Reversal Nature in Rainfall Pattern Over the Indian Heavy and Low Rainfall Zones in the Recent Era

Vasundhara Barde
Indian Institute of Technology Bhubaneswar
Palash Sinha (palash.iit@gmail.com)
Indian Institute of Technology Bhubaneswar https://orcid.org/0000-0002-7611-7382
UC Mohanty
Indian Institute of Technology Bhubaneswar
RK Panda
Indian Institute of Technology Bhubaneswar

Research Article

Keywords: Indian summer monsoon, heavy and low rainfall, climate change, change point detection, dry days

Posted Date: March 17th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-298721/v1

Version of Record: A version of this preprint was published at Theoretical and Applied Climatology on August 8th, 2021. See the published version at https://doi.org/10.1007/s00704-021-03740-8.

Abstract

This study presents the reversal nature in rainfall over heavy rainfall zone (HRZ; more than 80% of the long-period average (LPA) of the Indian summer monsoon rainfall (ISMR)) and low rainfall zone (LRZ; less than 40% of ISMR-LPA) in India. The India Meteorological Department (IMD) high-resolution (0.25˚×0.25˚) dataset is used from 1901 to 2016. The single and multiple change point detection techniques are used to find the change in rainfall pattern over both the regions. Further, the study period is divided into two halves P1 (1901-1958) and P2 (1959-2016) in order to study change in rainfall pattern in the recent and past periods. In P2, rainfall pattern gets reversed and interestingly ISMR has shown an increasing trend over LRZ and a decreasing trend is noticed over HRZ and the results are statistically significant. The increasing/decreasing number of moderate and high intensity rainfall events are the main cause for this reversal pattern. Additionally, the number of dry days is increased over the HRZ and deceased over the LRZ. This study further confirms that 'dry becomes drier and wet becomes wetter' paradigm is not solely acceptable for India. The present study provides information about changes in dry days and ISMR variability in the context of climate change, which will be useful to agricultural risk management, water resources, drought monitoring, model developers, and policy planer on the adaptation strategies for climate change.

1. Introduction

The Indian summer monsoon (ISM) is an important meteorological phenomenon, occurred in each year without failing and has the year-to-year variation (Gadgil et al., 2019) and this phenomenon is crucial for the country's economy because more than half of the employment of India is directly or indirectly depends on agricultural and allied sectors (Economic Survey 2017-18, 2018). The western and eastern branch of monsoon intersect over east India due to which the eastern zone receives an ample amount of rainfall compare to the western India (Rajeevan et al., 2010). The monsoon slowly sets over India in June and withdraws in September (Ding and Sikka, 2006). There are two prime hypotheses which explain monsoon circulation over India; in the first one it is believed that Indian monsoon is a gigantic land-sea breeze driven by land-sea contrast (Gadgil, 2007); alternatively, it is a movement of the Inter-Tropical Convergence Zone (ITCZ) (Gadgil, 2018). In both the hypotheses, distribution of rainfall is abiding i.e. eastern India experiences heavy rainfall and north-western part receives less rainfall. Till date, this spatial distribution of long-period average of seasonal rainfall over all India remains almost same, however, year-to-year fluctuation in rainfall amount is observed for ISM rainfall (ISMR).

Previously, many attempts have been made to understand the year-to-year variability of ISMR (Krishnamurti et al., 1998; Goswami and Mohan, 2001; Mohanty et al., 2005; Mishra et al., 2012; Sinha et al., 2013; Walker et al., 2015). The major concern in the variation of the ISMR is that its spatiotemporal distribution is non-uniform, hence it's variability is independent of latitude or longitude. For example, in Gujarat, out of 16 stations, 11 stations had experienced increased in Summer monsoon rainfall (SMR) by 5% per decade since 1960 (Dave, 2017), while over Jharkhand, which is located at the same latitude as Gujarat, had shown the 15.65% reduction in ISMR for the same time period (Sharma and Singh, 2017). On the other hand, the southern parts of Western Ghats have shown significantly decreased in ISMR whereas the northern parts of Western-Ghats have encountered a significant increase in ISMR which lies almost in the same longitude (Rajendran et al.„ 2012; Kothawale et al., 2017; Varikoden et al., 2019). Moreover, the other parts of the country also shows random increased or decreased in ISMR like Sindh river basin, located in Madhya Pradesh has shown an increased in the trend of ISMR since 1952 (Gajbhiye et al., 2016), Punjab state has also shown increased in the trend of ISMR for a 1901-2002 period (Krishan et al., 2015) while, Wainganga basin in central India has shown a significant decreasing in ISMR since 1949 (Taxak et al., 2014).

The monsoon core zone has also shown a declining in ISMR rainfall in the recent decades (Kulkarni et al., 2012; Guhathakurta et al., 2015). Northeast India, which is one of the homogeneous regions and has famous for its enormous rainfall, has experienced a significant reduction in rainfall after 1950 (Guhathakurta et al., 2015). A study on rainfall over different climatic zones of India based on the distribution of the Köppen climate, reveals that after 1975, region of tropical moist-evergreen rain forest becoming tropical dry land and semiarid-dry climate becoming desert land (Rao et al., 2016). Recently, Ramarao et al. (2019) have illustrated that compare to the previous decade, recent decades have experienced 10% expansion of the semiarid region over the Indian main landmass. Meanwhile, the well-known fact is that the long-term mean of ISMR remains unchanged (Mishra et al., 2012), which make us rethink that, whether it is possible, a region which has experienced low-rainfall previously, getting more rainfall recently compare to its' long period average (LPA) and other regions may experience a reduction in rainfall than corresponding regions LPA and it would be interesting weather famous 'dry gets drier and wet gets wetter' paradigm is applicable to the Indian region or not.

So, it is of interest to examine the spatiotemporal rainfall variability for the regions which receives ample and scant rainfall over India. Keeping this in mind, we focused our study over the Indian landmass into two regions where rainfall occurrence is less than 40% (referred as low-rainfall zone; LRZ) and above 80% (referred as heavy-rainfall zone; HRZ) of LPA of all-India ISMR, to perceive the changes in rainfall pattern under the umbrella of climate change. The areas that receive different amount of rainfall with respect to all-India ISMR including HRZ and LRZ are shown in Fig.1. In this study, we tried to figure out the change in ISMR variability of HRZ and LRZ by using the India Meteorological Department (IMD) daily rainfall datasets. We have carried out several statistical tests to confirm those results.

2. Data And Methodology

IMD has developed the high-resolution (0.25˚×0.25˚) daily rainfall analysis data-set (Pai et al., 2014) over India using varied station observations with time. In the preparation of the analysis data-set, the observations are not equally spread over India, about 1450 station records have been used for 1901 and with the progress of time around 6,955 station records have been used. Several studies have compared this data-sets against the other available analysis data-sets and validated with the station observations and confirmed that the quality of the high-resolution rainfall analysis of IMD is better than other available data sets (Pai et al., 2014; Nageswararao et al., 2016, 2019a; Sharma and Majumdar, 2017). This data-set has also shown its potentiality in analyzing long-term changes in extreme rainfall events at met-subdivision, district/local scales (Swain et al., 2019a, b; Nageswararao et al., 2019b).

In this study, we have used the same IMD daily rainfall data-set as discussed above for 116 years (1901-2016) during ISM season, because, ISM season receives of an about 80% of annual rainfall (Bollasina, 2014). Some standard homogeneity tests such as Buisand range test (BR), Pettitt homogeneity tests (Wijngaad et al., 2003; Kang and Yusof, 2012) have been applied to examine homogeneity in the rainfall distribution. Previous studies have reported that these methods found to be robust in detecting the homogeneity (Deni et al., 2008; Kang and Yusof, 2012; Goyal, 2014, Nageswararao et al., 2019b). The null hypothesis has set for the test as H_0: data time series is consistent and alternate hypothesis is H_1: data time series is not homogeneous. Further, the occurrence of consecutive dry days and various rainfall events based on IMD classification (Nageswararao et al., 2019a) have been examined for both the HRZ and LRZ regions. For a particular day, the occurrence of rainfall in between 0.1 to 2.5 mm is considered as a Very Low Rainfall (VLR), followed by 2.5 to 7.5 mm rainfall is considered as Low Rainfall (LR), 7.5 to 35.5 mm rainfall is considered as Moderate Rainfall (MR), 35.6 to 64.4 mm rainfall is termed as Rather Heavy Rainfall (RHR), 64.4 to 124.4 mm rainfall is considered as Heavy Rainfall (HR) and 124.5 to 244.4 mm is considered as Very Heavy Rainfall (VHR) and more than 244.4 mm is considered as Extremely Heavy Rainfall (EHR). The rainfall less than 0.1 mm is considered as a dry day.

Mann-Kendall trend test has been employed to explore the statistically significance of the trend for various rainfall events. Further, the data set is divided into two halves (1901-1958; and 1959-2016) to examine the change in ISMR pattern over HRZ and LRZ. It is reported that the seasonal mean rainfall at all-India scale does not change significantly, however, notable changes in the extreme rainfall events have been noticed (Goswami et al., 2006), thus, it is indeed noteworthy to investigate the changes the contribution of various rainfall events to the seasonal total. The contribution of the various rainfall events to the seasonal rainfall is calculated as follows,

$$\text{events contribution} = \frac{\text{Total rainfall amount by a particular event in the season}}{\text{total seasonal rainfall}} \times 100 \qquad \cdots(1)$$

We have evaluated the recent changes in the contribution of rainfall by different events to the monthly and seasonal total during June-September (JJAS).

