annual Rainfall (122-Year Period):* In this study, we identified years that exhibited extreme levels of rainfall from 1901

to 2022. These outlier years observed total annual rainfall that significantly deviated from the long-term average. By pinpointing these anomalies, we aimed to understand the frequency and impact of extreme rainfall events over the extended time frame.

- *Decadal Rainfall Trend Analysis:* Trend analysis is performed by calculating the mean of a 10-year moving window for the rainfall data. This approach helped us to study the rainfall trends across every decade from 1901 to 2022. Through this method we could observe whether the rainfall in each state increased, decreased or remained stationary over the passage of each decade.
- *Decade with the Highest/Lowest Rainfall and Years with Highest/Lowest Annual Rainfall:* This experiment was done to understand the highest and lowest rainfall encountered by each state over a century. We first determined the decade with the highest cumulative rainfall and lowest cumulative rainfall for every state. Additionally, we also determined the years observing the highest and lowest total annual rainfall.
- *Identification of Months with High Rainfall for Each State:* Monthly average rainfall for every month across the years from 1901 to 2022 was visualized with the help of time series line graph. Where each line graph plotted the average rainfall received for every month for that particular year.As part of this visualization, a consistent increase in rainfall during the monsoon across all the years was identified. Also, the states exhibiting significant fluctuations in rainfall was observed.
- *Percentile Analysis of IMD Rainfall Dataset (2010-2022):* A comprehensive percentile analysis was conducted on the rainfall data for the past 12 years from 2010 to 2022 across all the states. Focusing on the past 12 years(or recent decade) allows the analysis of more current trends and potential shifts in extreme rainfall events, which may better reflect current climatic conditions. This analysis helps identify extreme rainfall events by capturing those years where total annual rainfall falls above and below the 95^{th}percentile and 5^{th}percentile thresholds respectively.
- *Total Annual Rainfall Comparison (2018-2022):* A comparative analysis of the total annual rainfall across various states from 2018 to 2022 was conducted.The average annual rainfall received for each state for every year was calculated and plotted against a line chart. The aim of this experiment was to determine if there has been an increase in rainfall following the extreme event of 2018.
- *Mann-Kendell and Sen Slope Estimator:* Mann-Kendall Test helps to identify any significant monotonous increase or decrease in rainfall trends. Sen slope estimator estimates the rate and direction of the trend detected by Man-Kendall test.These two methods collectively provide valuable insights into the directional patterns and magnitudes of changes in rainfall trends over the period of study.We have formulated a hypothesis for evaluating the statistical significance of observed trends in rainfall data. Null hypothesis and alternate hypothesis are as follows:Null Hypothesis(H0): No significant directional patterns and magnitudes of changes in rainfall trends detected over the period of study;Alternate Hypothesis(Ha): Significant directional patterns and magnitudes of changes in rainfall trends detected over the period of study.
- *Pettitt Test:* A non-parametric statistical test used for detecting any significant change or discontinuity at a certain point of time in a time series data. This test is deployed to identify any abrupt shifts in rainfall for the period of study.Abrupt shift is identified by calculating mean before and after the change point.We have formulated a hypothesis for evaluating the statistical significance of observed trends in rainfall data. Null hypothesis and alternate hypothesis are as follows:Null Hypothesis(H0): There is no abrupt change detected over the period of study.Alternate Hypothesis(Ha): An abrupt change is detected at the change point index for the period of study. A lower p-value suggests stronger evidence against the null hypothesis. The magnitude of test statistics(U), which is computed by comparing the sums of the ranks

TABLE III
MONTHLY RAINFALL DISTRIBUTION FOR VARIOUS STATES (IN MM)

