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Rainfall Seasonality Changes over India Based on Changes in the Climate

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***Abstract*—**An individual seasonality index is used to study the seasonality of rainfall over India. The seasonality indicator is examined for two time periods: early (1901-1970) and recent (1971-2015). In some regions of India throughout the recent time (1971-2015), trend analysis using linear regression during these two periods reveals a downward trend in the seasonality index (i.e., decreasing values of the index), which implies shorter dry spells resulting in more consistent rainfall throughout the year.

***Keywords*—**Individual seasonality index, rainfall distribution, seasonality index, climate.

I. Introduction

THE Indian subcontinent now faces wider disparities between water availability and demand due to the spread of intensive agriculture, rising population, and growing urbanization. The seasonal and regional patterns of rainfall in India are highly unpredictable [1]-[4]. The Indian economy is strongly reliant on rainfall, with only around 80% of total rainfall coming from the Indian summer monsoon rainfall (ISMR), which occurs from June to September [45].

According to [5]-[8], the Indian winter monsoon rainfall (IWMR) in November and January also contributes somewhat to the annual rainfall. As a result, India has extremely seasonal rainfall distributions. Many studies are conducted primarily to highlight and comprehend the ISMR, as well as its dynamics, origin, and predictability throughout India [9]-[12].

Furthermore, substantial patterns in rainfall variability over India were discovered [13], [30] at the geographical, temporal, and inter-seasonal scales. Pre- and post-monsoon seasons are the subject of several studies in addition to ISMR investigations [14][16].

The study of the shifting rainfall seasonality pattern across India has received less attention than the vast quantity of research that has been done and/or is being conducted on the ISMR. Numerous industries and sectors, including residential, agricultural, industrial, transportation, and recreational, may be greatly impacted. Each of these water-demanding industries requires effective water management. Rainfall seasonality is the inclination of a place to have more rainfall in some months or seasons than in others [17], [43]. Furthermore, as several independent components are subsequently introduced, rainfall seasonality develops into a complicated notion [18], [19]. Furthermore, seasonal differences in rainfall levels have primarily been evaluated using rainfall seasonality, which does not provide a definitive indication of how wet or dry the seasons [20], [21]. Consequently, comparisons of the rainfall distribution in different Indian subregions must be done in addition to measuring the rainfall regimes. Reference [22] computed the Seasonality Index (SI) using harmonic analysis, and then they attempted to identify areas with similar rainfall patterns using this index. References [23]-[26] examined the seasonality and variability of rainfall across the northern region of Bangladesh, a country in South Asia.

It is possible that changes in the volume and duration of rainfall will result from a changing climate, and the magnitude of these changes may be dependent on the spatial distribution of rainfall. Rainfall in India is distributed quite unevenly, with significant variations in both time and space [27], [28]. Due to this, this area has a variety of rainfall patterns. This emphasizes how important it is to use a regime-specific technique and the appropriate index to identify the seasonality shift in rainfall patterns [31], [32].

There are extremely hot summers and severely cold transit or post-monsoon periods. In May, the highest temperatures typically range from 40 to 47 °C. A heat wave occurs during the season when daytime temperatures are 4 to 6 °C above average for a few days. Winter lows typically range from 4 to 9 °C and are below 0 degrees. or when a cold, northerly wind comes out of the Himalayan region. Occasionally in the morning hours after the passage of western disturbances, mist and fog also appear. The lowest recorded temperatures of -2.2 °C occurred on January 31, 1905, and January 16, 1970. The indirect effects of rainfall are caused by other ecological processes [29], [30]. The yearly rainfall directly influences the quantity of soil water that is accessible, making it a key element in deciding where plants are found. Nutrients in the soil may flow off if it is too wet or dry and not reach the roots of the plants, resulting in poor growth and general health. Furthermore, as previously indicated, excessive rain or overwatering can promote the growth of bacteria, fungi, and mold in the soil [33].

As a result, the primary goal of the current study is to determine the monthly distribution of rainfall in India by examining the seasonality and variability of rainfall across the country. The SI and different rainfall regimes throughout the whole Indian subcontinent have not yet been determined by any study utilizing observational gridded data [44], [45].

