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Decadal variation of southwest monsoon season rainfall over Central India under global warming

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सार– यह अध्ययन 1971 से 2020 तक मध्य भारत क्षेत्र में वर्षा की घटनाओं में दशकीय बदलाव की जांच करता है। वर्तमान अध्ययन में, हमने 1971 से 2020 तक मॉनसून ऋतु (जून-सितंबर) के दौरान स्टेशन-स्तरीय दैनिक वर्षा डेटा का उपयोग किया। परिणामों से पता चला कि पिछले दो दशकों 2001-2010 और उसके बाद 2011-2020 के दौरान मध्य भारत में अत्यधिक (> 204.5 मिमी/दिन) और बहुत अधिक (64.5 - 204.5 मिमी/दिन) वर्षा की घटनाओं में चिंताजनक रूप से वृद्धि हुई है। (जो 2001-2010 के दशक के दौरान अपने चरम पर थी)। मध्य भारत में जुलाई 1971 से 2020 तक भारी वर्षा श्रेणी में वृद्धि देखी गई है। मध्य प्रदेश में वर्षा की सभी तीन श्रेणियों में वर्षा में उल्लेखनीय वृद्धि देखी गई। भारत के पश्चिमी तटीय राज्य गुजरात में भी 1981 के बाद से सभी श्रेणियों में निरंतर वृद्धि देखी गई। बंगाल की खाड़ी से अत्यधिक नमी की आपूर्ति के कारण पूर्वी तटीय राज्य ओडिशा में भी ऐसा ही रुझान देखा गया। सभी वर्षा-दिवसों में, अधिक से बहुत अधिक वर्षा और अत्यधिक वर्षा, दोनों ही जुलाई और अगस्त के दौरान गुजरात में सबसे अधिक होती हैं। झारखंड और छत्तीसगढ़ जैसे अंतर्देशीय राज्यों की तुलना में तटीय राज्यों (गुजरात और ओडिशा) में अत्यधिक वर्षा की घटनाएँ अधिक थी। साथ ही, पिछले दो दशकों में अवदाब/चक्रवातों की संख्या में भी वृद्धि देखी गई। कृषि और जल प्रबंधन के लिए, भारत जैसे घनी आबादी वाले देश में दिन-प्रतिदिन की वर्षा परिवर्तनशीलता और अत्यधिक वर्षा के मामलों की सटीक निगरानी आवश्यक है।

ABSTRACT. This study examines the decadal variation of rainfall events over the central India region from 1971 to 2020. In the present study, we used daily station-level rainfall data during the monsoon season (June-September) from 1971to 2020. Results showed that during the last two decades, extreme (> 204.5 mm/day)and very heavy (64.5 – 204.5 mm/day) rainfall events have increased alarmingly over Central India, with their peak during the decade 2001 – 2010, followed by 2011-2020. Central India has observed increased heavy rainfall category activity from July 1971 to 2020. A significant increase in rainfall activity was found in Madhya Pradesh in all three rainfall categories. The western coastal state of India - Gujarat, also showed a continuous rise in all categories from 1981 onwards. A similar trend was observed for the eastern coastal state of Odisha due to the excessive moisture supply from the Bay of Bengal. Of all the rainy-day occurrences, both heavy to very heavy rainfall events and extreme rainfall are highest in Gujarat during July and August. The extreme rainfall events were more pronounced in coastal states (Gujarat and Odisha) than the inland states like Jharkhand and Chhattisgarh. At the same time, increase in the number of depressions/cyclones was found to be increased in the last two decades. For agriculture and water management, it is essential to accurately monitor the day-to-day rainfall variability and extreme rainfall cases in a densely populated country like India.

Key words– Extreme rainfall, Orography, Moisture advection, Depressions and cyclones, Southwest monsoon, Pettit test

1. Introduction

Indian Summer Monsoon is a meteorological phenomenon that holds essential relevance for various socio-economic sectors, particularly in agricultural practices and water resource management. The seasonal variability of monsoon rainfall significantly impacts the livelihoods of millions of people. The Indian monsoon is responsible for 78% of the rainfall over the Indian subcontinent (Gadgil and Murthy, 2003; Rajeevan *et al.*, 2006). The Indian monsoon exhibits considerable variability in both spatial and temporal scales across the country. While the western coastal Region and North East get seasonal rainfall of more than 200 cm, few states, like Rajasthan, have seasonal rainfall of < 50 cm. The variability is attributed to geographical and climatological factors.

Enhanced crop yields in India are encouraged due to farmers' reliance on monsoonal rainfall, as they have limited access to modern irrigation methods. In total, 55 percent of India's cultivated land (139.42 million hectares) relies on rainfall and cultivates 34 of the country's 40 main crops (Shagun, 2023). Agriculture heavily relies on monsoonal rain as the primary water source in most regions. Central India, known for its varied agro-climatic zones and fertile plains, is crucial in the country's agricultural sector. The agricultural output in this area heavily relies on the monsoon; the central parts of India encompass states such as Madhya Pradesh, Chhattisgarh, Maharashtra, and parts of Gujarat, Rajasthan, and Uttar Pradesh, exhibiting a diverse range of cropping systems, including rice-wheat rotations, cotton, soybean, and pulse cultivation. The long-term viability of agriculture in this area heavily relies on the timely arrival, duration, and distribution of monsoonal rainfall. An increasing trend of extreme monsoon rainfall events has been reported over central India from 1950-2015 (Roxy *et al.,* 2017; Nikumbh, 2021) and the Himalayas (Nandargi and Dhar, 2012).

An analysis of extreme and heavy to very heavy events (rainfall) using actual station data is being attempted in the present study to investigate the trend of such high-impact rainfall events over the central region of India that includes the states of Gujarat, Madhya Pradesh, Jharkhand, Chhattisgarh, Odisha, and West Bengal. Time series of station-wise daily rainfall data for the selected states were extracted from the 6000 rain gauge stations of IMD from 1971 to 2020. An analysis of daily rainfall between 1901 and 2010 by the Indian Institute of Tropical Meteorology (IITM), Pune, showed a decadal increase of about 6% in "extreme rainfall" events, with the frequency increasing post-1981. Various other studies have used gridded Rainfall data (0.25 x 0.25 gridded) for central India for different periods (Rajeevan *et al.,* 2010; Roxy *et al.,* 2017; Sankaran *et al.,* 2021). The present study, however, uses actual station-level data to derive a more accurate conclusion.