State	**Months**
Andra Pradesh	September(150), October(250), November(200 approx)
Arunachal Pradesh	June(600), July(750), August(600 approx)
Assam	June(500), July(500), August(500 approx)
Bihar	June(155mm),July(250mm), August(200mm)
Chhattisgarh	July(500), August(335), September(400 approx)
Delhi	July(150), August(200), September(100)
Gujarat	July(400), August(300), September(250 approx)
Haryana	July(300), August(300), September(250)
Himachal Pradesh	July(400), August(400), September(200)
Jammu&Kashmir	July(400), August(550), September(200)
Jharkhand	June(200), July(400), August(300-400), September(225)
Karnataka	May(150), July(120), August(125), September(150), October(180 approx)
Kerala	June(700), July(800), August(400), September(250), October(300), November(200)
Madhya Pradesh	June(200), July(400), August(400), September(300 approx)
Maharashtra	June(200), July(500), August(350)
Manipur	June(400)
Meghalaya	June(500), July(500), August(500 approx)
Mizoram	June(600), July(500), August(400 approx)
Nagaland	June(400), July(400), August(400 approx)
Odisha	June(300), July(500), August(450), September(200)
Punjab	July(275), August(250), September(100)
Rajasthan	July(200), August(200), September(100)
Sikkim	June(600), July(1000), August(700)
Tamil Nadu	September(200), October(250), November(200), December(300)
Telangana	July(250), August(250), September(200)
Tripura	June(600), July(500), August(400 approx)
Uttarakhand	July(400), August(450), September(300)
West Bengal	May(300), June(300), July(500), August(500), September(400 approx)

TABLE IV
RAINFALL DATA FOR VARIOUS STATES (IN MILLIMETERS)

State	2018	2019	2020	2021	2022
Andhra Pradesh	400	800	1200	850	900
Arunachal Pradesh	2156	2554	2425	2247	3022
Assam	1721	2051	2520	1728	2041
Bihar	798	1087	1090	1300	845
Chhattisgarh	870	1200	1180	1200	1590
Delhi	521	414	606	717	578
Gujarat	500	1100	3800	2650	2700
Haryana	940	1233	1154	1258	1201
Himachal Pradesh	2262	1736	485	1403	1433
Jammu & Kashmir	1095	886	254	831	864
Jharkhand	900	950	1200	1100	700
Karnataka	800	950	850	1150	1520
Kerala	2700	2600	2225	2800	2300
Madhya Pradesh	750	1240	800	700	750
Maharashtra	890	1320	1260	1200	1300
Manipur	951	1574	3788	604	801
Meghalaya	1866	2237	2662	1992	2199
Mizoram	1349	1370	1686	1296	1214
Nagaland	988	1603	3846	604	804
Odisha	2000	1475	1500	1950	1450
Punjab	809	782	646	854	924
Rajasthan	420	732	728	642	727
Sikkim	2255	2072	1573	3289	1814
Tamil Nadu	825	1000	1325	1943	1275
Telangana	925	1180	1225	1180	1390
Tripura	2077	2081	2343	2010	1872
Uttarakhand	1275	1252	454	1669	1229
West Bengal	1390	1430	1400	1820	1240

of observations before and after each potential change point, is used to assess the significance of the change point, high value indicates a significant change point.

V. EXPERIMENTAL RESULTS

- *Mean and Standard Deviation for years from 1901-2022:* TABLE I shows the mean and standard deviation of annual rainfall from 1901 to 2022. Mean and standard deviation vary significantly for each state, therefore in order to better understand the variation a box plot is created from TABLE I. The box plot graph Fig. 3 represents the total annual rainfall in the Y axis ranging from 0 to 4000 mm and states in the X axis arranged alphabetically. Each state has a box plot that indicates the distribution of the annual rainfall data. The main advantage of the box plot is to easily identify the rainfall pattern in each state.
  It can be observed that Arunachal Pradesh shows the greatest degree of deviation in terms of the total annual rainfall received, followed by Tripura, Mizoram,Sikkim, Nagaland, Kerala and Himachal Pradesh. Jammu & Kashmir, Punjab, Delhi and Haryana show less deviations. The states of Arunachal Pradesh and Tripura have the maximum number of outliers. Highest mean annual rainfall are observed in Sikkim, Arunachal pradesh, and Kerala.The lowest mean annual rainfall are observed in Rajasthan, Delhi and Gujarat.
- *Years with Extreme Levels of Annual Rainfall (122-Year Period):* The total annual rainfall data for 122 years from 1901 to 2002 is used to analyze the extremities.

