Frequency of extremes precipitation is projected to increase during the 21st century over Indian River Basins (IRBs)

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Introduction

- **Hydro-climatic extremes,** such as very intense precipitation and drought, are expected to increase with global warming, with their cumulative effects potentially posing severe impacts on different socio-economic sectors, such as agriculture, water resources, health, ecosystem services, urban infrastructure, etc.

- In the wake of recent global warming, an increase in extreme weather events such as extreme rainfall is observed globally, which has a severe impact on natural and man-made ecosystems (IPCC, 2021).

- In recent decades, it has been observed that around 20 to 80 million of the global population is affected by floods every year, whereas India experienced almost 19 disasters due to floods and had about 1282 mortality with 3.1 billion in economic losses during the year 2021 (CRED, 2021).

- More than 279 reported flood events in India from 1953 to 2018, affected about 2.167 billion population, killing more than one lakh people, and causing damage to more than 258 Mha crop areas (NITI Aayog Report 2021; CWC, 2019).

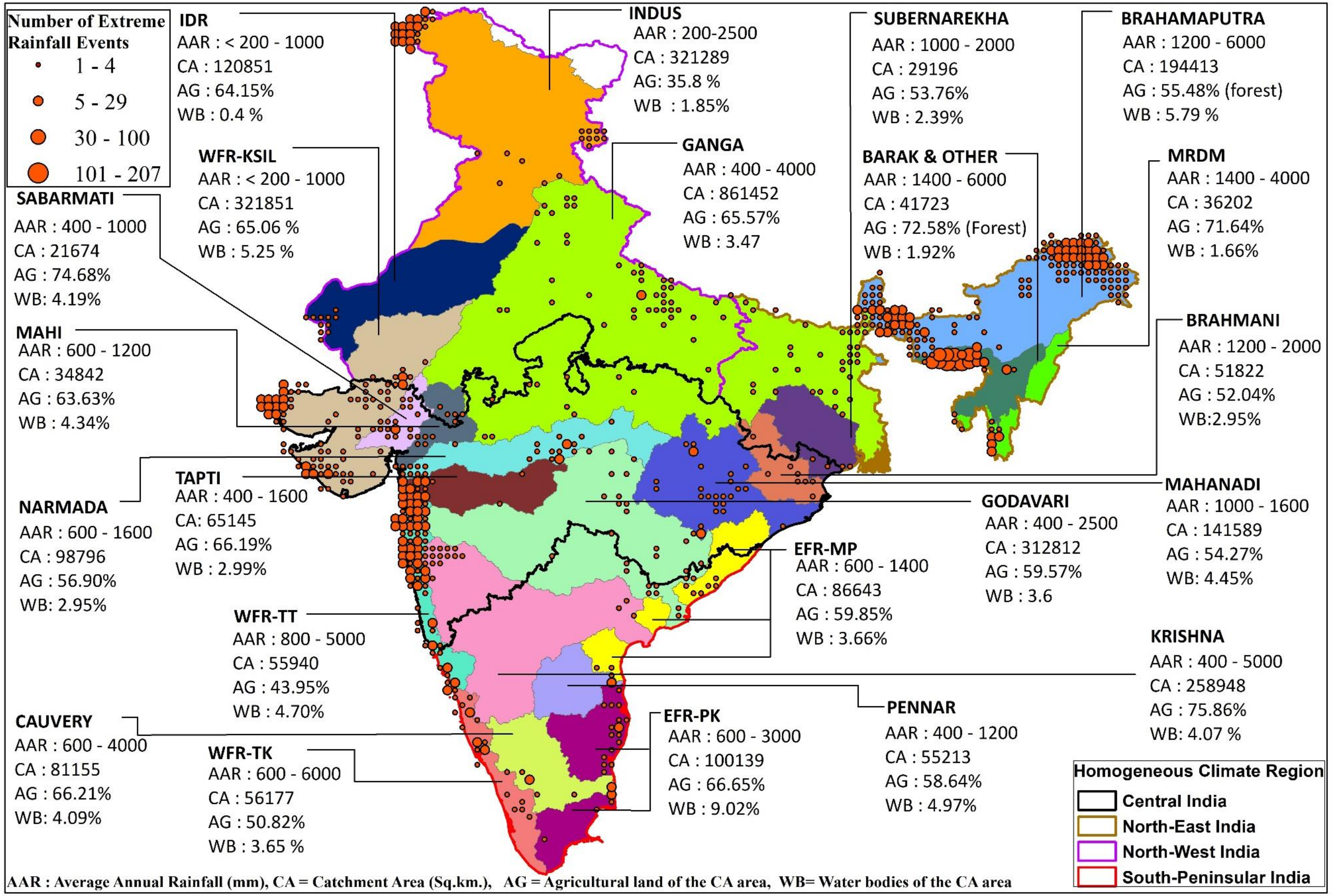
- Global warming has increased rapidly since the mid-20th-century due to increasing greenhouse gas emissions owing to more frequent and intense extreme climatic events resulting in more hydro meteorological hazards conditions (Fan et al., 2021).