In the present study, the rainfall variability in both spatial and temporal domains has been analyzed using the actual station rainfall observed data instead of the interpolated grid data. The rainfall activity (rainy days, rainfall >= 2.5 mm/day) and its intensity for both heavy to very heavy (>64.5-<204.5 mm/day) and extremely heavy rainfall events (>204 mm/day) have been analyzed to check if the rainfall has been confined to fewer but intense spells. Most of the study includes an increasing trend in extreme rainfall events from 1901 to 1920 (Bajrang *et al.*, 2023). A declining trend was observed over central India due to various thermodynamic and dynamic parameters and other factors like Moist static energy and Hadley circulation (Bajrang *et al.*, 2023). The frequency of rainy days during the monsoon activity over 122 days shows that the regions of northeast India and Konkan & Goa receive rainfall on more than 75 days. In central areas of PaschimBanga, Jharkhand, Chhattisgarh, and the narrow belt along the west coast, the frequency of rainy days is 50 – 75 days per season. The lowest frequency of rainy days (less than 15) is over west Rajasthan, south Tamil Nadu, and extreme northern India (PulakGuhaThakurta, Chapter 25: "Distribution of precipitation over India").A study reveals that the central India region doesn't receive much rain during the summer monsoon (Varikoden, 2020). The current study employs a change detection technique to analyze month-wise rainfall change over central India using the Pettitt test technique, and rainfall distribution maps are made using the ArcGIS environment. Orissa, Madhya Pradesh, and some parts of Gujarat are considered areas of moderately heavy rainfall regions (Report, 2014). The seasonally long period average is 90% concentrated over central India, 79% over northwest India, 93 % over the south peninsula, and 89% at the overall India level in 2014 (Report, 2014). Western disturbances in north India and monsoon low-pressure systems led to increased rainfall distribution in north, northwest, and central India.

The central belt of India is known for its physiography. Most central states, including Madhya Pradesh, Chhattisgarh, and Jharkhand, are in the Deccan Plateau region. Coastal plains exist in the Gujarat area and the northeastern part of Jharkhand, Orissa, and West Bengal, which is characterized by the northern plain areas. The northern plains support river density over the central part of India, high up to monsoonal rain, which plays a significant role in agricultural activity, and rainfall withdrawal is at its peak in August and September, when rice cultivation takes place. The main objective is to study

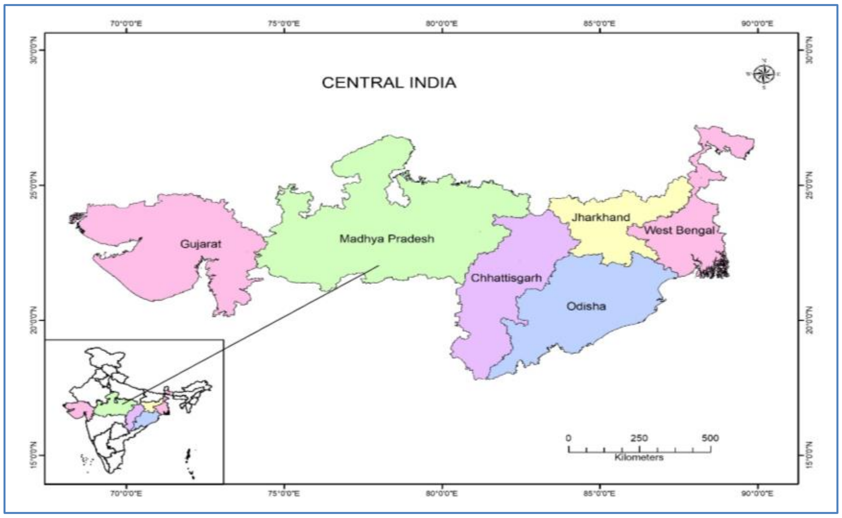

Fig. 1. Map showing the study area over Central India comprising states of Gujarat, Madhya Pradesh, Chhattisgarh, Odisha, Jharkhand and West Bengal

the climatic variability characterized by the summer monsoon rainfall over Central India, which is prone to extreme events that have seen an appreciable increase in the last decade, and forecasting these events is very challenging (Sen *et al.,* 2021).

We have investigated the changing rainfall patterns by studying the number of rainy days each decade. The decadal variability in terms of rainy days (rf >= 2.5 mm/day) and the occurrence of heavy rainfall (64.5- 115.5 mm/day), very heavy rainfall (115.6 – 204.4 mm/day), and extreme rainfall (> 204.5 mm/day) events using the station level data has been carried out. There has been an appreciable increase in the rainfall measuring stations of IMD under the DRMS (District Rainfall Monitoring System), which now has more than 6,400 rain gauge stations all over India, thereby increasing the reporting of rainfall events. This unique station-level data set gave us a unique opportunity to calculate the number of rainy days, heavy, very heavy, and extremely heavy rainfall cases over the last five decades.

2. Data and methodology

This study covers the monsoon core region and states of Central India, which lie between 20° N - 25° N latitude and 68° E - 88° E longitude (covering Gujarat, Madhya Pradesh, Chhattisgarh, Jharkhand, West Bengal, and Odisha, Fig. 1). Central India is crucial to the Indian monsoon's dynamics because of its diverse topography, which includes plateaus and plains. Rainfall variability in central India is more influenced by orograohy and moisture advection from the Arabian Sea and the Bay of Bengal. Cyclones and depressions occurring over the seas emphasize the rainfall over the central region.

Convective storms developed near coastal areas surge to create fluctuations in rainfall patterns, which affect the hydrological cycle and water management. This research aims to analyze extreme rainfall events and heavy to very heavy events during the monsoon season in Central India. In central India, Madhya Pradesh, Chhattisgarh, and parts of Maharashtra have varied orography. Its scene incorporates the Vindhya and Satpura ranges, which are responsible for the orographic rain. The torrential rain in central India is mainly affected by the southwest monsoon. The complicated exchange of elements like the Western Ghats, Eastern Ghats, the Straight of Bengal, and nearby geography impacts the strength and circulation of precipitation.