TABLE V
DECADES AND YEARS WITH HIGHEST AND LOWEST RAINFALL

State	**Highest Decade**	**Highest Year**	**Lowest Decade**	**Lowest Year**
Andhra Pradesh	2010-2020	2010	1910-1920	1904
Arunachal Pradesh	1940-1950	1948	1900-1910	2006
Assam	1980-1990	1948	2000-2010	2010
Bihar	1910-1920	1971	2010-2020	1966
Chhattisgarh	1900-1910	1919	1980-1990	2000
Delhi	1950-1960	2010	1990-2000	1918
Gujarat	2010-2020	2020	1990-2000	2002
Haryana	2010-2020	2010	1970-1980	1918
Himachal Pradesh	2000-2010	2013	1960-1970	2010
Jammu & Kashmir	1940-1950	1950	2010-2020	2020
Jharkhand	1900-1910	1999	1990-2000	1966
Karnataka	2010-2020	2010	1910-1920	1965
Kerala	2010-2020	1961	1970-1980	2010
Madhya Pradesh	2000-2010	2010	2010-2020	1918
Maharashtra	2010-2020	2021	1910-1920	1920
Manipur	1900-1910	2020	2000-2010	2006
Meghalaya	1990-2000	1988	1930-1940	2010
Mizoram	1980-1990	1984	2010-2020	2010
Nagaland	1900-1910	2020	2000-2010	2006
Odisha	1920-1930	1961	1960-1980	1979
Punjab	1940-1950	2010	1910-1920	1972
Rajasthan	2010-2020	2010	1970-1980	1918
Sikkim	1910-1920	1998	2010-2020	2010
Tamil Nadu	2010-2020	1996	1990-2000	2002
Telangana	2010-2020	2010	1910-1920	1920
Tripura	1980-1990	1984	2000-2010	2010
Uttarakhand	1910-1920	1936	2010-2020	2020
West Bengal	1980-1990	1971	2000-2010	2010

In order to provide a visual understanding of the extremities, a heat map is generated, which is used for visualizing the annual rainfall data across 28 states and for 122 years respectively. The heat map generated is shown in Fig. 4. In Fig. 4, three color codes repetitively used to represent the mean annual rainfall for each state. The color code varies from light to dark color, light representing the lowest rainfall and dark representing the highest rainfall for that particular state alone. Hence, each state represents its unique pattern of lowest rainfall to highest extreme rainfall. For instance, the first column represents the state of Andhra Pradesh. In Andhra Pradesh, lowest rainfall of 367.967mm is observed during the year 1904 and it is represented in white color. Whereas, highest rainfall of 1726.74 mm was observed during 2010 and it is represented in dark blue color. The color variations are specific within each column, thereby representing the unique pattern for each state. Such a representation helps to easily identify the years with high, low and medium rainfall with each state for a 122 year period. This is helpful for understanding the overall distribution of rainfall in India. In reference to the heat map, in 1948, Arunachal Pradesh got the maximum annual rainfall(4834.15297 mm) in the past 122 years and similarly, in 2002, Tamil Nadu got the minimum annual rainfall (65.444244 mm).