3. Results

3.1 Characteristics of heavy and low rainfall zone of India

The percentage distribution of various rainfall amount have been shown in Fig. 1a, the rainfall more than 80% i.e. HRZ is shown in Fig.1b, and less than 40% i.e. LRZ is shown in Fig. 1c. Out of 34 met-subdivisions over the Indian main land, on an average 7-8 come under HRZ category and 13-14 are LRZ category (Fig. 1b and Fig. 1c). It may be noted that some met-subdivisions are experiencing both the categories i.e high and low rainfall, however the locations are different. Therefore, we carry rainfall analysis based only on HRZ and LRZ regions instead of state or met-subdivision level. The contribution of various rainfall events to the seasonal rainfall is shown in Fig. 1d and Fig. 1e. It is seen that MR is the major contributing event for both HRZ (43%) and LRZ (48%). Apart from MR event, the heavy rainfall category rainfall events such as RHR, HR, VHR, and EHR have a substantial contribution in seasonal rainfall for the HRZ (Fig. 1d), however, LR and MR have more contribution to the seasonal rainfall for the LRZ (Fig. 1e).

To get a clear picture of the changes in ISMR distribution, it is very important to identify the area where the heavy or more intense rainfall events (HRm) and the total number of dry days (DD) are increased and/or decreased. Here, we have examined four combinations with increasing/decreasing of HRm and DD. Fig. 2 shows the spatial pattern of the different combination for the increased/ decreased in DD and HRm events over India by using Man-Kendall test with a 90% confidence level, very limited study is available for combination of DD and HRm events that’s why we choose 90% confidence level. It is found that the North Western Ghats which shows the increased in seasonal rainfall have experienced decreasing in HRm and increasing in DD, hence, the intense rainfall events are concentrated over smaller region and experience more severe over that region. Apart from that region, Madhya Maharashtra, north-central part of India and some parts of north-west India also has experienced decreasing in HRm and increasing in DD (Fig. 2a), this analysis confirms the result presented in the previous study by Prathipati et al. (2019). Over central India (from east of Gujarat to Odisha), some parts of Uttarakhand, northeast India and the south of Western Ghats, HRm and DD both are increased (Fig. 2b). Furthermore, along east-coast, parts of the Indian peninsular region, parts of north-east India and western Rajasthan, HRm events are increased and DD is decreased (Fig. 2c), while over south Adhara Pradesh coast, parts of Tamil Nadu, Arunachal Pradesh, and parts of Rajasthan both DR and HRm events are decreased (Fig. 2d). It is also observed that major parts of HRZ come under the increased in DD and decreased in HRm events (more than half) and a very small parts are experiencing increased HRm events (Fig. 2a, Fig. 2b); while the major parts of LRZ are experiencing increased in HRm events (Fig. 2b, Fig. 2c). This implies, HRZ and LRZ both are losing their identity based on heavy or more rainfall events. Thus, it is interesting to analyze the change in overall seasonal rainfall for these regions.

For the single change-point detection, the Standard Normal Homogeneity Test (SNHT) is used to calculate the change point detection at the starting and the endpoint of data-series, however, BR and Pettit test are used to detect change point in the middle of the data series (Martinez et al., 2010). But SNHT shows more than one point for the inhomogeneity or change point because of various climatic or non-climatic facto and it gives a poor performance in detection of change-point at the beginning of the series (Toreti et al., 2011). So, BR test is mostly used for any distribution data (Taxak et al., 2014). Fig. 3 shows the BR and Pettit’s test which are used for the single change point detection and multiple change-point detections over HRZ and LRZ. The HRZ shows a less variability in data (Fig. 3a) and more fluctuations are observed for LRZ (Fig. 3b) as data is not equally spread over space, and the number of stations is also get changed with time. The year 1961 is a change-point year for HRZ and 1930 is for LRZ by using the BR test. The single change-point year by using Pettit’s test in terms of change in mean depicts in Fig. 3c and Fig. 3d. For the HRZ, 1961 is the change in mean rainfall year and the rainfall over this region get reduced after 1961 (Fig. 3c), similarly, for the LRZ, 1930 is a change in mean rainfall year, rainfall gets increased after this year (Fig. 3d).

The multiple change-point detection technique is used to find changes in rainfall with a small time interval (Fig. 3e and Fig. 3f). For the multiple point detection technique, two algorithms are used, offline and online. In the offline algorithm, entire data is checked once and find the change points within it and the online algorithm (which is also known as real-time change point detector) run simultaneously with a process to check the change in current point with the previous one (Aminikhanghahi and Cook, 2017). In this study, the offline method is used to detect change points in the time series. The R-software's change-point package is used to calculate the change in the mean of yearly seasonal rainfall.

We found that 1920, 1930, 1950, 1952 and 1999 are change points for the mean rainfall over HRZ (Fig. 3e) and 1905, 1915, 1917, 1930 and 1964 (Fig. 3f) are the change points for the LRZ, interestingly, the year 1930 is a changing point and similar with the single point detection as noticed in the previous section. It is also noted that after 1960 both regions i.e. HRZ and LRZ are experiencing the change in mean rainfall. To understand the change in the standardized rainfall anomaly for both region, we divide study time into two equal halves i.e. P1 (Period 1: 1901 to 1958) and P2 (Period 2: 1959 to 2016). The midpoint of this division is near to change the point of HRZ (1961 by single and multiple change-point detections) and LRZ (1964 by multiple change-point detection). Over HRZ the difference between changing point is large compare to LRZ.

3.2 Observed climate change over HRZ and LRZ

The special report on "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" of the Intergovernmental Panel on Climate Change (IPCC) provides definition for climate change, according to the report the climate change can be identified by using various statistical test such as changes in the mean, changes in variability and that change must be continue for the decades or more (Field et al., 2012). The Report also provides a definition for the climate extremes as "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable" (Field et al., 2012). The Probability Density Function (PDF) is a mathematical function and widely used to identify climate change (Field et al., 2012; Paeth et al., 2013; Mattews et al., 2016).

The PDF of seasonal average rainfall for each LRZ and HRZ has been computed for both the periods to understand whether there has been any shifting (change in per mm) in the mean rainfall in the recent period compared to the earlier period. The Gaussian curve of PDF for ISMR during P1 and P2 has shown in Fig. 4, the mean rainfall of HRZ shows a shift to the left side in P2 and distribution extends beyond 25^{th} percentile of P1 which imply that seasonal mean is decreased (Fig. 4a). At the same time, the PDF curve gets fatter in P2 indicates that the variance of ISMR over HRZ is increased in P2 (Fig. 4a). On the other hand, the mean rainfall of LRZ has shifted towards right side that suggesting the mean seasonal rainfall is increased and variance is also slightly changed (Fig. 4b). In the recent period P2, the mean rainfall is decreased by 50 mm over HRZ and increased over LRZ by 10 mm. It is also noticed that in P2, climate extreme (excess and deficit) are increased over both zones, over HRZ deficit rainfall condition is increased and over LRZ excess rainfall condition is increased.

In order to understand further in deep, 5-years mean series and standardized anomaly are computed. Trend analysis with a binned of 5-year mean suggests an increasing trend in ISMR over HRZ during the P1, and a decreasing trend during P2, while for LRZ, ISMR shows an increasing trend in P1 (Fig. 4c) and no trend in P2 (Fig. 4d). The trend of rainfall averaged over the individual five years (pentad) starting from 1901-1905 has been presented in Fig. 4. The long-term (1901-2015) trend for the HRZ shows a decreasing trend (Fig. 4c) and LRZ shows an increasing trend (Fig. 4d). It is also found that number of excess (deficit) is increased (decreased) in P2 over LRZ, while a reverse picture in depicted for HRZ. Supplementary Fig. 1 shows the standardized anomaly for HRZ and LRZ. It is observed that 11 excess, 7 deficit and 40 normal rainfall years have occurred during P1 and 8 excess, 13 deficits and 37 normal monsoons took place during P2 over HRZ (Supplementary Fig. 1a). When analyzing the monsoon conditions for LRZ during two periods, it is observed that 4 excess, 10 deficit and 43 normal rainfall years have been ensued during P1, while 13 excess, 8 deficit and 37 normal rainfall years are observed during P2 (Supplementary Fig. 1b). It is fascinating to notice that the total number of normal rainfall years are changed and total number of climate extreme (excess + deficit) is increased over both the regions during the recent Period. Further, our findings are supported by Duncan et al. (2013), where they have shown that inter-annual ISMR variability shows a decreasing trend over eastern (which is HRZ) and an increasing trend over west and south India (which is LRZ) during 1951 to 2007 period.

Spatial distribution of the various rainfall events is presented in Fig. 5. The left side column (Fig. 5a, c, e, g, i, k) represents the spatial distribution of various rainfall events for HRZ and right side column (Fig. 5b, d, f, h, j, l) represents the spatial distribution of various rainfall events for LRZ. The details analysis of figures suggest that VLR and LR events has increased over northeast India (Fig. 5a,c) and LR to MR events are decreased over HRZ (Fig. 5c, e) On the other hand, over LRZ, VLR and LR events are decreased in P2 (Fig. 5b, d), while MR to VHR events are increased over LRZ (Fig. 5f, h , j). Recently, Prathipati et al. (2019) pointed out an inconsistency in the frequency of rainfall event over India during ISM season, they have shown that the number of HR events are increased over most parts of Madhya Maharashtra, Jammu & Kashmir, west central India, which are the parts of LRZ. The trends for various rainfall events is checked by using the Mann-Kendall trend test and presented in Table 1. It is found that the MR and RHR events are significantly decreased over HRZ and significantly increased over LRZ.