Data was obtained for the present study from the Indian Meteorological Department. This study was performed over the central states of India, including Gujarat, Madhya Pradesh, Jharkhand, Chhattisgarh, Orissa, and West Bengal, for the period 1971–2020. The selected data was used to examine rainfall events in three regimes: rainy, heavy to very heavy, and extreme. The analysis for the current study is done using Python software. We calculated values for the rainfall parameters for each regime. Rainy days (rf >= 2.5 mm/day) and the occurrence of heavy rainfall (64.5- 115.5 mm/day), very heavy rainfall (115.6 – 204.4 mm/day), and extreme rainfall (>204.5 mm/day) according to the Indian Meteorological Department (IMD) criteria. The number of station-level data used in the study is shown in Fig. 2. We applied an 80% filter to our dataset to overcome the effects of missing values and data gaps. Statistical techniques have been used to calculate the sum of all districts and their station and rainfall event values for interpretation.

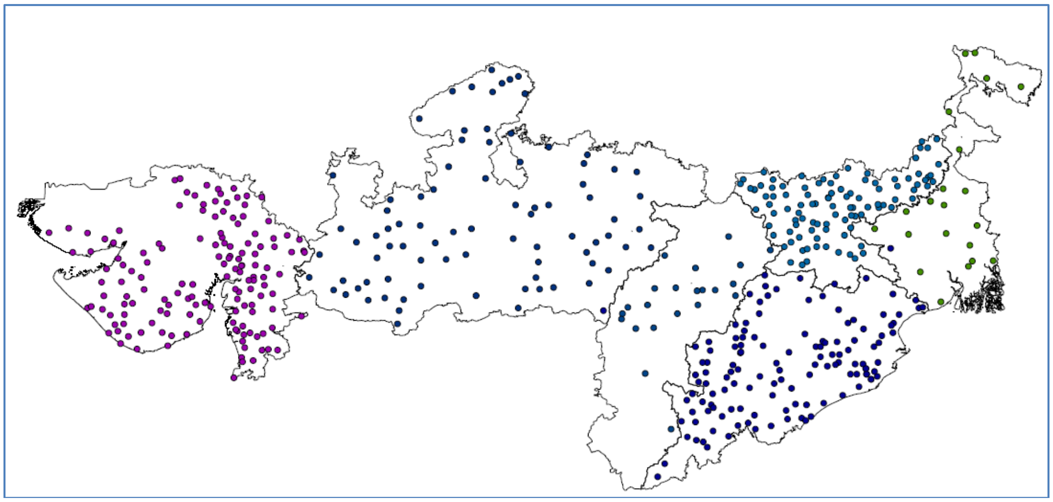

Fig. 2. Rainfall stations over Central India covering the study region

TABLE 1

Number of rainy days

NUMBER OF RAINY DAYS	COLOUR
LOW	(light blue)
MODERATE	(medium blue)
HIGH	(dark blue)

We have also used the Pettitt test analysis to the rainfall data set of central Indian states that experienced the abrupt shifting of the change point. The Pettitt test constitutes a valuable method for detecting change points in hydrological time series data, including rainfall events such as rainy days, heavy to very heavy, and extremely heavy events. This technique enables us to achieve a prediction of rainfall patterns and significant change points, which is important to decision-makers and planners in executing water resource management.

3. Results and discussion

3.1. *Rainy days*

Rainfall variability has been studied using the dataset across the central states of India. Figs. 3-8 shows the number of rainy days greater than 2.5 mm per day. Maps illustrate the study for 1971-2020 in five decades: 1971-1980, 1981-1990, 1991-2000, 2001-2010, and 2011-2020. Each figure utilizes a scale of colors, which shows the number of rainy days that have occurred in several decades. Choropleth maps were used to show the number of rainy days across the region. The lowest number of rainy days were shown in a light blue color (3.01-8.50 mm/day), moderate values by medium blue (8.50-13.99), and dark blue color indicates the highest number of rainy days (13.99-19.50). The values given in the braces vary concerning each state.

The colors in Table 1 denote the frequency of rainfall; the brighter color shows the low frequency of rainy days; the medium blue color depicts the medium frequency of rainfall; and the dark shade of blue indicates the highest number of rainy days across central states.

Fig. 3. shows the concentration of rainy days in three categories: lowest (3.01–8.50), moderate (8.50–13.99), and highest (13.99–19.50). The lowest number of rainy days is shown by the light blue color (3.01-8.50 mm/day), moderate values by medium blue (8.50-13.99), and dark blue color tells about the highest number of rainy days (13.99-19.50). In the 1970s and 1980s, moderate and the highest number of rainy days were observed in Gujarat's eastern and southern regions. Navsari and Tapi received more rainfall than other districts. 1981 to 1990 showed a rainfall pattern similar to the previous decade. Rainfall variability was not much different between 1990 and 2000; the number of rainy days was identical in both decades. Meanwhile, rainy days were found to be increased across the whole of Gujarat except for Kuchh and Morbi districts during the decade 2001-2010. An increase in the rainfall intensity was found in the southern districts of Gujarat during the last decade, 2011-2020. Kumari *et al.* (2025) has shown an increase in monsoon depressions in Arabian Sea and decrease in Bay of Bengal during the last four decades. However, in our study we have found that the coastal states have received more rainfall activity than the inland states.