Our examination for extremities in rainfall patterns

TABLE VI
NUMBER OF EXTREME RAINFALL EVENTS AND ITS CORRESPONDING YEARS FOR ALL THE STATES

State	No of years with extreme rainfall	Years
Andhra Pradesh	3	1979, 2007, 2010
Arunachal Pradesh	7	1948, 1974, 2006, 2007, 2008, 2009, 2010
Assam	7	1948, 1974, 1984, 2006, 2008, 2009, 2010
Bihar	7	1936, 1956, 1966, 1971, 2009, 2015, 2018
Chhattisgarh	3	1917, 1919, 2000
Delhi	5	1917, 1918, 1933, 1967, 2010
Gujarat	2	2002, 2020
Haryana	7	1905, 1918, 1933, 1961, 1975, 2002, 2010
Himachal Pradesh	7	1950, 1972, 1973, 2010, 2013, 2017, 2020
Jharkhand	6	1917, 1919, 1966, 1971, 1999, 2011
Jammu & Kashmir	10	1914, 1917, 1950, 1961, 1972, 1988, 2007, 2009, 2010, 2020
Karnataka	4	1965, 2010, 2021, 2022
Kerala	4	1924, 1959, 1961, 2010
Madhya Pradesh	5	1918, 1944, 1959, 1973, 2010
Maharashtra	3	1918, 1920, 1972
Manipur	5	1911, 1981, 2006, 2020, 2021
Meghalaya	6	1988, 1993, 1995, 1999, 2009, 2010
Mizoram	6	1978, 1984, 1986, 1987, 1988, 2010
Nagaland	5	1911, 1981, 2006, 2020, 2021
Odisha	4	1961, 1973, 1979, 2010
Punjab	7	1917, 1950, 1955, 1972, 1988, 1995, 2010
Rajasthan	3	1917, 1918, 2010
Sikkim	5	1902, 1905, 1995, 1998, 2010
Tamil Nadu	8	1913, 1996, 2001, 2002, 2003, 2008, 2016, 2021
Telangana	5	1920, 1988, 1990, 2010, 2013
Tripura	5	1978, 1984, 1986, 1988, 2010
Uttarakhand	4	1918, 1936, 2010, 2020
West Bengal	5	1971, 1972, 1999, 2009, 2010

revealed noteworthy findings provided in Fig. 4. The 21 out of 28 states under consideration displayed extreme rainfall events for the year 2010. Interestingly, the majority of these states demonstrated higher extremities whereas a selected group of states including Mizoram, Tripura, Assam, Meghalaya, Arunachal Pradesh, Himachal Pradesh, Sikkim, Jammu Kashmir, Odisha and Kerala showed lower extremities. In 122 years Jammu Kashmir experienced 10 instances of extremity in rainfall whereas Gujarat only experienced 2. These insights shed light on the diverse and erratic nature of rainfall distribution across the states in India.

In the TABLE VI number of extreme rainfall events and its corresponding years for all the states are provided. From the table observed, Jammu and Kashmir has 10 extreme rainfall events followed by Tamil Nadu, Arunachal Pradesh, Assam,Haryana,Himachal Pradesh,Punjab. Gujarat has the least number of extreme rainfall events followed by rainfall events followed by Andhra Pradesh, Chhattisgarh, Maharashtra, Rajasthan.

- *Analysis of Decadal Rainfall Patterns:* Analysis of decadal and annual rainfall patterns [TABLE V] reveals that, it can be noted that the year with the highest or lowest rainfall does not necessarily fall under the decade with the highest or lowest average rainfall. For instance, in the state of Uttarakhand, the decade of 1910-1920 is recorded as the decade with highest average rainfall whereas the year of highest rainfall (1936) does not belong to the same decade. Similarly, in Delhi, the decade from 1990 to 2000 experienced the lowest average annual rainfall, while the lowest annual rainfall on record was in 1918. From the Fig. 2 the decadal rainfall for each state is drawn and it is drawn in such a way that the X axis and Y axis are common for all the states. The X axis varies from 1900 to 2020(years), whereas the Y axis varies from 0 to 3500 mm of rainfall. So for each state the quantity of rainfall represents the amount of rainfall in each particular state varying across standard scale. The graph is capable of reflecting the states with higher rainfall and it also shows the patterns of the states with lowest amount of rainfall. The intention of this graph is to give a visual appearance of the states with higher rainfall and the states with lower rainfall. The amount of relative difference between the states is visually evident.
- *Monthly Average rainfall:* Monthly rainfall average for each state for the 122 years is prepared and the months with highest average rainfall are shown in TABLE III. From this table a clear seasonal distribution can be observed across the various states of India. The states of Tamil Nadu and Andhra Pradesh mainly receive rainfall during the months of October to December due to the northeast or retreating monsoon, whereas most other states, including Kerala, Maharashtra, Madhya Pradesh, and multiple northeastern states, receive rainfall primarily because of the southwest monsoon. It can also be seen from TABLE III, the states such as Kerala receive a high-