Table 1

Mann-Kendall trend test for various rainfall events during P1 and P2 for seasonal rainfall. The value greater than 0.05 is confident at 95 % level

Rainfall events	HRZ				LRZ			
	Z for P1	*p-value*	Z for P2	*p-value*	Z for P1	*p-value*	Z for P2	*p-value*
VLR	2.415	0.0157	-1.328	0.184*	2.052	0.040	-0.021	0.983*
LR	2.414	0.0157	-1.113	0.265*	2.066	0.038	0.0353	0.971*
MR	2.320	0.0202	-1.046	0.295*	1.945	0.051	0.129	0.896*
RHR	2.079	0.0375	-0.402	0.687*	1.73	0.083	0.275	0.782*
HR	1.757	0.0788*	-0.509	0.610*	1.086	0.277*	-0.550	0.582*
VHR	0.911	0.0559*	1.060	0.951*	1.012	0.311*	1.254	0.209*
EHR	0.2171	0.537*	0.947	0.882*	0.7848	0.432*	0.482	0.629*

Dry spells having different time-length and the total number of dry days for HRZ and LRZ have presented in Fig. 6. During 1901-2016 time-span, north-west and southern part of LRZ has experienced the number of dry days (Fig. 6a). The difference in dry days number between P1 and P2 reveals an increased in dry days over HRZ in P2 and decreased over north-west LRZ (Fig. 6b). Also, the different consecutive dry days (CDD) trends are presented in Supplementary Fig. 2. The increased in the total number of dry days is consequences of decreased in seasonal rainfall over HRZ, similarly, over LRZ seasonal rainfall is increased and the total number of dry days has decreased. Several studies have shown that monsoonal rainfall has been decreased over India especially monsoon core zone due to land use land cover, reduction in moisture supply from the Bay of Bengal, weakening of tropical easterly jet which are consequences of global warming (Rao et al., 2004; Naidu et al., 2011; Kulkarni 2012; Panda and Kumar, 2014; Paul et al., 2016). Here, we found that the rainfall is reduced over HRZ and rainfall is increased over LRZ. In P2, major contributing events (MR) and HRm which account combined effect of heavy rainfall events (HR, VHR and EHR) have decreased over HRZ except September (Fig. 7 a,b) and in revere, all these events are increased over LRZ (Fig. 7c, d).

The detailed analysis of the number of various rainfall events for each month of June-September (JJAS) has shown that the decreased in percentage (%) of the contribution of MR and HRm events (Fig.7) over HRZ is due to decreased in MR and HR events almost every month in P2 (Supplementary Fig. 3). In June and September, the number of low-intensity rain events (VLR and LR) has decreased (more than 200 events) along with MR events (Supplementary Fig. 3), that’s why the percentage (%) of the contribution of HMR events get increased in July and September (Fig. 2b). Over the LRZ, the MR and VHR events have increased for each month in P2 (Supplementary Fig. 3) which results in increased in percentage (%) of the contribution of the MR and HR events at seasonal and monthly scale (Fig. 7c, d). The difference in mean rainfall between HRZ and LRZ get reduced since 1901 (Supplementary Fig. 4). Over HRZ, low and medium intensity rainfall events have shown a decreasing trend and VHR and EHR has shown an increasing trend at 95% confidence level. Over LRZ, the LR, MR, RHR and VHR have shown an increasing trend at 95% confidence level. Overall, HRZ has experienced a decrease in seasonal rainfall and slightly increased in heavy rainfall events where LRZ has experienced an increased in both seasonal and heavy rainfall events in P2.

4. Discussion

The part of HRZ, mostly an extended area of monsoon core zone, have experienced reduction in ISMR in the warming environment (Kulkarni, 2012; Roxy, 2017). Several studies have shown that the Arabian Sea Surface Temperature (SST) is increased during the last few decades (Roxy et al., 2014), and the increased Arabian SST have a good association with below normal rainfall of the Gangetic Plains (Mishra et al., 2012) which is also parts of HRZ. The occurrence of monsoon depressions over the Bay of Bengal is reduced and moves southward in the recent period (Vishnu et al., 2016) probably seed to the reduction in atmospheric moisture for rainfall over HRZ. At the same time, monsoon rainfall is reduced and shows a pole-ward shift in a warming climate (Sandeep et al., 2018). As result of both, the HRZ containing monsoon core region experienced a reduction in seasonal rainfall. The Western-Ghats is also come under HRZ region. The south of Western-Ghats have shown a significant decreased in seasonal rainfall because of the weakening in south-westerly winds, slackened vertical velocity, weakening of mean meridional circulation and northward movement of Low-Level Jet (Rajendran et al., 2012; Varikoden et al., 2018).

Moreover, Rajendran et al. (2012) have shown that the lapse rate is getting reduced because of increased temperature in the upper atmosphere compared to the lower atmosphere. Moreover, presence of large number of aerosols over the foothills of Himalaya cause dimming effect of sun; the reducing surface temperature over north-central India cause for the less convection rate and therefore reduction in seasonal rainfall over HRZ. At the same time, Solmon et al. (2015) have shown that the increased in aerosol depth over the Arabian Sea and increased in rainfall over the southern peninsula is highly correlated. So, aerosols play an important role to change the pattern of rainfall over HRZ and LRZ.

We found that the long-term seasonal rainfall has shown a decreasing trend for HRZ and increasing trend for LRZ (Fig. 4). After 1970, a significant increasing trend in seasonal rainfall is observed over Gujarat state and western districts of Maharashtra, which are the parts of LRZ (Guhathakurta et al., 2013; Dave et al., 2017). A study of rainfall analysis of 30 met-subdivisions of India has shown that major parts of Punjab (a parts of LRZ), Hariyana (a parts of LRZ) and coastal Katakana has significantly increased in rainfall whereas Chhattisgarh (a parts of HRZ) has significantly decreased in seasonal rainfall (Kumar et al., 2010).

The pentad (5-year binned) analysis shows that the ISMR has been reduced over both LRZ and HRZ but the rate of reduction is greater over HRZ (Fig. 4). The MR and RHR events play a key role for both increased in seasonal rainfall over LRZ and decreased in seasonal rainfall over HRZ. The VHR events are increased over both the regions. Mishra et al. (2018) have shown that the temperature and heavy rainfall events are increased over India since 1900 and the light precipitation events are reduced in the warming temperature years. Our finding is supported by these reports as various rainfall events are increased over

LRZ (Supplementary Fig. 3). When the air temperature is increased by 1°C the water holding capacity of atmosphere is increased approximately by 7% (Trenberth, 2011; Nageswararao et al., 2016), and the surface air temperature over north-western and southern India (LRZ) is increased and over central north India, it is decreased (HRZ) (Ross et al., 2017). So, more (lesser) atmospheric water is available for rainfall over LRZ (HRZ) during the recent period compared to earlier period. Recently, Saha et al. (2017) has shown that east-west coastal asymmetry is observed for the summertime near surface wind.

The correlation between El-Nino and below normal rainfall is one of the signs of seasonal rainfall over India (Yadav et al., 2013; Yadav and Roxy, 2019), recently Equatorial Indian Ocean Oscillation (EQUINOO) an atmospheric circulation sets new relation with Indian seasonal rainfall, the positive period of EQUINOO enhanced the convection over the western Indian Ocean and suppress convection over the eastern Indian Ocean and it has a good correlation with ISMR. During positive Period of EQUINOO Indian has experienced normal to excess rainfall and situation becomes opposite in the negative phase (Surendran et al., 2015; Gadgil et al., 2019). The Indian Ocean Dipole (IOD) is an oceanic phenomenon, calculated by the difference of western Indian Ocean (WIO) SST and eastern Indian Ocean SST, the positive phase of IOD (pIOD) cause the convection over WIO and good rainfall over the Indian subcontinent (Karumari et al., 2001; Saji and Yamagata, 2003). Cai et al. (2014) have shown that during extreme pIOD events, westerlies and eastward flowing upper ocean currents get reverse that cause to anonymous dry condition over central and eastern Indian and strong convection over the westward side which triggers flood-like condition in eastern African countries. We found that the excess rainfall events are also increased over LRZ, which is the west side of India. They have also reported that in the warming climate, extreme pIOD events will be likely occur more frequently. The frequent occurrence of deficit rainfall events over HRZ and heavy rainfall event over LRZ confirms the result presented by Cai et al. (2014). In 2019 ISM season, LRZ has experienced greater number of flood events and the large part of HRZ experienced below normal rainfall condition till mid-September. This shows the rainfall distribution slowly change and getting reverse over India, LRZ is experiencing a positive deviation from LPA and HRZ is experiencing a negative deviation from LPA. The understanding of the reverse in variability is important to water resources, flood and drought management and policy-making, and model developers of the country. The result are highly helpful to the policy planner for making adaptation strategies in the context of changing climate.

5. Conclusions

The analysis of seasonal rainfall for heavy rain zone (HRZ) and less rainfall zone (LRZ) is carried out by using 116 years (1901-2016) IMD high-resolution (0.25˚× 0.25˚) gridded rainfall analysis data-set for the summer monsoon season. The Indian main landmass is divided into two zones based on the amount of seasonal rainfall, the HRZ and LRZ. The HRZ area which receives rainfall more than 80% of all-India LPA and LRZ is the area which receives rainfall less than 40% that of all-India LPA. By using different single change point detection techniques, the pattern of rainfall gets change for 1930 and 1961 onward over LRZ and HRZ, respectively. Since 1960, mean rainfall is decreased over HRZ and from 1964 over LRZ. The HRZ has experienced increased in both dry days and heavy rainfall events; However, LRZ has experienced increased in heavy rainfall events and decreased in dry days.