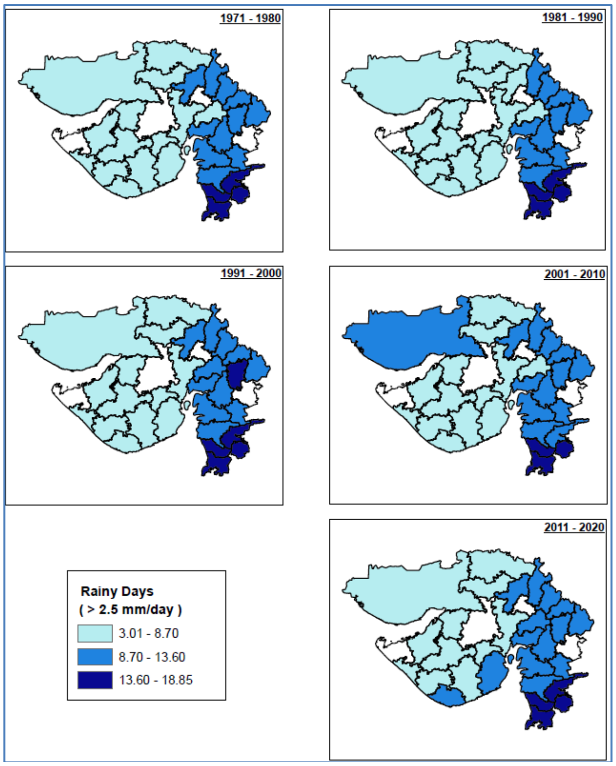

Fig. 3. Average decadal monthly rainfall map of Gujarat state from 1971-2020

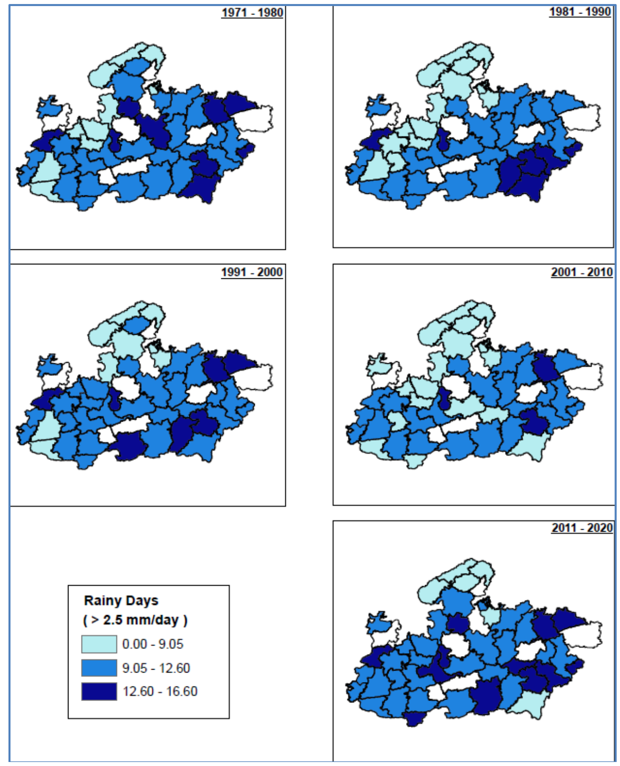

Fig. 4. Average decadal monthly rainfall of Madhya Pradesh from 1971-2020

Fig. 4 shows that the districts of the eastern Madhya Pradesh (MP) region received moderate to heavy rainfall during all decades. During 1971-1980, several heavy rainy days occurred in the central and eastern areas. Large scale weather phenomena such as depressions and cyclones, originating in the Bay of Bengal, provide rainfall to the region. In 1981–1990, moderate rainy days were found in the central and southeastern parts of the region.

The number of moderate rainy days has increased, and the southeast part of the region received the highest rainfall. Rainfall variation was found in the decade 1991-2000. The rainfall activity was found to be decreased in the decade 2001 -2010. The concentration of rainy days was highest in the central and southern parts of the region. Significant rainfall activity was observed over the districts of western MP in the decade 2011-2020. In the first three decades, the frequency of rainy days was very low in the region's Morena district (North MP). The number of rainy days was always highest in some districts like Mandla, Jabalpur, Seoni, Chhindwara, Umariya, and Dindori. The central and southern parts of the state had the highest frequency of average rainfall compared to other districts. Balghat received a low amount of rain in the years 2001-2010. The trend of rainy days increased throughout all the decades for the period 1971-2020. In the decade 2011-2020, the concentration of rainy days was higher in the westernmost and central parts of the region.

Fig. 5 shows the decadal variation of the number of rainy days with more than 2.5 mm for Chhattisgarh. During1971-1980, moderate rainy days were found in the northern part of the region. The frequency of rainy days was high in central and southern districts. For this period, the concentration of rainy days was high in Kanker, Raipur, Bastar, Rajgarh, and Mungeli districts. Some districts, such as Korba and Rajnandgaon, received the lowest rainfall. In 1981-1990, the northern part of the region experienced moderate rainy days, with 11 to 15 rainy days. Moisture incursion along the winds circulates across the region's northern plains, leading to heavy rainfall episodes. In the decade 1991-2000, many rainy days aligned with the spatial extent's northern and central parts. Moisture-laden rainfall from the Bay of Bengal was responsible for the heavy rainfall in the region.

The northern part of the region corresponds to a substantial amount of rainfall; Jashpur and Rajgarh consistently show high frequencies of rainy days. Low pressure or cyclonic conditions evolve over central or eastern areas, resulting in heavy rainfall distribution. In 2001-2010, rainfall variability spread was found over the