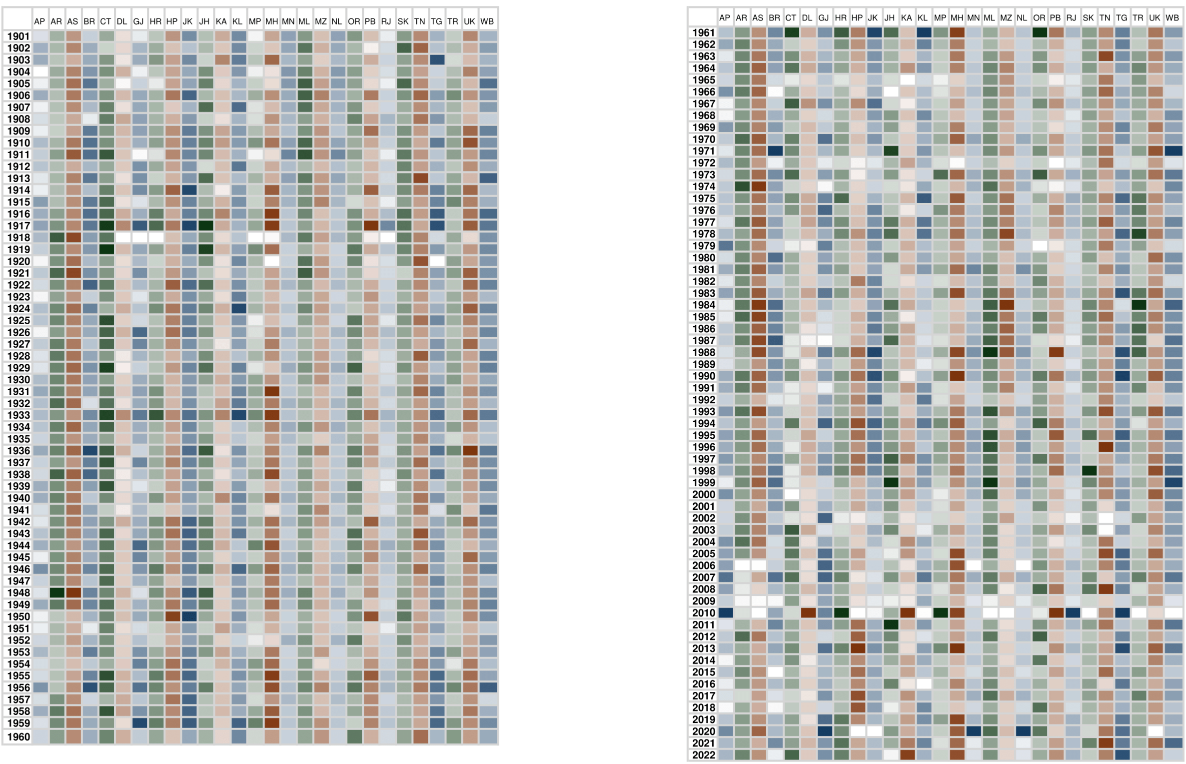

Fig. 4. Visualization of rainfall from extreme low to high levels for all the states through heat map