Further, the data set is divided into two equal halves P1 (1901-1958) and P2 (1959-2016) (which is nearest to change point for HRZ and LRZ) to investigate the changes in spatiotemporal distribution of rainfall. It is found that the HRZ has experienced more excess rainfall year in P1 and more deficit rainfall events in P2. Conversely, LRZ has experienced the number of excess rainfall years in P2. The seasonal rainfall analysis for two zones (HRZ and LRZ) of India for the last century has shown that the “dry gets drier and wet gets wetter” paradigm is not absolute over India particularly for the summer monsoon season, as HRZ has experienced a reduction in seasonal rainfall and LRZ has experienced an increase in seasonal rainfall. The decrease in the number of moderate and heavy rainfall events (LR, MR, RHR, HR and VHR) reduces over HRZ as their contribution is largely important to seasonal rainfall. Seasonal rainfall has increased over LRZ because of the increased number of low, moderate, and heavy rainfall events. The extreme rainfall events are increased over both the regions. The further understanding of the process behind this change is important as HRZ has a large number of tributary areas, the number of rivers including India’s one of the biggest dam-Hirakud, large agricultural area. Similarly, LRZ is also not fully prepared for frequent extreme rainfall events and necessary action plan may be needed for the LRZ region for adaptation under the scenario of the climate change. In addition, almost one third of the districts which is more than half of the agriculturall land are predominant rainfed region and the agriculture is solely depends on the summer monsoon rainfall. Thus, there are needs for proper planning of the agricultural practice and suitable adaptation strategies for both the HRZ and LRZ regions.

Declarations

Acknowledgements

This research is the outcome of the research project of IIT Bhubaneswar, entitled as ‘Study of the effects of Climate change on Hydro-meteorological Processes: Droughts and Floods at Different Spatial and Temporal scales in Eastern India’ sponsored by Department of Science and Technology, Government of India. In addition, the authors acknowledge the India Meteorological Department (IMD) for providing observed gridded high-resolution data-set.

Author’s contribution

VB and PS identified and designed the problem and flow of the research work in discussions with UCM. VB carried out the all the analysis consulting primarily with PS. The manuscript was developed by VUB and PS taking input from UCM, RKP. All authors contributed to improving the analyses and presentation of results in the manuscript.

Data availability

The datasets used for representing the results will be available from the principal author on request.

Conflict of Interest:

The authors declare that there is no conflict of interest in this manuscript. The authors also declare no competing financial interests.

Funding Information:

Funding information is not applicable / No funding was received.

Code Availability:

The code used for the analysis can be available from the principal author on request after the publication.

Ethics approval:

Not Applicable.

Consent to participate:

Not Applicable.

Consent for publication:

Not Applicable.

References

1. Aminikhanghahi, S. and Cook, D.J., 2017. A survey of methods for time series change point detection. *Knowledge and information systems*, *51*(2), pp.339-367.
2. Ashok, K., Guan, Z. and Yamagata, T., 2001. Impact of the Indian Ocean dipole on the relationship between the Indian monsoon rainfall and ENSO. *Geophysical Research Letters*, *28*(23), pp.4499-4502.
3. Bollasina, M.A., 2014. Hydrology: Probing the monsoon pulse. *Nature Climate Change*, *4*(6), pp.422-423.
4. Cai, W., Santoso, A., Wang, G., Weller, E., Wu, L., Ashok, K., Masumoto, Y. and Yamagata, T., 2014. Increased frequency of extreme Indian Ocean Dipole events due to greenhouse warming. *Nature*, *510*(7504), pp.254-258.

5. Dave, H., James, M.E. and Ray, K., 2017. Trends in intense rainfall events over Gujarat State (India) in the warming environment using gridded and conventional data. *International Journal of Applied Environmental Sciences*, *12*(5), pp.977-998.
6. Deni, S.M., Jemain, A.A. and Ibrahim, K., 2008. The spatial distribution of wet and dry spells over Peninsular Malaysia. *Theoretical and applied climatology*, *94*(3-4), pp.163-173.
7. Ding, Y. and Sikka, D.R., 2006. Synoptic systems and weather. In *The Asian Monsoon* (pp. 131-201). Springer, Berlin, Heidelberg.
8. Duncan, J.A., Dash, J. and Atkinson, P.M., 2013. Analysing temporal trends in the Indian Summer Monsoon and its variability at a fine spatial resolution. *Climatic change*, *117*(1-2), pp.119-131.
9. Field, C.B., Barros, V., Stocker, T.F. and Dahe, Q. eds., 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change*. Cambridge University Press.
10. Gadgil, S., 2007. The Indian Monsoon. *Resonance*, *12*(5), pp.4-20.
11. Gadgil, S., 2018. The monsoon system: Land–sea breeze or the ITCZ?. *Journal of Earth System Science*, *127*(1), p.1.
12. Gadgil, S., Francis, P.A. and Vinayachandran, P.N., 2019. Summer monsoon of 2019: understanding the performance so far and speculating about the rest of the season. *Current Science*, *117*(5), p.783.
13. Gajbhiye, S., Meshram, C., Mirabbasi, R. and Sharma, S.K., 2016. Trend analysis of rainfall time series for Sindh river basin in India. *Theoretical and applied climatology*, *125*(3-4), pp.593-608.
14. Ghasemi, A. and Zahediasl, S., 2012. Normality tests for statistical analysis: a guide for non-statisticians. *International journal of endocrinology and metabolism*, *10*(2), p.486.
15. Goswami, B.N. and Mohan, R.A., 2001. Intraseasonal oscillations and interannual variability of the Indian summer monsoon. *Journal of Climate*, *14*(6), pp.1180-1198.
16. Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanan, M.S. and Xavier, P.K., 2006. Increasing trend of extreme rain events over India in a warming environment. *Science*, *314*(5804), pp.1442-1445.
17. Goyal, M.K., 2014. Statistical analysis of long term trends of rainfall during 1901–2002 at Assam, India. *Water resources management*, *28*(6), pp.1501-1515.
18. Guhathakurta, P. and Saji, E., 2013. Detecting changes in rainfall pattern and seasonality index vis-à-vis increasing water scarcity in Maharashtra. *Journal of Earth System Science*, *122*(3), pp.639-649.
19. Guhathakurta, P., Rajeevan, M., Sikka, D.R. and Tyagi, A., 2015. Observed changes in southwest monsoon rainfall over India during 1901–2011. *International Journal of Climatology*, *35*(8), pp.1881-1898.
20. Kang, H.M. and Yusof, F., 2012. Homogeneity tests on daily rainfall series. *Int. J. Contemp. Math. Sciences*, *7*(1), pp.9-22.
21. Kothawale, D.R. and Rajeevan, M., 2017. Monthly, Seasonal, Annual Rainfall Time Series for All-India, Homogeneous Regions, Meteorological Subdivisions: 1871-2016.

22. Krishan, G., Chandniha, S.K. and Lohani, A.K., 2015. Rainfall trend analysis of Punjab, India using statistical non-parametric test. *Current World Environment*, *10*(3), pp.792-800.
23. Krishnamurti, T.N., Sinha, M.C., Jha, B. and Mohanty, U.C., 1998. A study of South Asian monsoon energetics. *Journal of the atmospheric sciences*, *55*(15), pp.2530-2548.
24. Kulkarni, A., 2012. Weakening of Indian summer monsoon rainfall in warming environment. *Theoretical and Applied Climatology*, *109*(3-4), pp.447-459.
25. Kumar, V., Jain, S.K. and Singh, Y., 2010. Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal–Journal des Sciences Hydrologiques*, *55*(4), pp.484-496.
26. Martínez, M.D., Serra, C., Burgueño, A. and Lana, X., 2010. Time trends of daily maximum and minimum temperatures in Catalonia (ne Spain) for the period 1975–2004. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *30*(2), pp.267-290.
27. Matthews, T., Mullan, D., Wilby, R.L., Broderick, C. and Murphy, C., 2016. Past and future climate change in the context of memorable seasonal extremes. *Climate Risk Management*, *11*, pp.37-52.
28. Ministry of Finance, Government of India (2018) Climate change and Agriculture in Economic Survey 2017-2018, chapter 6, 82–101. Government of India. URL http://mofapp.nic.in:8080/economicsurvey/pdf/082-101 Chapter 06 ENGLISH Vol 01 2017-18.pdf.
29. Mishra, A.K., Nagaraju, V., Rafiq, M. and Chandra, S., 2019. Evidence of links between regional climate change and precipitation extremes over India. *Weather*, *74*(6), pp.218-221.
30. Mishra, V., Smoliak, B.V., Lettenmaier, D.P. and Wallace, J.M., 2012. A prominent pattern of year-to-year variability in Indian Summer Monsoon Rainfall. *Proceedings of the National Academy of Sciences*, *109*(19), pp.7213-7217.
31. Mohanty, U.C., Nageswararao, M.M., Sinha, P., Nair, A., Singh, A., Rai, R.K., Kar, S.C., Ramesh, K.J., Singh, K.K., Ghosh, K. and Rathore, L.S., 2019. Evaluation of performance of seasonal precipitation prediction at regional scale over India. *Theoretical and Applied Climatology*, *135*(3-4), pp.1123-1142.
32. Mohanty, U.C., Raju, P.V.S. and Bhatla, R., 2005. A study on climatological features of the Asian summer monsoon: dynamics, energetics and variability. *Pure and applied geophysics*, *162*(8-9), pp.1511-1541.
33. Nageswararao, M.M., Mohanty, U.C., Ramakrishna, S.S.V.S., Nair, A. and Prasad, S.K., 2016. Characteristics of winter precipitation over Northwest India using high-resolution gridded dataset (1901–2013). *Global and Planetary Change*, *147*, pp.67-85.
34. Nageswararao, M.M., Sannan, M.C. and Mohanty, U.C., 2019a. Characteristics of various rainfall events over South Peninsular India during northeast monsoon using high-resolution gridded dataset (1901–2016). *Theoretical and Applied Climatology*, *137*(3-4), pp.2573-2593.
35. Nageswararao, M.M., Sinha, P., Mohanty, U.C., Panda, R.K. and Dash, G.P., 2019b. Evaluation of district-level rainfall characteristics over Odisha using high-resolution gridded dataset (1901–2013). *SN Applied Sciences*, *1*(10), p.1211.
36. Naidu, C.V., Krishna, K.M., Rao, S.R., Kumar, O.B., Durgalakshmi, K. and Ramakrishna, S.S.V.S., 2011. Variations of Indian summer monsoon rainfall induce the weakening of easterly jet stream in the

warming environment?. *Global and Planetary Change*, *75*(1-2), pp.21-30.