II. Methodology and Data Used

The Indian Meteorological Department (IMD) provided

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gridded rainfall data at 0.25 x 0.25 for the years 1901-2015 [30] using data on daily rainfall collected from 6,955 evenly distributed rain-gauge stations, some of which are exceptional.

The IMD developed a grid-deployed rainfall data-gathering system to identify outliers in the northern Indian states of Jammu and Kashmir. Following thorough quality checks, the available station data were interpolated using the Shepard interpolation method into regular grids. The rainfall gridded data set reproduces the orographic rainfall and its gradient more accurately due to the better resolution of the gridded rainfall. It is important to note that the specific techniques and tools used can vary depending on the data characteristics, the spatial and temporal scale of the study, and the available resources. Additionally, advancements in remote sensing technologies and numerical weather prediction models can also contribute to more accurate and detailed rainfall data grids [41], [42].

Two distinct eras were identified throughout the 1901-2015 research period: the early period (1901-1970) and the recent period (1971-2015), which were used to track developments in the SI.

Nowadays, the study is selected in light of countless additional investigations completed by different authors [35]-[37] that utilized the period from 1970 onward as the current climate to see changes throughout the Indian area. Because most of the human radiative forcings have occurred in the last 30 years, [38] defined the time following 1970 as the global warming era.

In contrast, one can only estimate the mean seasonality for the entire period using the mean SI, depending on the availability of the length of the data record. The interannual differences in seasonality may be found by analyzing the individual seasonality index (SI_i), which is the index that is determined for each year using the mean monthly rainfall. Consequently, the temporal changes in seasonality will be monitored using the mean individual seasonality index (SI_i). The following widely used seasonality index (SI_i) was created by [34]:

$$\text{SIi}=\frac{1}{Ri}\sum_{n=1}^{n=12}\left|x_{in}-\frac{R_i}{12}\right|$$

In the given research year, Ri represents the total yearly rainfall, while X_{in} denotes the actual monthly rainfall for month n. Even though this index can only describe the seasonality pattern in very basic terms, it can be a highly helpful tool for analyzing differences in seasonality both temporally and spatially [39], [40]. The deviation of the rainfall distribution in a particular year is larger with higher index values (Table I). In addition, the calculation of the index's all-India average is employed to illustrate its variation with latitude. and year, and looked for any missing values. We collected data on seasonal rainfall in the tehsils of Jaipur and analyzed it using descriptive methods. The analysis included weekly, monthly, and seasonal rainfall patterns. The results were informative and helped shed light on rainfall patterns in the region. Overall, it was a useful exercise in understanding weather patterns in Jaipur district.

Using the SIi over a longer period j (years), the long-term mean SIi for each location may be calculated as follows:

$$\text{SI}_i=\frac{i}{j}\sum_{j=1}^{j=n}SI_i$$

The resulting index will have a lower magnitude because the averaging process smoothes out year-to-year "noise" in the monthly rainfall values. This is an alternative index with a formula that is similar to that which can be used to calculate the index using long-term average monthly rainfall data directly (SI).

III. Results and Discussion

The distribution of the monthly rainfall climatology pattern in India over the early and recent eras is shown in Table I. The seasonal precipitation regime is represented by the individual seasonality index (SI_i).