- National Water Policy 2018, suggested that an Integrated Water Resources Management taking River Basin / Sub-Basin as a unit should be the main principle for planning, development, and management of water resources.

Definition of the Problem

How do the hydro-climate extremes changes over the different Indian River Basins (IRBs)?

Study Area



IDR
AAR : < 200 - 1000
CA : 120851
AG : 64.15%
WB : 0.4 %

INDUS
AAR : 200-2500
CA : 321289
AG: 35.8 %
WB : 1.85%

SUBERNAREKHA
AAR : 1000 - 2000
CA : 29196
AG : 53.76%
WB : 2.39%

BRAHAMAPUTRA
AAR : 1200 - 6000
CA : 194413
AG : 55.48% (forest)
WB : 5.79 %

WFR-KSIL
AAR : < 200 - 1000
CA : 321851
AG : 65.06 %
WB : 5.25 %

GANGA
AAR : 400 - 4000
CA : 861452
AG : 65.57%
WB : 3.47

BARAK & OTHER
AAR : 1400 - 6000
CA : 41723
AG : 72.58% (Forest)
WB : 1.92%

MRDM
AAR : 1400 - 4000
CA : 36202
AG : 71.64%
WB : 1.66%

SABARMATI
AAR : 400 - 1000
CA : 21674
AG : 74.68%
WB: 4.19%

MAHI
AAR : 600 - 1200
CA : 34842
AG : 63.63%
WB : 4.34%

BRAHMANI
AAR : 1200 - 2000
CA : 51822
AG : 52.04%
WB:2.95%

TAPTI
AAR : 400 - 1600
CA: 65145
AG : 66.19%
WB : 2.99%

NARMADA
AAR : 600 - 1600
CA : 98796
AG : 56.90%
WB: 2.95%

MAHANADI
AAR : 1000 - 1600
CA : 141589
AG : 54.27%
WB: 4.45%

GODAVARI
AAR : 400 - 2500
CA : 312812
AG : 59.57%
WB : 3.6

EFR-MP
AAR : 600 - 1400
CA : 86643
AG : 59.85%
WB : 3.66%

WFR-TT
AAR : 800 - 5000
CA : 55940
AG : 43.95%
WB : 4.70%

KRISHNA
AAR : 400 - 5000
CA : 258948
AG : 75.86%
WB: 4.07 %

PENNAR
AAR : 400 - 1200
CA : 55213
AG : 58.64%
WB : 4.97%

CAUVERY
AAR : 600 - 4000
CA : 81155
AG : 66.21%
WB: 4.09%

WFR-TK
AAR : 600 - 6000
CA : 56177
AG : 50.82%
WB : 3.65 %

EFR-PK
AAR : 600 - 3000
CA : 100139
AG : 66.65%
WB : 9.02%

AAR : Average Annual Rainfall (mm), CA = Catchment Area (Sq.km.), AG = Agricultural land of the CA area, WB= Water bodies of the CA area

Data and Methodology

Observed Rainfall / Simulated Precipitation

We have used daily gridded rainfall data by India Meteorological Department (**IMD**) and simulated precipitation outputs from Coupled Model Intercomparison Project-6 (**CMIP6**). The 22 major IRBs have been extracted by using a Digital Evaluation Model (DEM) taken from Shuttle Radar Topography Mission (**SRTM**).

Table 1. Datasets Used

Product	Period	Spatial resolution	Web Link
SRTM-DEM	-----	90 m	http://srtm.csi.cgiar.org/
Landsat-MSS/TM/ETM+	-----	60 m / 30 m	https://earthexplorer.usgs.gov/
Rain Gauge Products (IMD)	1901 - 2022	0.25 × 0.25	http://www.imd.gov.in
TRMM 3B42v7	1998 - 2017	0.25 × 0.25	https://earthdata.nasa.gov/
Coupled Model Intercomparison Project-6 (CMIP6)	1950 - 2100	1° × 1°	https://esgf-node.llnl.gov/search/cmip6

Intensity of the extreme rainfall

The intensity of rainfall events between 64.5 and 124.4 mm / day is considered as **Heavy Rainfall** (HR), the rainfall events between 124.5 and 244.4 mm /day is considered as **Very Heavy Rainfall** (VHR), and the rainfall events are greater than and equal to 244.5 mm /day is considered as **Extremely Heavy Rainfall** (EHR).