37. Paeth, H., Steger, C. and Merkenschlager, C., 2013. CLIMATE CHANGE—IT'S ALL ABOUT PROBABILITY. *Erdkunde*, pp.203-222.
38. Pai, D.S., Sridhar, L., Rajeevan, M., Sreejith, O.P., Satbhai, N.S. and Mukhopadhyay, B., 2014. Development of a new high spatial resolution (0.25× 0.25) long period (1901–2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. *Mausam*, *65*(1), pp.1-18.
39. Panda, D.K. and Kumar, A., 2014. The changing characteristics of monsoon rainfall in India during 1971–2005 and links with large scale circulation. *International journal of climatology*, *34*(15), pp.3881-3899.
40. Paul, S., Ghosh, S., Oglesby, R., Pathak, A., Chandrasekharan, A. and Ramsankaran, R.A.A.J., 2016. Weakening of Indian summer monsoon rainfall due to changes in land use land cover. *Scientific Reports*, *6*(1), pp.1-10.
41. Prathipati, V.K., CV, N. and Konatham, P., 2019. Inconsistency in the frequency of rainfall events in the Indian summer monsoon season. *International Journal of Climatology*, *39*(13), pp.4907-4923.
42. Rajeevan, M., Gadgil, S. and Bhate, J., 2010. Active and break spells of the Indian summer monsoon. *Journal of earth system science*, *119*(3), pp.229-247.
43. Rajendran, K., Kitoh, A., Srinivasan, J., Mizuta, R. and Krishnan, R., 2012. Monsoon circulation interaction with Western Ghats orography under changing climate. *Theoretical and Applied Climatology*, *110*(4), pp.555-571.
44. Ramarao, M.V.S., Sanjay, J., Krishnan, R., Mujumdar, M., Bazaz, A. and Revi, A., 2019. On observed aridity changes over the semiarid regions of India in a warming climate. *Theoretical and Applied Climatology*, *136*(1-2), pp.693-702.
45. Rao, B.S., Rao, D.B. and Rao, V.B., 2004. Decreasing trend in the strength of Tropical Easterly Jet during the Asian summer monsoon season and the number of tropical cyclonic systems over Bay of Bengal. *Geophysical Research Letters*, *31*(14).
46. Rao, V.B., Franchito, S.H., Gerólamo, R.O.P., Giarolla, E., Ramakrishna, S.S.V.S., Rao, B.R.S. and Naidu, C.V., 2016. Himalayan warming and climate change in India. *American Journal of Climate Change*, *5*(4), pp.558-574.
47. Ross, R.S., Krishnamurti, T.N., Pattnaik, S. and Pai, D.S., 2018. Decadal surface temperature trends in India based on a new high-resolution data set. *Scientific reports*, *8*(1), pp.1-10.
48. Roxy, M.K., Ghosh, S., Pathak, A., Athulya, R., Mujumdar, M., Murtugudde, R., Terray, P. and Rajeevan, M., 2017. A threefold rise in widespread extreme rain events over central India. *Nature communications*, *8*(1), pp.1-11.
49. Roxy, M.K., Ritika, K., Terray, P. and Masson, S., 2014. The curious case of Indian Ocean warming. *Journal of Climate*, *27*(22), pp.8501-8509.
50. Saha, A., Ghosh, S., Sahana, A.S. and Rao, E.P., 2014. Failure of CMIP5 climate models in simulating post-1950 decreasing trend of Indian monsoon. *Geophysical Research Letters*, *41*(20), pp.7323-7330.

51. Saha, U., Chakraborty, R., Maitra, A. and Singh, A.K., 2017. East-west coastal asymmetry in the summertime near surface wind speed and its projected change in future climate over the Indian region. *Global and Planetary Change*, *152*, pp.76-87.
52. Saji, N.H. and Yamagata, T., 2003. Possible impacts of Indian Ocean dipole mode events on global climate. *Climate Research*, *25*(2), pp.151-169.
53. Sandeep, S., Ajayamohan, R.S., Boos, W.R., Sabin, T.P. and Praveen, V., 2018. Decline and poleward shift in Indian summer monsoon synoptic activity in a warming climate. *Proceedings of the National Academy of Sciences*, *115*(11), pp.2681-2686.
54. Sharma, S. and Mujumdar, P., 2017. Increasing frequency and spatial extent of concurrent meteorological droughts and heatwaves in India. *Scientific reports*, *7*(1), pp.1-9.
55. Sharma, S. and Singh, P.K., 2017. Long term spatiotemporal variability in rainfall trends over the State of Jharkhand, India. *Climate*, *5*(1), p.18.
56. Sinha, P., Mohanty, U.C., Kar, S.C., Dash, S.K., Robertson, A.W. and Tippett, M.K., 2013. Seasonal prediction of the Indian summer monsoon rainfall using canonical correlation analysis of the NCMRWF global model products. *International journal of climatology*, *33*(7), pp.1601-1614.
57. Surendran, S., Gadgil, S., Francis, P.A. and Rajeevan, M., 2015. Prediction of Indian rainfall during the summer monsoon season on the basis of links with equatorial Pacific and Indian Ocean climate indices. *Environmental Research Letters*, *10*(9), p.094004.
58. Swain, M., Sinha, P., Mohanty, U.C. and Pattnaik, S., 2019. Dominant large-scale parameters responsible for diverse extreme rainfall events over vulnerable Odisha state in India. *Climate Dynamics*, *53*(11), pp.6629-6644.
59. Swain, M., Sinha, P., Pattanayak, S., Guhathakurta, P. and Mohanty, U.C., 2020. Characteristics of observed rainfall over Odisha: An extreme vulnerable zone in the east coast of India. *Theoretical and Applied Climatology*, *139*(1-2), pp.517-531.
60. Taxak, A.K., Murumkar, A.R. and Arya, D.S., 2014. Long term spatial and temporal rainfall trends and homogeneity analysis in Wainganga basin, Central India. *Weather and Climate Extremes*, *4*, pp.50-61.
61. Toreti, A., Kuglitsch, F.G., Xoplaki, E., Della-Marta, P.M., Aguilar, E., Prohom, M. and Luterbacher, J., 2011. A note on the use of the standard normal homogeneity test to detect inhomogeneities in climatic time series. *International Journal of Climatology*, *31*(4), pp.630-632.
62. Trenberth, K.E., 2011. Changes in precipitation with climate change. *Climate Research*, *47*(1-2), pp.123-138.
63. Varikoden, H., Revadekar, J.V., Kuttippurath, J. and Babu, C.A., 2019. Contrasting trends in southwest monsoon rainfall over the Western Ghats region of India. *Climate Dynamics*, *52*(7-8), pp.4557-4566.
64. Vishnu, S., Francis, P.A., Shenoi, S.S.C. and Ramakrishna, S.S.V.S., 2016. On the decreasing trend of the number of monsoon depressions in the Bay of Bengal. *Environmental Research Letters*, *11*(1), p.014011.
65. Walker, J.M., Bordoni, S. and Schneider, T., 2015. Interannual variability in the large-scale dynamics of the South Asian summer monsoon. *Journal of Climate*, *28*(9), pp.3731-3750.

66. Wijngaard, J.B., Klein Tank, A.M.G. and Können, G.P., 2003. Homogeneity of 20th century European daily temperature and precipitation series. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *23*(6), pp.679-692.
67. Yadav, R.K. and Roxy, M.K., 2019. On the relationship between north India summer monsoon rainfall and east equatorial Indian Ocean warming. *Global and Planetary Change*, *179*, pp.23-32.
68. Yadav, R.K., Ramu, D.A. and Dimri, A.P., 2013. On the relationship between ENSO patterns and winter precipitation over North and Central India. *Global and planetary change*, *107*, pp.50-58.