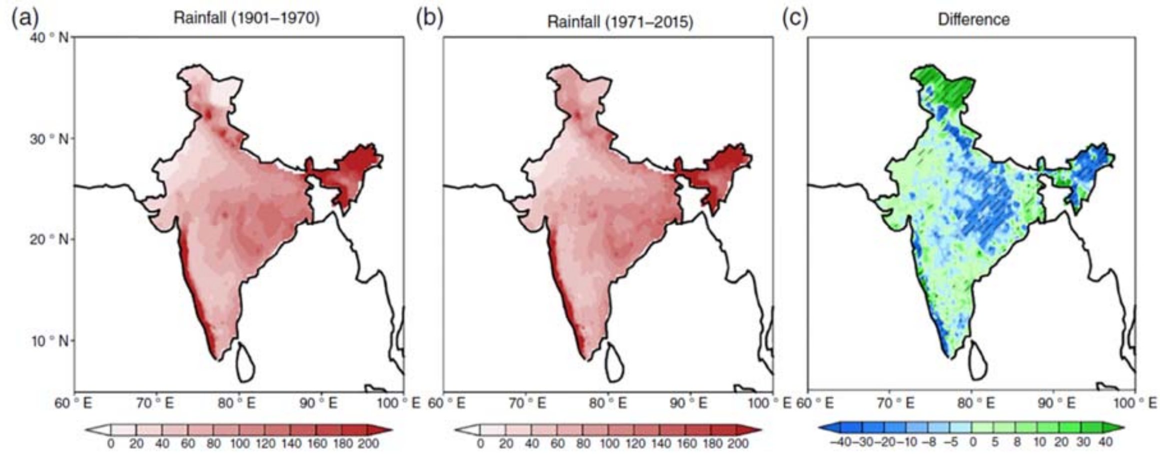

Fig. 1 Monthly rainfall (mm/month) climatology for the Indian area over three different eras: (a) early (1901–1970), (b) recent (1971–2015), and (c) the difference between the early and recent periods; The area that is hatched displays a 99% confidence level

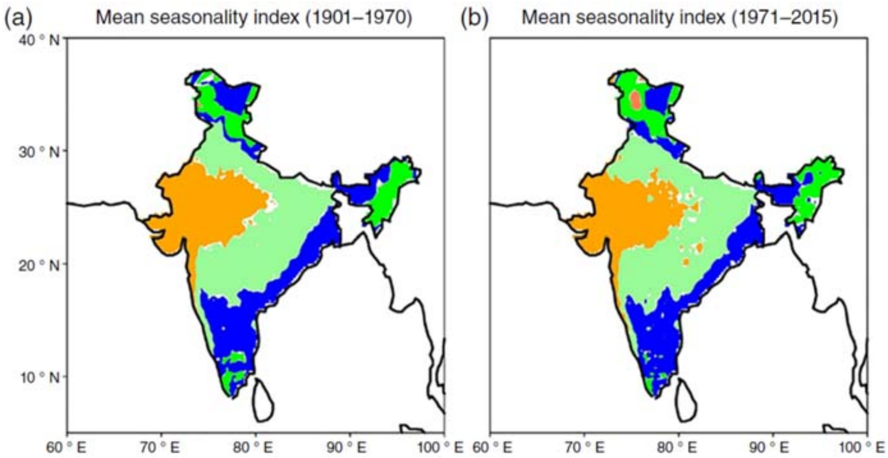

Fig. 2 Average individual seasonality index for the Indian area for the (a) early (1901-1970) and (b) modern (1971-2015) periods

TABLE I
MONTHLY RAINFALL CLIMATOLOGY

SIi	Precipitation regime
< 0.19	Precipitation spread throughout the year
0.20–0.39	Precipitation spread throughout the year but with a definite wetter season
0.40–0.59	Rather seasonal with a short drier season
0.60–0.79	Seasonal
0.80–0.99	Markedly seasonal with a long dry season
1.00–1.19	Most precipitation in less than 3 months
> 1.20	Extreme seasonality, with almost all precipitation in 1–2 months

This disparity between the early and recent times is depicted in Figs. 1 (a) and (b), respectively, and is also shown in Fig. 1 (c). While the difference between the recent and early eras (Fig. 1 (c)) demonstrates a significant variance in total monthly rainfall, the climatological pattern between the early (Fig. 1 (a)) and recent (Fig. 1 (b)) periods does not reveal much of a difference in rainfall throughout the Indian region. Over most of central and northern India, as well as the northeast, there is an obvious decline in the pattern of rainfall. Nonetheless, the northwest, southern India, and the Ladakh area in Jammu and Kashmir's northernmost regions have all witnessed an increase in rainfall patterns recently.