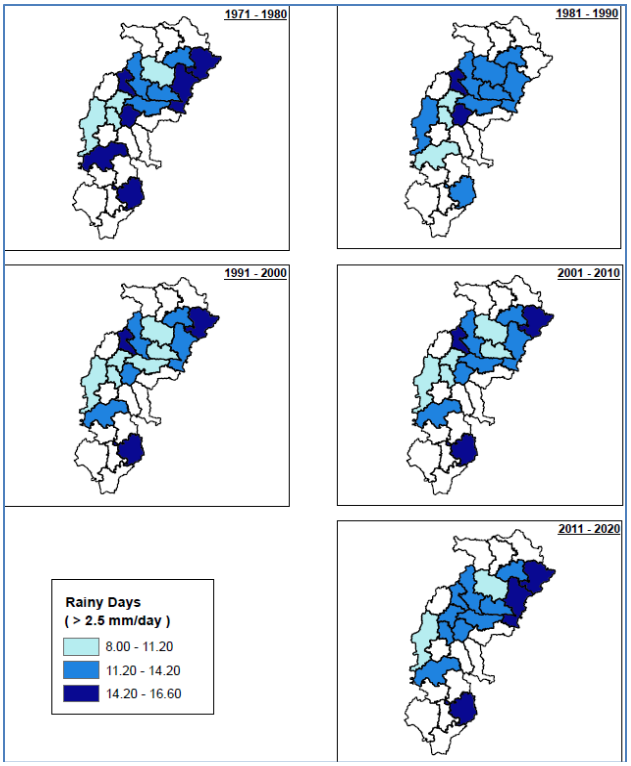

Fig. 5. Average decadal monthly rainfall map of Chhattisgarh from 1971 to 2020

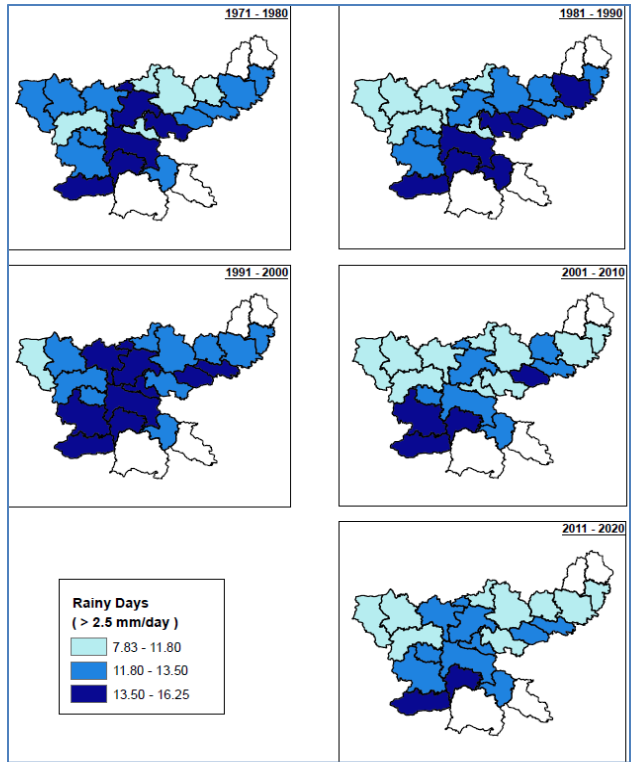

Fig. 6. Average decadal monthly rainfall map of Jharkhand from 1971 to 2020

entire region. Rainfall occurrences were mostly similar in the decade 2011-2020. The northern part of Chhattisgarh is not much far from Satpura and Vindhya highlands, which makes the conditions favorable to rainfall due to encountering the winds.

Fig. 6 shows that high occurrences of rainfall were found in the central and northern parts of the Jharkhand region. An increasing trend was observed throughout the decades from1971 to 2020. Moderate amounts of rainfall delivered by the medium blue color carrying value (10-14 mm/day) and intense spells of rainfall have been seen enormously in the central part of the region by the dark blue color (14-17 mm/day). If we examine the decade 1971-1980, the number of rainy days captured in the central and southern parts of the region and the degree of rainfall measured was similar to the next decade 1981–1990. However, the concentration of the highest rainy days lies in the eastern part as well.

Geographical factors influence the rainfall distribution in Jharkhand, with moisture retention from the Bay of Bengal contributing to the highest rainfall in the northern and central regions. The frequency of the highest rainfall was captured in Chatra, Hazaribagh, Ramgarh, Ranchi, Khunti, Gumla, and Simdega districts for the years 1991-2000. The topography of the region is very favorable for heavy precipitation. The concentration of rainfall in the southern parts of the state always seems highest. The number of rainy days was significant over the entire region in 1991-2000 and 2001-2010. A decrease in the rainfall intensity was found in the last decade, 2011-2020, in the Simdega and Khunti regions of Jharkhand.

Fig. 7 Rainfall variability in Odisha state depends on multiple factors that affect the rainfall distribution. The southwest monsoon is a key factor responsible for rainfall in the entire region. Maps represent the frequency of rainy days, 8 to 18, in three categories with separate color shades. During 1971-1980, rainy days were considerably higher in the northern and southern parts. Raygada and Sambalpur received the highest rainfall than other districts. The rainfall pattern shows an increasing trend from 1971 to 2000. Cyclonic conditions and depression originate across the region, bringing plenty of rainfall to the Odisha state. The frequency of rainy days has increased in the western part of the region from 1981 to 1990. Balangir, Jharsuguda, Sundargarh, and Sambalpur districts received heavy rainfall.

Moisture supply from the Bay of Bengal significantly affects rainfall, and also topography, eastern Ghats, and other highlands influence weather phenomena,