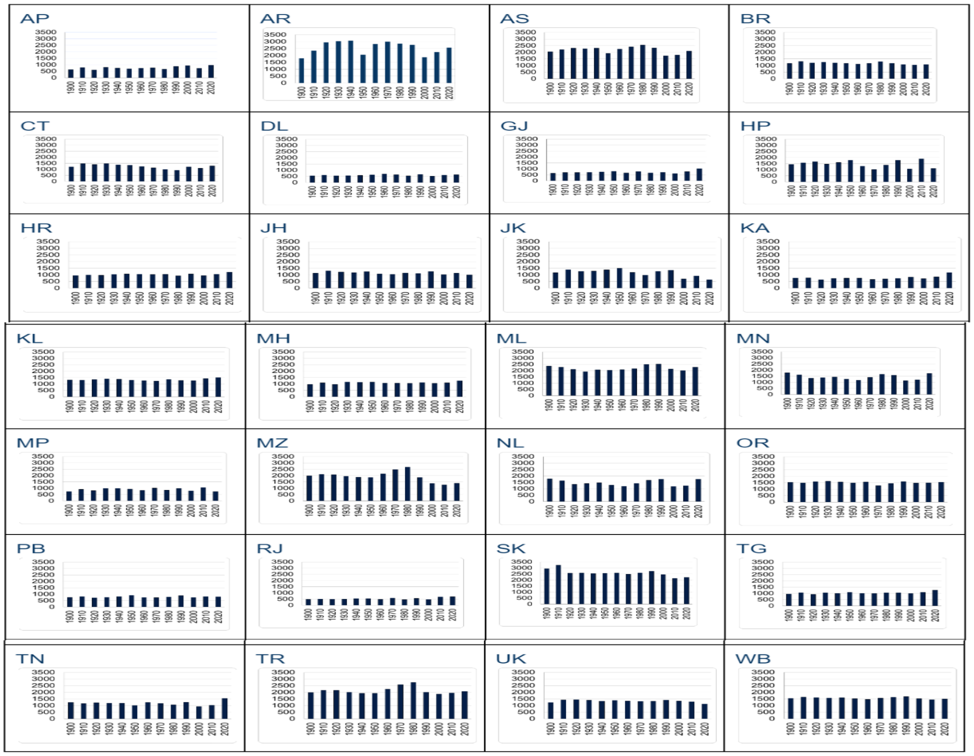

Fig. 2. Decadal Rainfall Analysis Across The States

est monthly average of 1200 mm followed by Sikkim with 1000 mm during the month of July. Whereas states such as Delhi, Rajasthan receive a highest monthly average of 200 mm rainfall during the month of August. It shows the varied rainfall pattern over the different states in the Indian subcontinent.

- *Percentile Analysis from 2010-2022:* The percentile analysis is conducted on 12 years of rainfall data for the years from (2010-2012). For each state the corresponding year's crossing the 95th percentile and 5th percentile are shown in TABLE II. A distinctive trend observed in the year 2010 can be seen from TABLE II. Haryana, Punjab, Rajasthan, Delhi, Telangana, Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra observed rainfall level above 95 percentile in the year 2010 while during the same year states such as West Bengal, Chhattisgarh, Mizoram, Tripura, Assam, Meghalaya, Arunachal Pradesh, Sikkim, Odisha, Himachal Pradesh, and Jammu Kashmir observed lower than 5 percentile rainfall level.
- *Total Annual Rainfall Comparison (2018-2022):* The average annual rainfall for each state for the recent 5 years from 2018 to 2022 is presented in TABLE IV. From the table after the extreme rainfall event in 2018, most of the states such as Kerala, Tamil Nadu, Telangana, Andhra Pradesh, Karnataka, Sikkim etc. show years with highest annual rainfall than 2018. The TABLE IV presents a comprehensive outline of the regional variation in annual rainfall pattern.
- *Mann-Kendell and Sen Slope Estimator:* For all states analyzed, a p-value surpassing the 0.05 threshold in the Mann-Kendall test provides evidence of the absence of a statistically significant monotonic increase or decrease in rainfall trends for the 122 year period.This suggests that, within the specified time frame, there is no strong statistical evidence to support a consistent upward or downward trend in the annual rainfall for the individual states.
- *Pettitt Test:* A p-value below 0.05 in the Pettitt test signals a significant shift in total annual rainfall for all states. Among the 122 years, short intervals of time (2 years) are tested consecutively for better detection of abrupt shifts; pinpointed at change point index 1. This result implies that there is strong statistical evidence supporting a substantial alteration in the rainfall patterns.