Figures

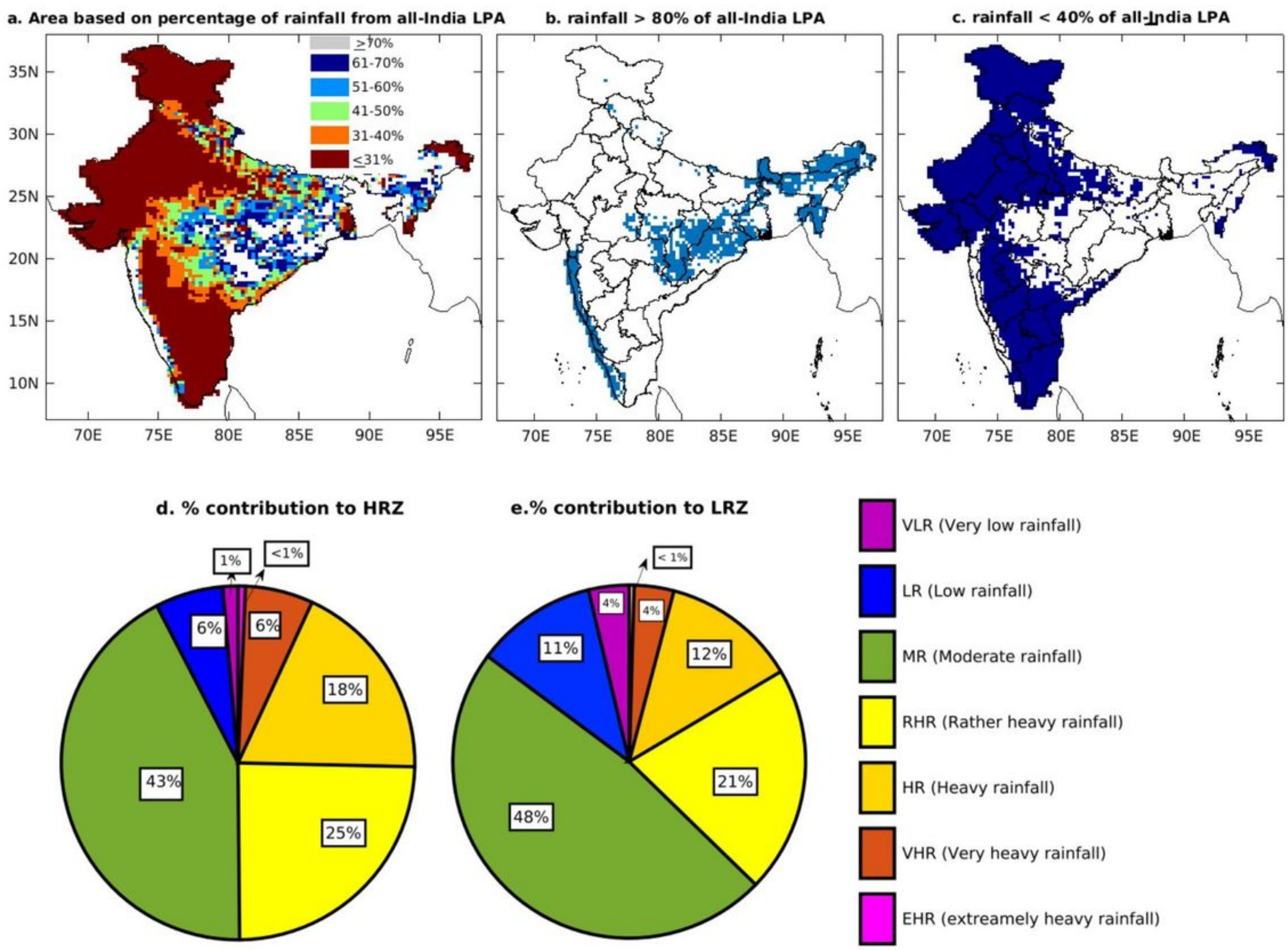

Figure 1

Climatological rainfall distribution of the Indian summer over India, (a) the different areas with various color (shaded) indicate the zones having climatological rainfall amount (in %) with respective to all-India long period average (LPA) during Indian summer monsoon season (854.63 mm) (b) the zones in blue color (shaded) represent the area of India where climatological rainfall is 80% or more (heavy rainfall zone: HRZ) with respect to all-India seasonal rainfall climatology, and (c) the zones in orange color (shaded) represent the area of India where climatological rainfall is 40% or less (Low rainfall zone: LRZ) with respect to all-India seasonal rainfall climatology (d) contribution of various rainfall events to the seasonal rainfall for the HRZ and (e) contribution of various rainfall events to the seasonal rainfall for the LRZ. The computation has been carried out using India Meteorological Department (IMD) rainfall analysis at 0.25°×0.25° horizontal resolution for the period of 116 years (1901-2016).

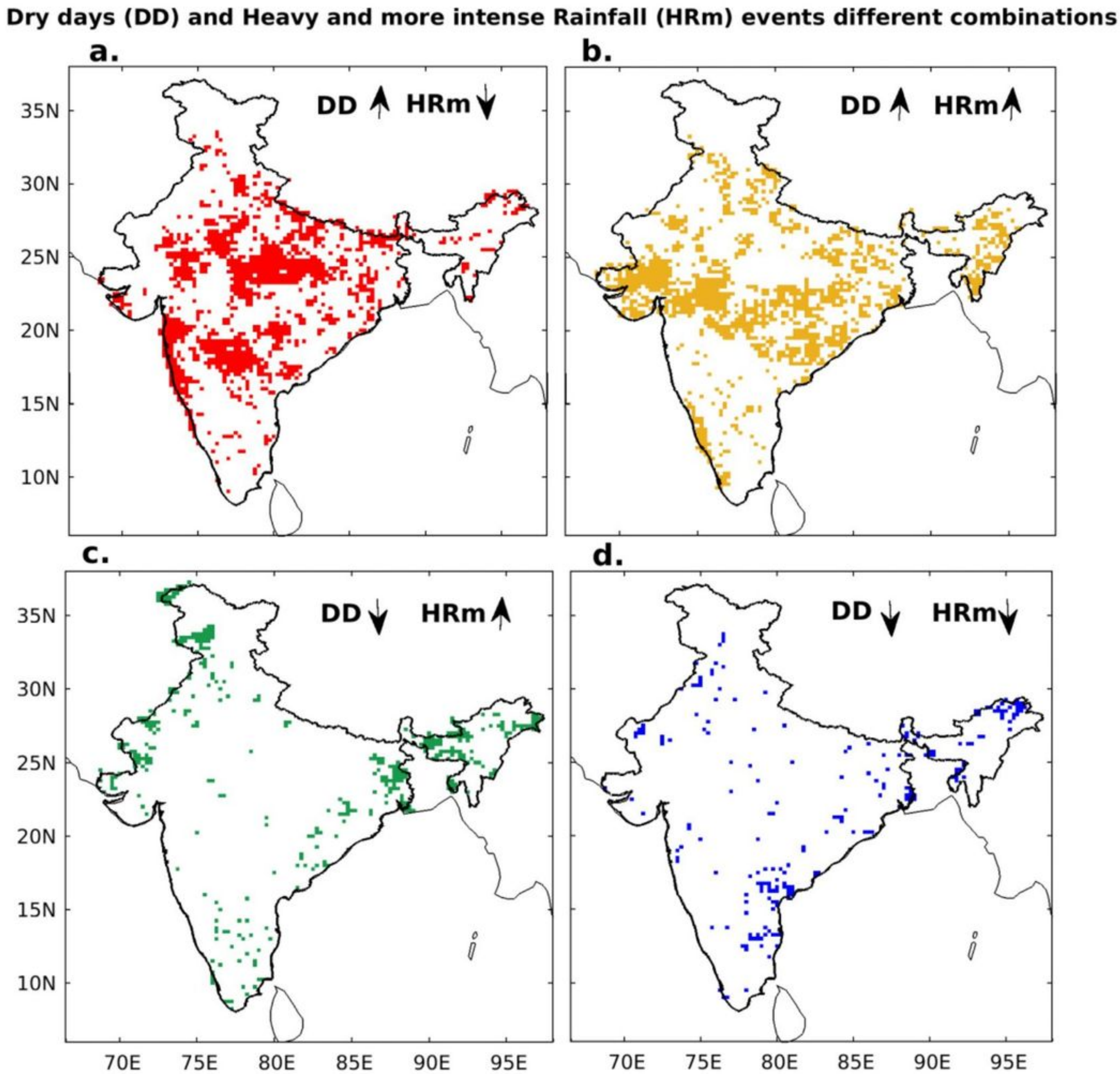

Figure 2

Spatial distribution of Mann-Kendall trends for heavy and more intense rainfall (HRm) events and total number of dry days at 90% of confidence level (a) the regions where dry days increased and HRm decreased shown in red color, (b) the regions where both dry days and HRm events increased shown in yellow color, (c) the regions where dry days decreased and HRm events increased shown in green color, and (d) the regions where both dry days and HRm events decreased shown in blue color during 116 years time period (1901-2016).