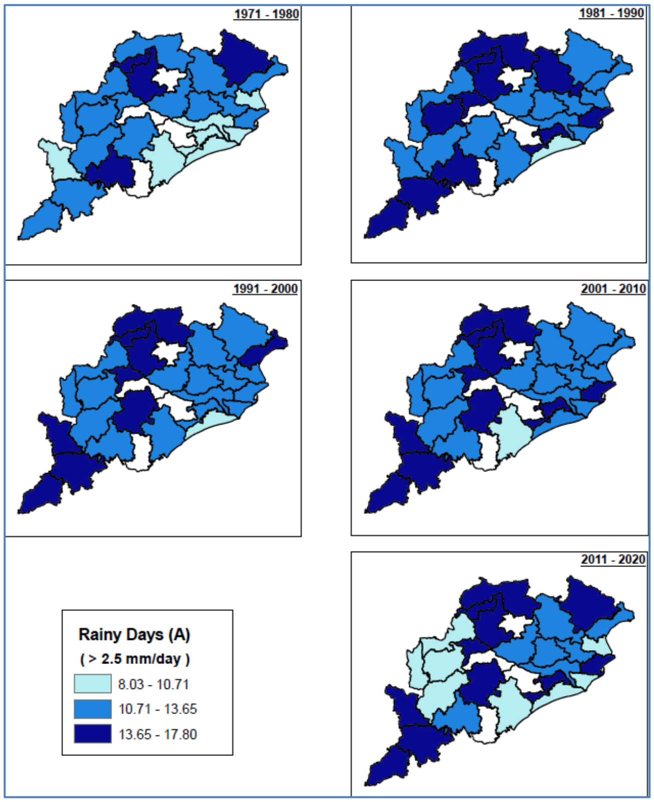

Fig. 7. Average decadal monthly rainfall map of Odisha from 1971-2020

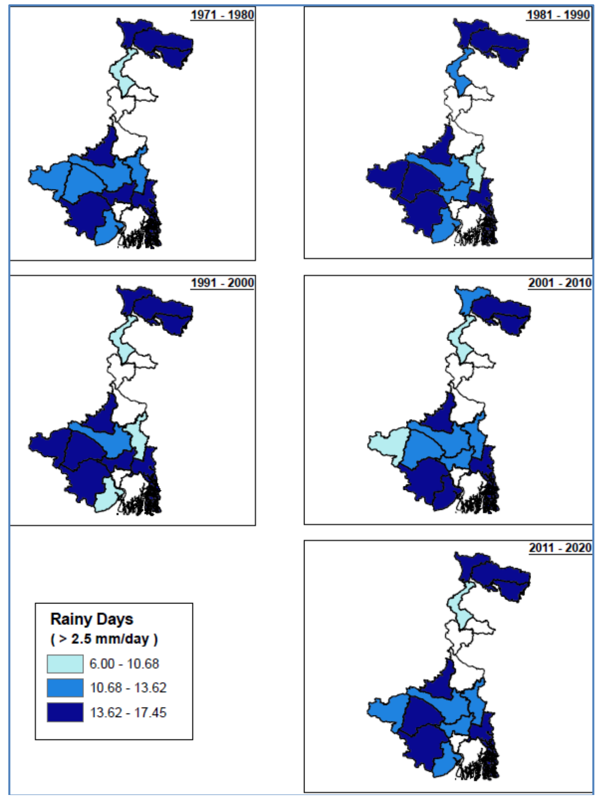

Fig. 8. Average decadal monthly rainfall map of West Bengal from 1971-2020

which lead to higher rainfall events. In 2001-2010, rainfall was similar to the previous decades. Rainy days have increased in the southern part, including Malkagiri, Korput, and Nabarangpur districts. Odisha is located near the coast of the Bay of Bengal; many factors, such as moisture incursion and land-sea thermal contrast, influence rainfall variability. Even though a decrease by 32 % in the monsoon depression over Bay of Bengal was reported by A Kumari *et al.* 2025, an increase in the frequency of rainy days was found in our study.

Fig. 8. shows that the frequency of rainy days in West Bengal was higher for all of the decades from 1971 to 2020. The southern part of the region received an enormous amount of rainfall in the decades 1971-1980; a higher frequency of rainy days has been observed in the northern part at the same time. During 1981-1990, a higher number of rainy days were found in the entire region except the central part. Monsoonal winds reach the Indian subcontinent and then start moving towards the Bay of Bengal, resulting in heavy rainfall in the whole region. Rainfall distribution is high in northern and southern regions such as Darjiling, Jalpaiguri, Kochbihari, Puruliya, Bankura, East Midnapore, Birbhum, and the North 24 Parganas. Most regions with the darkest shades indicate a higher frequency of rainfall; rainfall variability in West Bengal must be linked with moisture advection from the Bay of Bengal. Variability in monsoon rainfall was seen in the Central region of India; most of the region receives plenty of rainfall; on the other hand, some regions showcase a moderate frequency of rainfall. Among these states, West Bengal recorded the highest rainfall almost every decade.

3.2. *Trend analysis*

Line charts depict the percentage of rainfall events across the central region of India. In this study, we created a line chart analysis for the central Indian region with its extreme and heavy rainfall percentages and developed line charts for all states. This analysis was performed on the time series data from 1971 to 2020 (Fig. 9). Linear charts showed considerable variation in extremely high or heavy rainfall percentages for the time series dataset. The results demonstrate the fluctuation in rainfall events. Notably, the peak of points can interpret the seasonal variability in rainfall time series. A few years have a high percentage, which can be responsible for flood or flash flood conditions across the region. Line charts emphasize robust planning for resources, drainage systems, and infrastructure resilience.

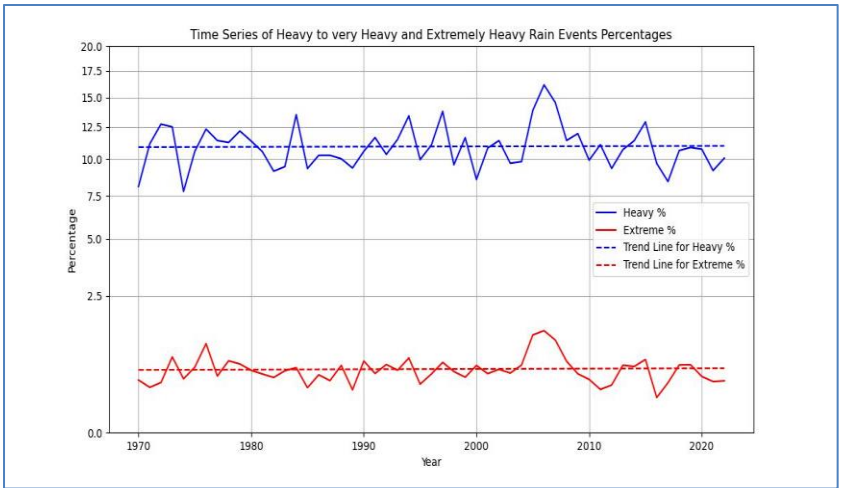

Fig. 9. Extremely Heavy and Heavy to very heavy rainfall in central India from 1971 to 2020