Conclusion

In conclusion, this study provides a unique and thorough investigation of rainfall patterns across India, spanning 122 years of national IMD rainfall data. Analysis of mean and standard deviation of annual rainfall from 1901 to 2022 is performed. A box plot is used to present the variation of mean and standard deviation. It can be identified that Arunachal Pradesh shows the greatest degree of deviation received and Jammu & Kashmir shows less deviation in terms of the total annual rainfall. To identify extremities, statistical methods along with other general analysis were used. The results were presented graphically in the form of a heat map that

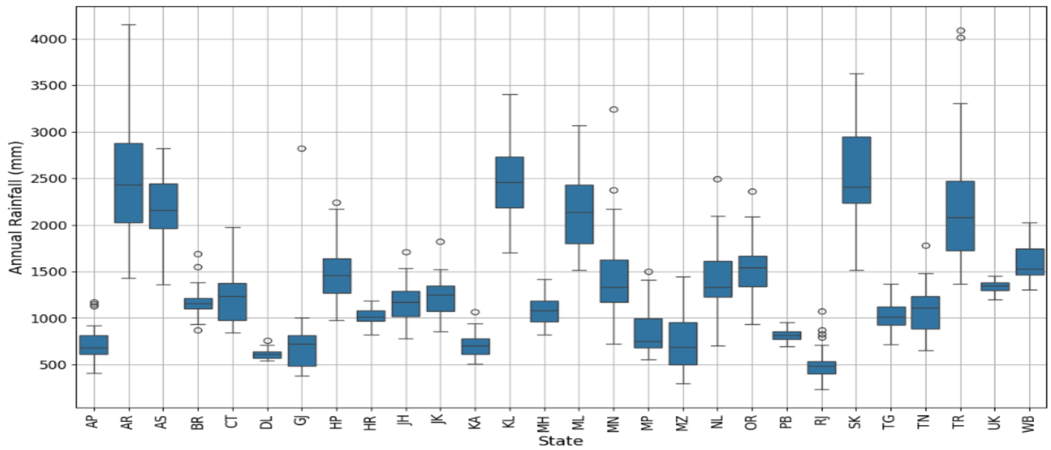

Fig. 3. Total annual rainfall distribution for each state using boxplot.

showed extreme high and low rainfall for all the states for the span of 122 years .An analysis of decadal rainfall trends from 1901 to 2022 provided insights on long-term rainfall patterns. Additionally, years exceeding the 95th percentile and falling below the 5th percentile from 2010 to 2022 for each state were identified, emphasizing the variability in rainfall extremes.Monotonic trends in annual rainfall were explored using the Mann-Kendall and Sen Slope estimator, with the Pettitt test detecting abrupt changes in rainfall patterns.This study, conducted on a state-wide scale, revealed the absence of significant monotonic increases or decreases in rainfall trends. This lack of pronounced trends is attributed to the extensive geographical coverage of the state. Instead, noticeable abrupt shifts in rainfall were observed at frequent intervals. Additionally, it was observed that the year of the highest or lowest rainfall may not necessarily align with the decade of highest or lowest rainfall for the state.This discrepancy highlights the erratic nature of rainfall patterns at the state level.Furthermore, states experiencing rainfall due to southwest and northeast monsoons were identified, contributing to a comprehensive understanding of the diverse precipitation dynamics observed over the studied period. However, a limitation exists in the dataset's lack of granularity regarding regional rainfall patterns and corresponding precipitation duration. Looking ahead, future research aims to delve into more region-specific rainfall analyses, extending to Union territories, districts, villages, and taluks, providing an even more detailed understanding of India's diverse precipitation dynamics.

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