The rainfall patterns show an undeniable similarity in results. There is a clear pattern that needs to be acknowledged and taken into consideration. The primary focus is on studying and analyzing the changes that occur in the seasonal patterns over a specific period. By conducting thorough research and gathering accurate data on these changes, we aim to gain a better understanding of their impact on various aspects such as climate, agriculture, tourism, and more. Our team is dedicated to providing comprehensive insights and solutions that can help mitigate the challenges posed by these seasonal variations. Each grid point throughout the Indian area has its distinct SI for the early and recent periods computed in the current study. As previously stated, the long-term mean individual SI is determined using the annual individual SI. Using the SIi, a comparison of the geographical distribution of rainfall regimes is conducted for the early and recent times, as seen in Figs. 2 (a) and (b).

In some of the locations, like the northern Jammu and Kashmir regions in northeastern and central India, it demonstrates a noticeable shift. In both the early and recent eras, the northwest region with the greatest SIi, ranging between 1.2 and 1.4, exhibits "extreme seasonality, with almost all rainfall in 1-2 months," as per the categorization of seasonal rainfall regimes, as seen in Table I.

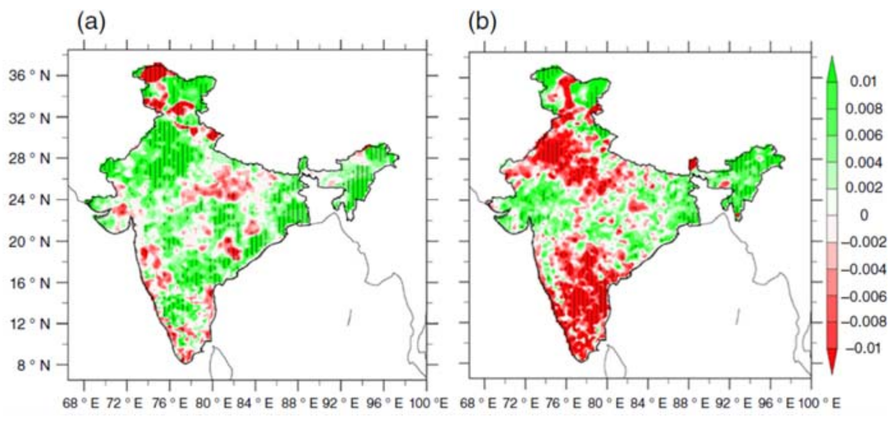

Fig. 3 Mean individual seasonality index's trend over the Indian area for the following periods: (a) early (1901-1970) and (b) current (1971-2015); a 99% confidence level is shown by the hatching area

Analogously, the central Indian area, which is likewise the monsoon core region and gets rainfall mostly during the Indian summer monsoon (ISM), is characterized by a rainfall regime having "most of the rainfall in 3 months or less."

Figs. 3 (a) and (b), for the early and recent eras, respectively, depict the geographical pattern of a strong linear trend in SIi magnitude. As opposed to the early era (Fig. 3 (a)), the trend in the index indicates a large falling value, which results in decreased seasonality in the recent period (Fig. 3 (b)) throughout the southern Indian peninsula and certain portions of northwest and central India. Except for the northernmost region and the area close to the Himalayan foothills, which exhibit lesser declining patterns, most of the areas exhibited very little or negligible positive tendencies throughout the early era. Additionally, several northern and northeastern Indian regions exhibit high positive values that point to enhanced seasonality, which eventually causes dryness in these areas.

Fig. 4 displays the latitudinal distribution of mean individual SI changes over the Indian subcontinent for both the early and recent periods. Both eras show a noticeable decline in the index as one approaches north of 25. When comparing the recent time to the earlier period, this decline is more noticeable.