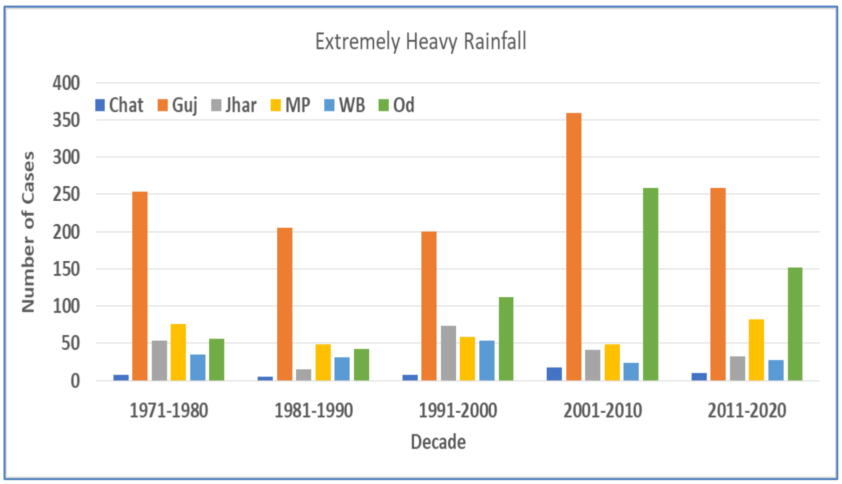

Fig. 10. State wise charts showing the number of extremely rainfall events.(legend- chat: Chhattisgarh; guj: Gujarat; jhar: Jharkhand; mp: Madhya Pradesh; wb: West Bengal; ors: Odisha)

This representation of rainfall distribution is linked with climatic shifts and environmental changes. The rainfall pattern has changed dramatically over the past 10-15 years, affecting numerous sectors like agriculture, hydropower production, water resources, etc. In India, 68% of total cultivated land is considered rainfed agriculture, which serves a lot of livestock (60%) and human population (40%) (Praveen *et al.*, 2020).

Extreme rainfall events were reported in the years 2005–2010 (Roxy *et al.*, 2017). The red line shows the extremely heavy percentage of rainfall. This trend line indicates stationary rainfall variability across the central region of India. The blue line also depicts a heavy to very heavy percentage of rainfall. As a trend pattern of extreme percentage, a heavy rainfall trend was detected from 2005 to 2010. In the preceding study, we utilized multiple techniques to study rainfall variability over the central region. On the basis of all the analysis, we found that the decade 2001–2010 had higher rainfall variability. Fluctuation in rainfall distribution was noteworthy in the time series dataset.

3.3. *Decadal rainfall variation for different categories*

Fig. 10 shows the decadal variation of the number of extreme rainfall events (>204.5 mm/day). Extreme rainfall events were found to be higher in Gujarat, followed by Odisha. Both these are coastal states, whereas the inland states, Chattisgarh and Jharkhand, reported fewer cases of extreme rainfall. During the decade 1971-1980, Madhya Pradesh had the second highest number of extreme rainfall cases, whereas from 1991- 2000 onwards, a shift in trend was found in Odisha. During the decade 2001-2010,

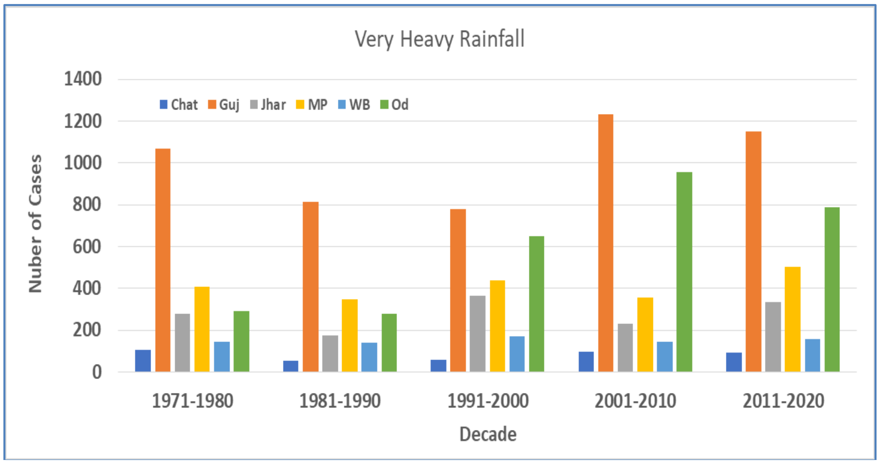

Fig. 11. State wise charts showing the number of Very Heavy rainfall events. (legend- chat: Chhattisgarh; guj: Gujarat ;jhar: Jharkhand; mp: Madhya Pradesh; wb: West Bengal; ors: Odisha)

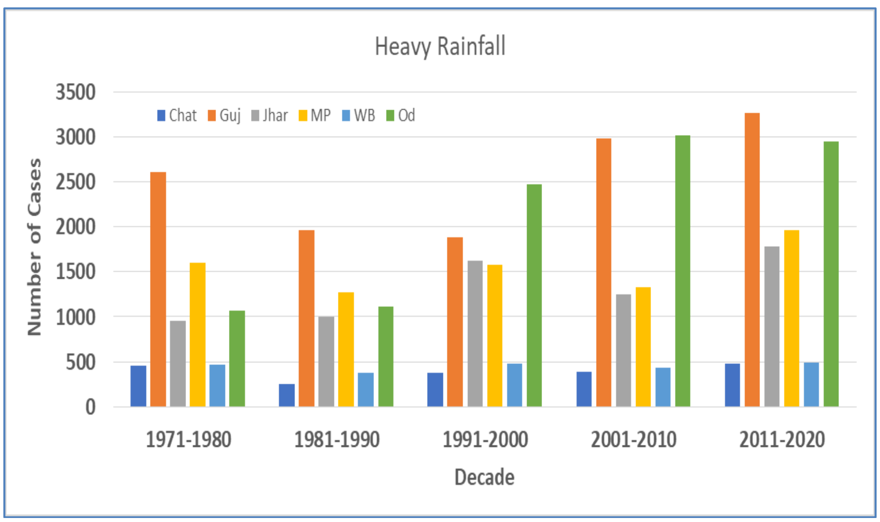

Fig. 12. State wise charts showing the number of Heavy rainfall events. (legend-chat :Chhattisgarh; guj: Gujarat ;jhar: Jharkhand; mp: Madhya Pradesh; wb: West Bengal; ors: Odisha)

highest number of extreme rainfall and very heavy rainfall cases were reported in Gujarat and Odisha (coastal states) than the inland states. The difference between them was significant during this decade. Accoring to IMD eAtlas, during this decade, more number of depressions, and cyclones were formed in Bay of Bengal (63) and Arabian Sea (23).