Generalized Extreme Value (GEV) Distribution

The GEV distribution is used to estimate the return level of rainfall events at every grid point in the study. Let’s suppose Rm is the annual maximum of daily rainfall in the used rainfall series, then GEV distribution is defined as :

$$P_r\,(R_m \leq R) = \exp\,[-\,\{1+ \xi\,(R - \mu)/\Psi\,\}^{1/\xi}] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$1/n = [1+ \xi\,(R_n - \mu)/\Psi]^{1/\xi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$R_n = [\mu + (\Psi n^{\xi}) - (1/\xi)]\ , \text{ for } \xi \neq 0 \text{ and } R_n = (\mu + \Psi \log n)\ , \text{ for } \xi = 0 \qquad \ldots\ldots\ldots(3)$$

Bias Correction

The Linear Scaling (LS) applying on uncorrected data, and it perfectly matches the monthly mean rainfall value with the observed rainfall value. The first step involved in the method LS is calculated the monthly scaling factor as the ratio of the long-term monthly mean of observed data and model data (for the same time period selected in observed). In the second step, the scaling factor is multiplied by each of the daily values of uncorrected data for the corresponding month.

$$p_{d_{bc\,(hist)}} = p_{d_{mod}} \frac{[\mu_m \mu(Pd_{obs})]}{[\mu_m(Pd_{mod})]} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (4)$$

$$p_{d_{bc\,(proj)}} = p_{d_{scn}} \frac{[\mu_m \mu(Pd_{obs})]}{[\mu_m(Pd_{mod})]} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (5)$$

Percentage Departure

The study computes the grid-based percentage departure of realized rainfall from average rainfall. The percentage departure of rainfall for an individual year at every grid point was expressed as

$$\%\ \text{Departure} = \left(\frac{\text{Annual rainfall for an individual year} - \text{Average of longterm annual rainfall}}{\text{Average of longterm annual rainfall}}\right) 100 \qquad \ldots\ldots\ldots\ldots\ldots\ (6)$$

Standardized Precipitation Index

Standardized Precipitation Index (SPI) is a probability (i.e., statistical) index representing abnormal wetness and dryness. The decadal changes in SPI at 12- months running window is used to compare the dry to wet condition across IRBs.

$$\text{SPI} = (R - R_{mean}) / \sigma R \qquad \ldots\ldots\ldots\ldots\ldots\ (7)$$

Where, R denotes precipitation and σ indicates standardized deviation

Percentage Change

The Percentage change of precipitation is computed from equation (8). The changes in precipitation over the IRBs in the 21st century performed according to IPCC 2021 is for the **Near** (2021-2040), **Mid** (2040-2060), and **Far**-future (2071-2100) relative to 1981- 2014.

$$\%\ \text{change} = [(\text{Particular year} - \text{long term average}) / \text{long term average}] * 100 \qquad \ldots\ldots\ldots\ (8)$$

Precipitation Extremes

The bias-corrected CMIP6 datasets are used to calculate the precipitation extremes after applying the **Multi-Model Ensemble (MME)** approach (Wang et al., 2022). To estimate the changes in hydro-climate extremes, we used the **Expert Team on Climate Change Detection and Indices** (**ETCCDI**), demonstrated in Table 2.

Table 2 ETCCDI Indices used in the study.

ETCCDI indices name	**Indices**	**Unit**	**Definition**
Annual total wet-day PR	PRCPTOT	mm	Sum of daily PR>=1.0 mm
Contribution from moderate wet days	R75pTOT	%	Annual total rainfall when daily wet day amount > 75th percentile (%); 90th percentile (%); 95th percentile (%); 99th percentile (%); (100*r99p/PRCPTOT)
Contribution from heavy wet days	R90pTOT		
Contribution from very heavy wet days	R95pTOT		
Contribution from extremely wet days	R99pTOT		
Max 5-day PR	Rx5day	mm	Annual max consecutive 5-day rainfall
Number of 5-day PR	R5day	days	Number of 5day heavy PR
Consecutive dry days	CDD	days	Number Consecutive dry days
Consecutive wet days	CWD	days	Number Consecutive wet days

MK-Trend Test

The trend analysis performed at every grid point is carried out using the Mann–Kendall trend test method to consider linear trends. Sen's method is used to estimate the slope of the trend.