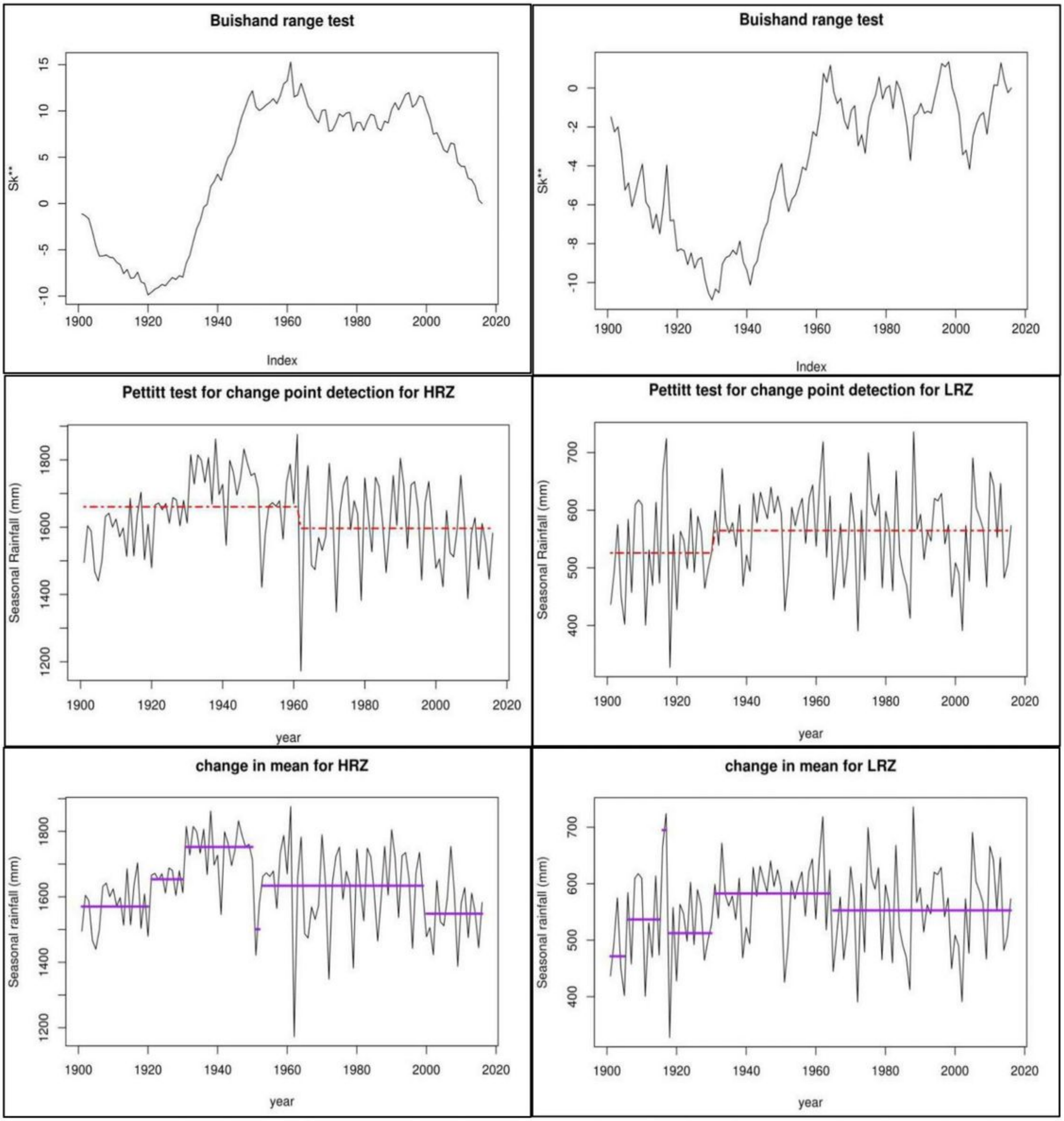

Figure 3

The single change point detection and multiple change point detection by using Buishand range (BR) test (a) for HRZ region and (b) for LRZ region, Pettitt test (c) for HRZ region and (d) for LRZ region and change in mean test (e) for HRZ region and (f) for LRZ region.

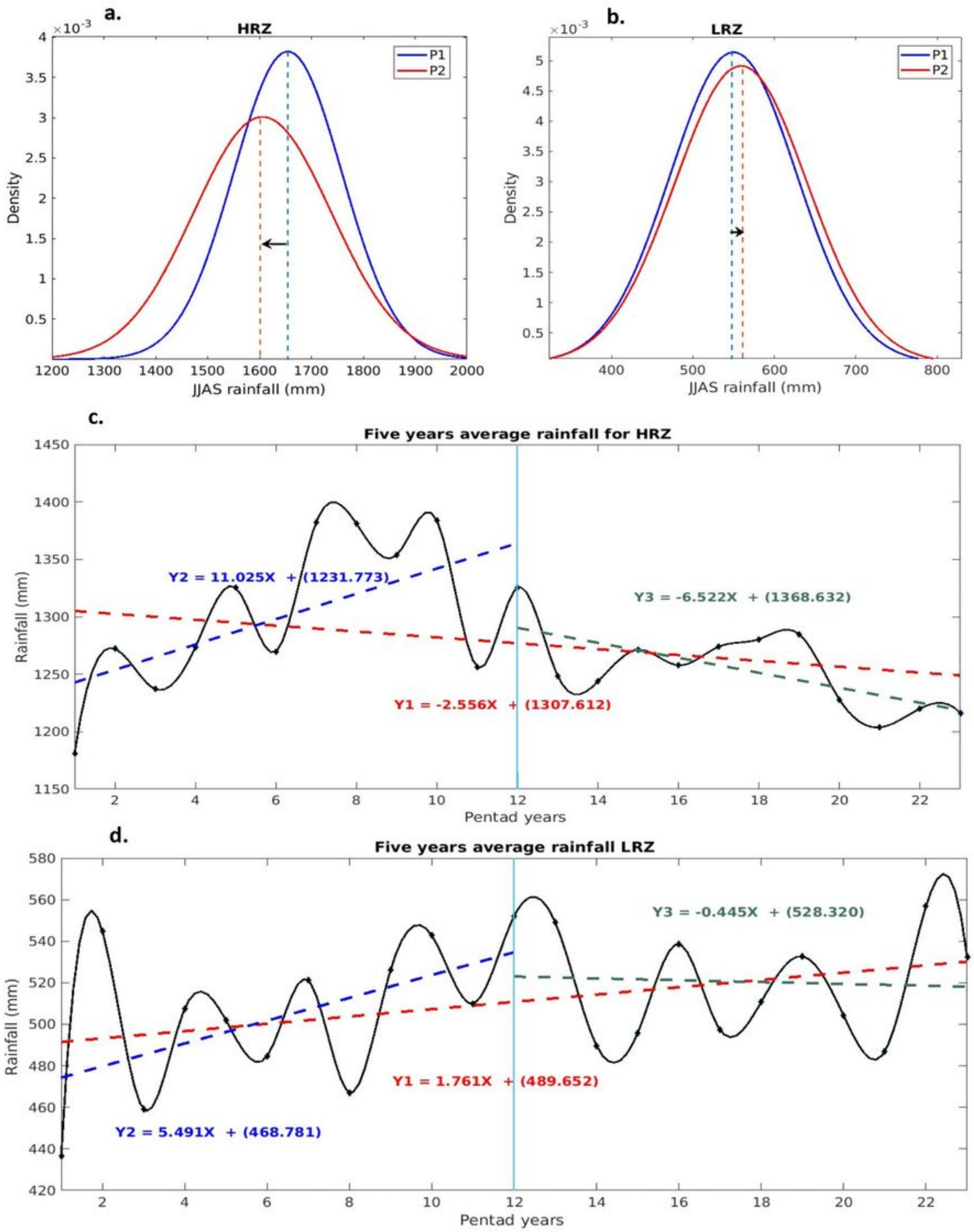

Figure 4

The probability density function of seasonal rainfall for (a) HRZ and (b) LRZ during P1 and P2.The blue color line shows the earlier period P1 (1901-1958) and red line shows the recent period P2 (1959-2016),

(c) the five years average rainfall for HRZ, the red dotted line shows trend for total time period, blue color line shown trend for P1 and green color line shows trend for P2 and (d) same as (c), only for LRZ.