Similar to extreme rainfall cases, very heavy rainfall (115.6 – 204.4 mm/day) events were found to be higheragain in the coastal states of Gujarat and Odisha (Fig. 11). These were followed by MP, Jharkhand, Chattisgarh and West Bengal. Heavy rainfall events (64.5 – 115.5 mm) were found to increase in the last two decades, 2001- 2010 and 2011-2020, compared to earlier periods (Fig. 12). All states in Central India showed an increase in heavy rainfall cases during the 2011-2020 when compared with 1971-1980. However, an increase was found in the number of heavy rainfall events decadal wise for Odisha. Again, coastal states Gujarat and Odisha showed the highest cases, followed by MP, Jharkhand, West Bengal, and Chhattisgarh.

3.4. *Pettitt test analysis*

The Pettitt test is used in non-parametric statistical analysis to identify change points present in a time series data (Petitt, 1979). These change points can be observed

TABLE 2

Pettit test results for three rainfall categories for the selected data (Significant p value should be less than 0.05 for change point detection)

State	Rainy days P- value	Year	Heavy to very heavy P - P-Value	Year	Extremely heavy rain P value	Year
Odissa	0.07714	197909	0.1037	199106	0.0571	199106
Madhya Pradesh	1	201006	1	201009	1	200606
Gujarat	0.1481	200306	0.3025	200306	0.9369	197507
Jharkhand	0.2486	200808	0.1432	200808	0.1598	198908
Chhattisgarh	0.9009	199108	0.5704	197807	0.4394	199808
West Bengal	0.1989	199507	0.0395	200806	0.3046	200009

in time series datasets in the hydrological, environmental, and climatic disciplines. The change point detection method is noteworthy for calculating a single change point in the mean of a series. The Pettitt test is considered a hypothesis governed by significant p values. If the p-value is less than its significant value, the hypothesis will be rejected. Mann-Whitney U statistics characterizes this test to analyze the rank of datasets and allows for detecting unknown points in time series (Mallakpour & Villarini, 2016). The Pettitt test constitutes a valuable method for detecting change points in hydrological time series data, including rainfall events such as rainy days, heavy to very heavy, and extremely heavy events. This technique enables us to achieve a prediction of rainfall patterns and significant change points, which is important to decision-makers and planners in executing water resource management.

In the present study, we employed the Pettitt test on the rainfall time series data in the central India, including Gujarat, Madhya Pradesh, Chhattisgarh, Jharkhand, Odisha, and West Bengal from 1971- 2020. The Pettitt test results for each dataset are summarized in the Table 2. For the heavy to very heavy category in West Bengal, a significant change point was detected, at the time point 200806, which corresponds to June 2008. The significant pvalue should be less than 0.05 for a change point to be detected. This change point indicates a potential shift in the pattern of heavy to very heavy rain events in the dataset of West Bengal. A change point was also found in the extreme rainfall category for Odisha during June 1991. For the other datasets, no significant change points were detected, suggesting that there were no abrupt changes in the pattern of rainy days or extremely heavy rain events over the analyzed period and within the given dataset.

For the present study, we employed the topo-raster interpolation technique to interpret the results and utilized the Pettitt test to detect significant change points over central states. By analyzing historical data on rainfall and utilizing modern techniques and tests, we can provide an interface to climatic patterns. Previous studies observed the rainfall trend and pattern and the impact of rainfall and temperature on numerous aspects of humans and the environment. Implications of future work with the integration of rainfall extreme events and temperature into various sectors of agriculture, climate patterns, and water resource management can be addressed. Rainfall variability varies according to the physiography of the region. India has different topographies, such as the Gangetic plains, plateau, and central highlands.

5. Conclusions

This study examines the decadal analysis of rainfall events in central India from 1971 to 2020. The present study has used actual daily station rainfall data during the monsoon season (June-September) for the study period. Results showed that during the last two decades, extreme (> 204.5 mm/day) and very heavy (64.5 – 204.5 mm/day) rainfall events have increased alarmingly over Central India, with its peak during the decade 2001 – 2010 followed by 2011-2020. Central India has also witnessed an increase in heavy rainfall category activity during July (monsoon season) from 1971 to 2020. A significant increase in rainfall activity is found in all three categories of Madhya Pradesh. The western coastal state of India - Gujarat, shows a continuous rise in all rainfall categories, from 1981 onwards. A similar trend is observed for the eastern coastal state of Odisha due to the extensive moisture supply from the sea area. Of all the rainy-day occurrences, both heavy to very heavy rainfall events and extreme rainfall are highest in Gujarat during July and August. The relative frequencies of both heavy to very heavy rainfall and extremely heavy rainfall events are higher in the eastern parts of India as compared to the western states. This could be due to active monsoon conditions (south easterlies) in the east coast and moisture transport.

The extreme rainfall and very heavy rainfall events were more pronounced over the coastal states (Gujarat and Odisha) than the inland states like Jharkhand, Chhattisgarh and West Bengal. During the last two decades, these two rainfall categories were found to be increased alarmingly causing floods and economic losses. At the same time, increase in the number of depressions/cyclones formed in the Indian sea regions, was found to be increased in the last two decades. Interestingly, during 1991-2000, interior states showed enhanced rainfall activity than other states when compared with other decades. The Pettitt test has detected a change point in the time series data of West Bengal for the heavy to very heavy rainfall category in June 2008. A change point in the extremely heavy rain category was also detected for Odisha in June 1991.

This study can be extended further by integrating temperature. Concentration of rainfall and temperature illustrates the relative research that determines the relation between two variables. The warming of the surface is a dominant factor that affects the variability in rainfall and triggers global warming. Rainfall patterns are changing due to global warming; is this a myth, or is their distribution gradually changing? Monsoonal rainfall distribution can affect factors like agriculture practices, hydrology, climatology, and water resources.

Conflict of Interest

The authors declare no competing interests.

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