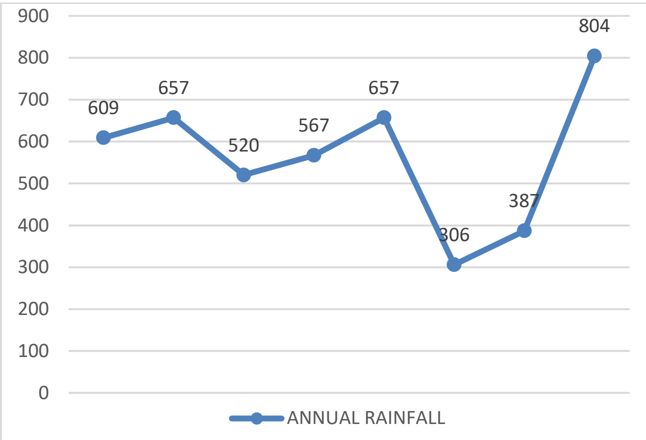

Fig. 4 Distribution of mean individual seasonality index annually

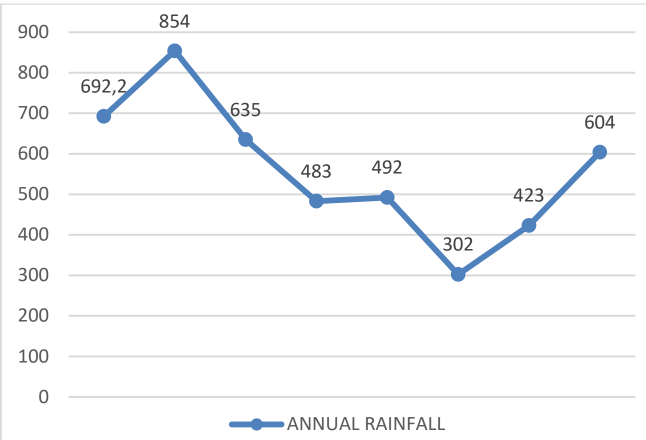

Fig. 5 Distribution of mean individual seasonality index annually

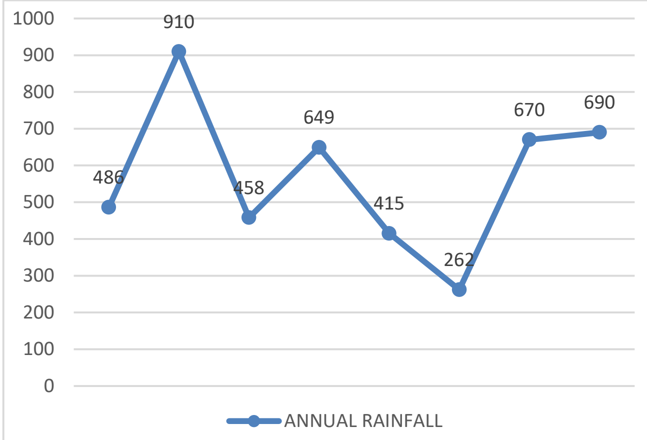

Fig. 6 Distribution of mean individual seasonality index annually

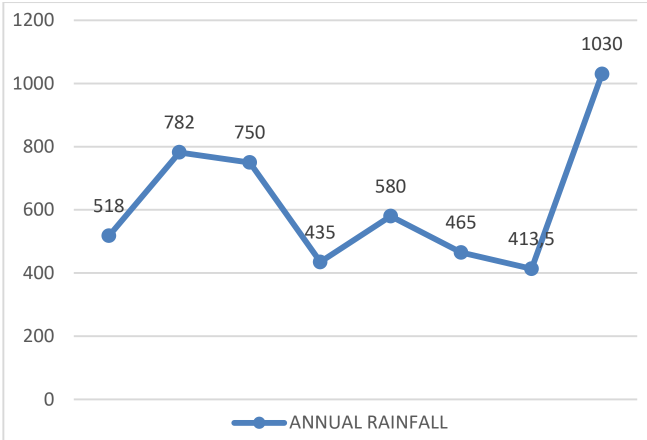

Fig. 7 Distribution of mean individual seasonality index annually

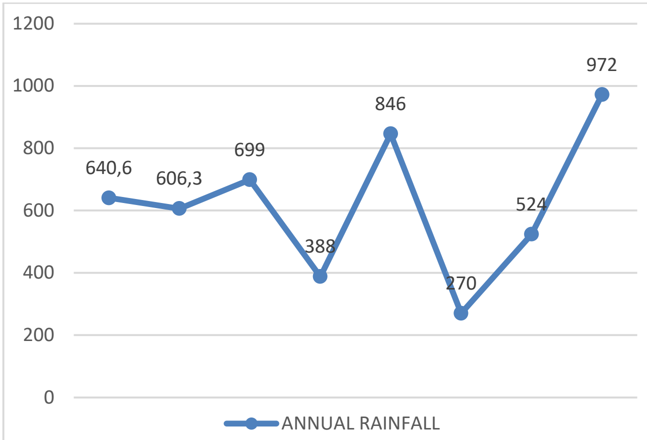

Fig. 8 Distribution of mean individual seasonality index annually

The early and current eras of the index's scatter plot are displayed in Fig. 5. Comparing the early and recent periods, the former is marked by lower index values (more seasonal rainfall) while the latter shows relatively higher index values. Additionally, Fig. 5 shows how the rainfall regimes have changed across the Indian subcontinent. Fig. 6 depicts the correlation between the mean individual seasonality indices and the annual rainfall in the Indian area for the whole research period, which runs from 1901 to 2015.

Annual rainfall and the mean individual seasonality indicators, which vary greatly from year to year, are clearly inversely related. The distribution of the wettest months in a given year may be determined using the replicability index, which is calculated as the mean individual SI divided by the individual SI for each year (Fig. 7). Increased replicability index values signify the recurrence of months with maximum rainfall distributed across a smaller number of months. Fig. 8 illustrates that greater index values are seen in the early era and lower index values are observed in the recent period. This indicates that the wettest month is happening in more months of the year during the recent period.

The changes in rainfall seasonality in India, driven by climate change, have significant and varied effects on human populations. These impacts manifest in various aspects of daily life, livelihoods, and overall well-being. Here are some ways in which altered rainfall patterns affect people in India:

A. Agricultural Impacts

Crop Yield Variability: Changes in rainfall seasonality can lead to unpredictable crop yields, affecting agricultural productivity. Farmers may face challenges in planning planting and harvesting, resulting in economic losses.

Food Security: Reduced crop yields and increased vulnerability to extreme weather events can contribute to food insecurity, impacting the nutritional well-being of communities.

B. Water Scarcity and Access