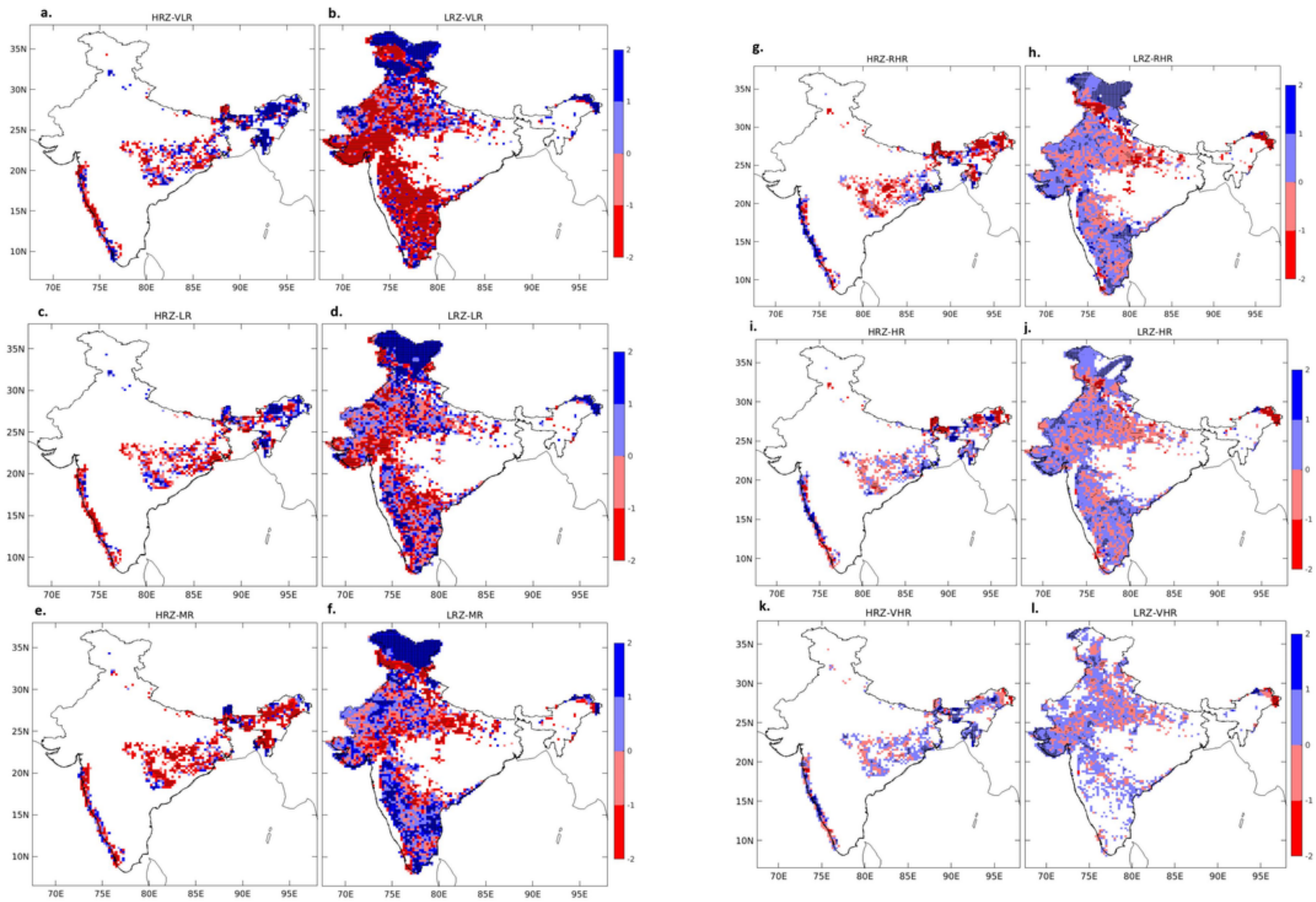

Figure 5

Spatial distribution of the difference of various rainfall events during P-I, P-II. The hatched region shows value for 90% of confidence level, '+' used for increased dry spell and '-' used for decreased dry spell. The left side column (a, c, e, g, i and k) represents various rainfall events for HRZ and right side column (a, c, e, g, i and k) represents various rainfall events for LRZ .

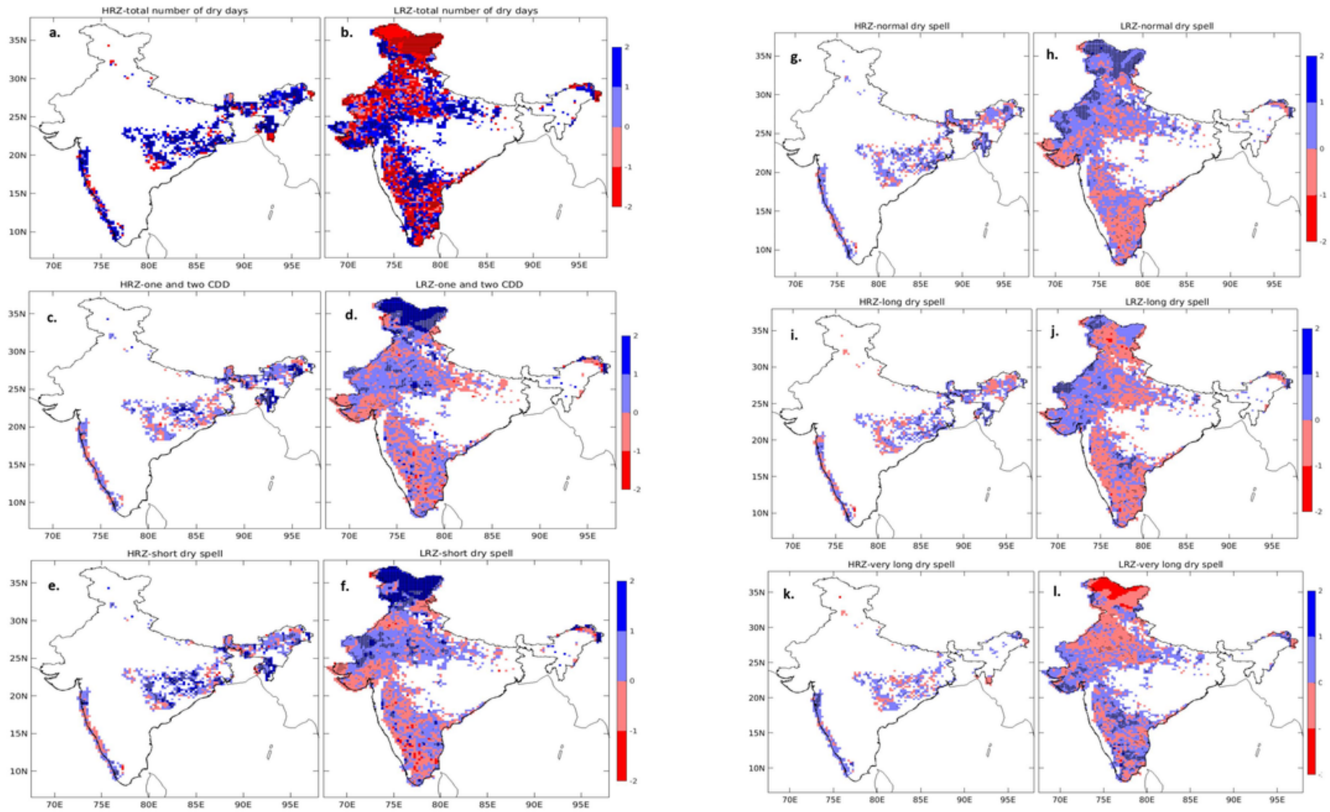

Figure 6

Spatial distribution of the difference between total number of dry days and various dry spell during P1, P2. The hatched region shows value for 90% of confidence level, ‘+’ used for increased dry spell and ‘-’ used for decreased dry spell. (a) total number of dry days over HRZ (c) one to two consecutive dry day (CDD) for HRZ, (e) short dry spell (3 and 4 CDD) for HRZ, (g) normal dry spell (5 to 7 CDD) for HRZ, (i) long dry spell (8 to 14 CDD) for HRZ, (k) very long dry spell (> 14 CDD) for HRZ, (b), (d), (f), (h), (j) and (l) are same as (a), (c), (e), (g), (i) and (k) respectively, only for LRZ.

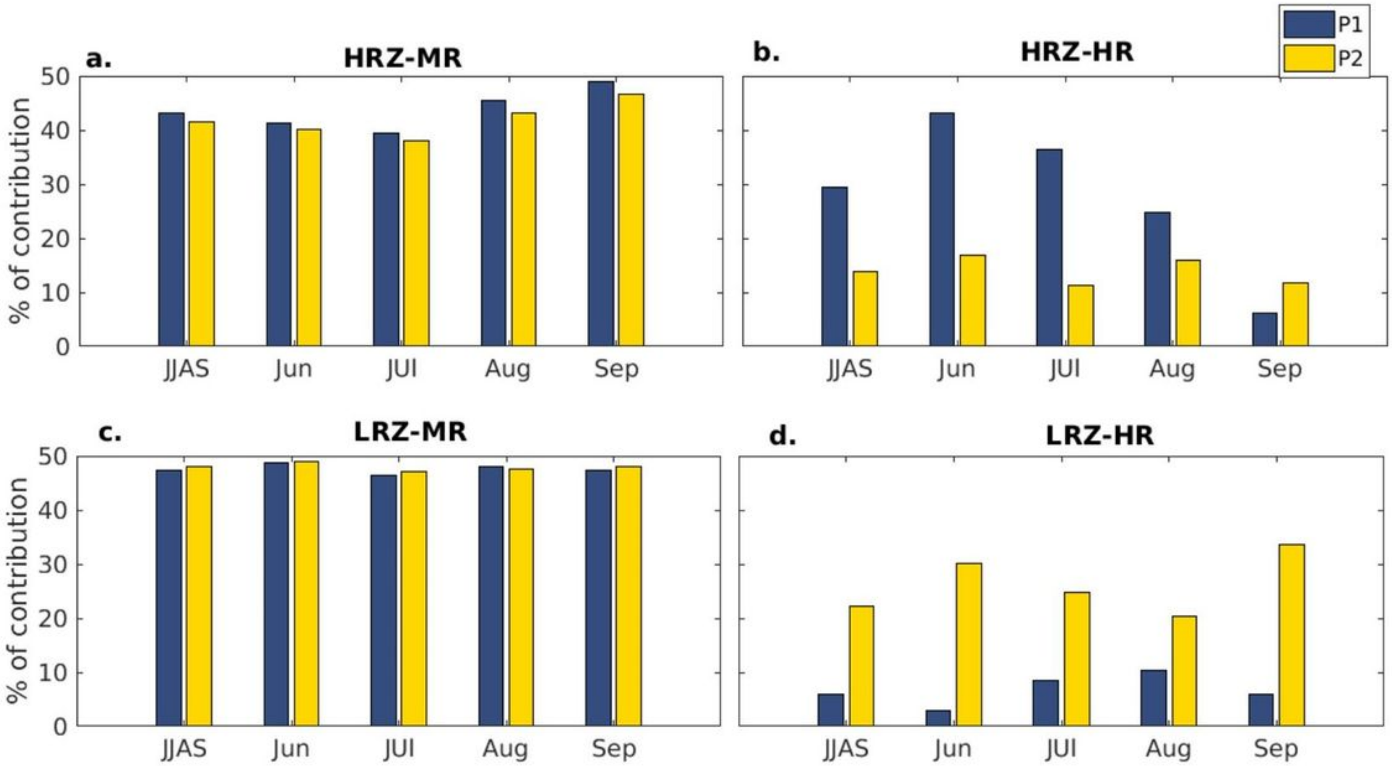

Figure 7

The percentage (%) of contribution of major contributing rainfall event-moderate rainfall (MR) and heavy rainfall events (HR) for seasonal as well as monthly basis (a) MR events for the HRZ, (b) HR events for the HRZ, (c) MR events for the LRZ, (d) HR events for the LRZ.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarymaterials.docx