Reduced Water Availability: Changes in rainfall patterns may lead to water scarcity, affecting both rural and urban areas. Diminished water sources can impact daily activities, agriculture, and industries.

Impacts on Livelihoods: Many livelihoods, such as those in agriculture and related sectors, are closely tied to water availability. Water scarcity can lead to economic hardships, particularly for communities dependent on rain-fed agriculture.

C. Health Challenges

Waterborne Diseases: Altered rainfall patterns can influence water quality and contribute to the spread of waterborne diseases. Increased flooding may lead to the contamination of water sources, posing health risks to communities.

Vector-Borne Diseases: Changes in temperature and humidity patterns can affect the distribution of disease vectors, potentially expanding the geographical range of diseases like malaria and dengue.

D. Migration and Displacement

Climate-Induced Migration: As livelihoods are disrupted by changes in rainfall patterns, communities may be forced to migrate in search of better opportunities. This can lead to increased competition for resources and potential conflicts.

E. Infrastructure Vulnerability

Floods and Landslides: Intense rainfall and flooding can damage infrastructure, including roads, bridges, and buildings. This poses risks to public safety and can disrupt transportation and communication networks.

F. Social and Economic Inequities

Impact on Vulnerable Communities: The effects of changing rainfall patterns often disproportionately affect vulnerable and marginalized communities. Those with limited resources and adaptive capacity may struggle more to cope with the challenges posed by climate change.

G. Adaptation Challenges

Challenges in Coping Strategies: Rapid changes in rainfall patterns may outpace the ability of communities to adapt. Traditional coping strategies may become less effective, requiring the development and implementation of new adaptive measures.

IV. Conclusion

In India, there are two primary rainfall regimes: "seasonal" in the northeast and "extreme seasonality with almost all rainfall in 1-2 months" in the northwest. Compared to "extreme seasonality" locations with the highest index values, these "seasonal" rainfall regimes with lower index values have a shorter dry season. The Indian summer monsoon's (ISM) dominance is one of the primary causes of the region's reduced variability and rainfall regimes, which include significant seasonal and seasonal in northeast and central India.

The mean individual seasonality index (SI) climatology across the early and recent periods shows clear variances in regional patterns. Furthermore, the index's tendency indicates a downward pattern in some areas recently, which may result in lower SI in these areas and suggest a broader spread of the yearly rainfall throughout different months. The index's longitudinal variation also reveals a decline at higher latitudes, particularly more recently than in the early era, suggesting a change in the mean spatial distribution of rainfall over India. This seasonality pattern variation may indicate alterations in the atmospheric circulation over the Indian subregion.

In summary, recent studies on the Indian subcontinent's surface area can offer a succinct picture of how rainfall varies throughout the year, which may be useful in identifying any variances in seasonality. Also, one may utilize this straightforward SI to recognize and describe the distribution of the various rainfall regimes.

The focus is on studying seasonal changes in sub-regions of India to provide insights and solutions for challenges related to agriculture, tourism, and climate. India has a variety of distinct local climates governments. Thus, this research highlights the significance of contemplating more research in light of upcoming monsoon attempts drafting.

Although there is some bias among the various time series, there is strong consistency across all of the time series, according to a comparative analysis of the interannual variation of the all-India southwest monsoon season rainfall derived from different rainfall gridded data sets along with IMD operational all-India rainfall time series (IMD_OP). Moreover, during the whole data period (1901–2010), the southwest monsoon rainfall time series obtained from the IMD4 strongly coincided with the IMD_OP series. Additionally, it was noted that, except for the rank difference, the top and bottom 10 rainfall years in the time series of both the IMD4 and IMD_OP were almost identical.

The rainfall distribution features, such as known heavy rainfall areas in the orographic regions of the west coast and over the northeast, decreased rainfall in the leeward side of the Western Ghats, etc., were also more realistic and better presented due to IMD4's higher spatial resolution and the higher density of rainfall stations that were used in its development. The possibility to incorporate observations from a large number of rain gauges across the county for the development of IMD4 has been made possible by the daily shifting network of enough rain gauges from around the nation for gridding. It should be noted, nonetheless, that there were a lot of variances in the data that was available from these rain gauges.

Another benefit of this strategy is the chance to utilize observations from newly installed rain gauges around the nation. At the same time, the real-time data processing process will not be impacted in any way should any of the current rain gauges close in the future. Since this data collection will be updated in real-time by IMD, it may also be utilized for critical operational services including forecasting stream flow, flooding, and real-time drought monitoring at different temporal and geographical scales.

The mean annual rainfall and the seasonal mean rainfall patterns for each of the four seasons were found to have almost comparable large-scale climatological characteristics across all data sets. For instance, the large-scale features such as maximum rainfall areas along the west coast and over northeast India, rapid decreases in rainfall in the leeward side of the Western Ghats, and minimum rainfall over northwest India were depicted in the spatial distribution of the annual and southwest monsoon season rainfall climatology in all the data sets. Nonetheless, in comparison to IMD1 & IMD2, the zone of greater rainfall regions along the west coast was smaller in the higher resolution data sets [IMD3, IMD4, & APHRO (narrowest in IMD4)].

To compare different gridded data sets, the major climatological features of India's rainfall were as follows: (a) large-scale spatial patterns of mean annual rainfall and mean rainfall during each of the four seasons (winter (January–February), pre-monsoon (March–May), southwest monsoon (June–September), and post-monsoon (October–December)); (b) annual mean cycle of daily, monthly, and seasonal rainfall in all of India.

All of the data sets showed the same mean annual cycle of rainfall across India, with a peak in the monsoon season and a low in the winter. APHRO displayed a dry bias against all other data sets throughout the annual cycle (whether on a daily, monthly, or seasonal scale), and all India values for IMD3 and IMD4 were almost equal, with IMD4's annual cycle of rainfall being somewhat wetter than IMD3's across all time scales (daily, monthly, seasonal, & annual). Nonetheless, IMD2 showed the greatest values during the yearly cycle's peak section (July–September), whereas IMD1 showed the highest values for the majority of the other segments.

The temporal variation of monthly all-India rainfall for the year and for each of the four seasons was one of the rainfall variability aspects compared across the several gridded rainfall data sets that were evaluated. It also studied how the rainfall during the southwest monsoon season in India varied over time using different gridded data sets.

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