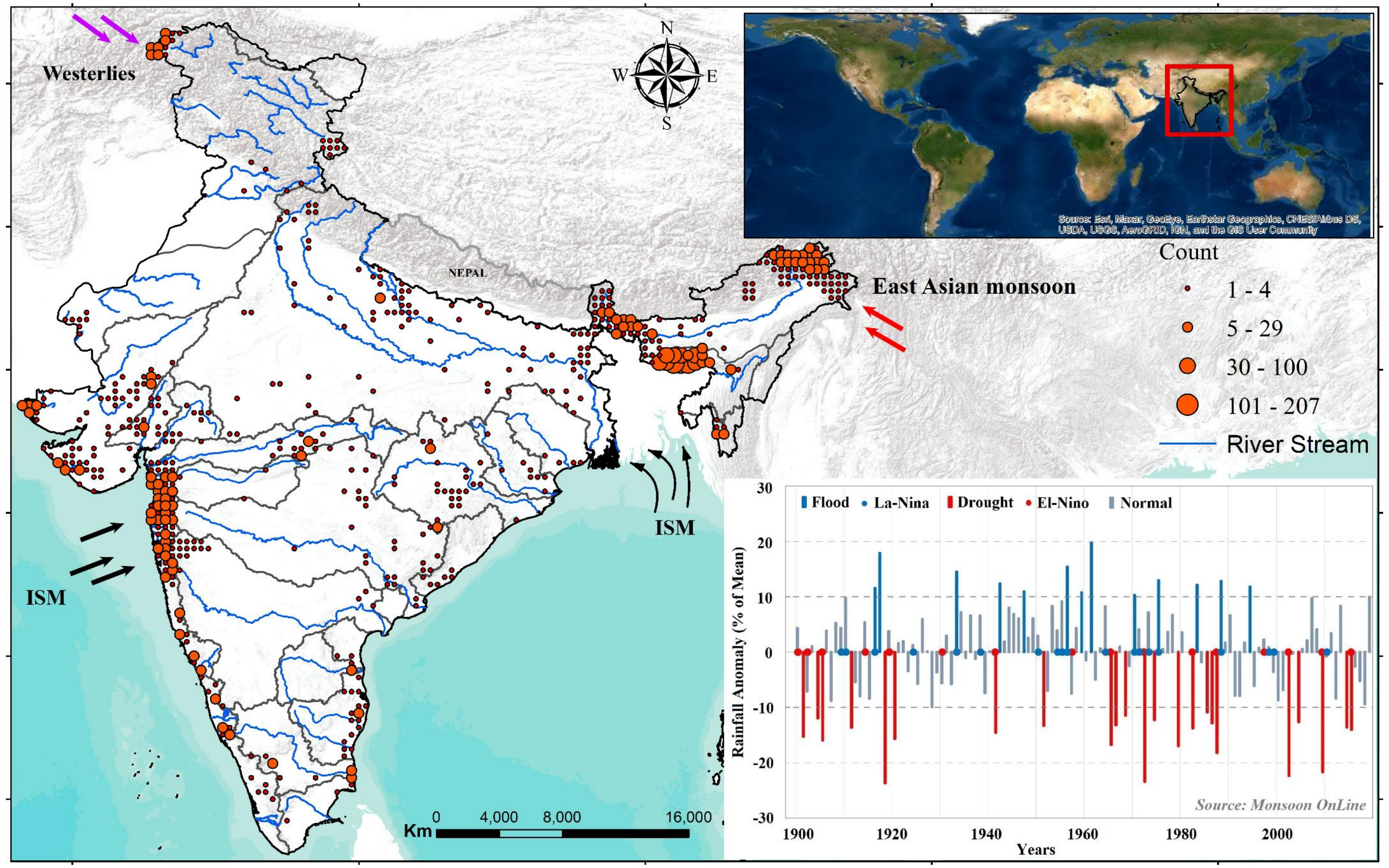


Fig. 1 Overview of the Indian River Basins (IRBs).

- The excess monthly rainfall departure (>20%) has been observed over the Brahmaputra and NE-Ganga river basins.

- The high probability of monthly sum rainfall (300 to 1000 mm) has been observed in WFR-TT and WFR-TK in PI-IRBs.

- West flowing and western part of the Indian river basins (IRBs) shows the high number of rainfall extremes at 99.99th percentile with having threshold values about ≥300 mm/day in the period of time from 1901 to 2019.

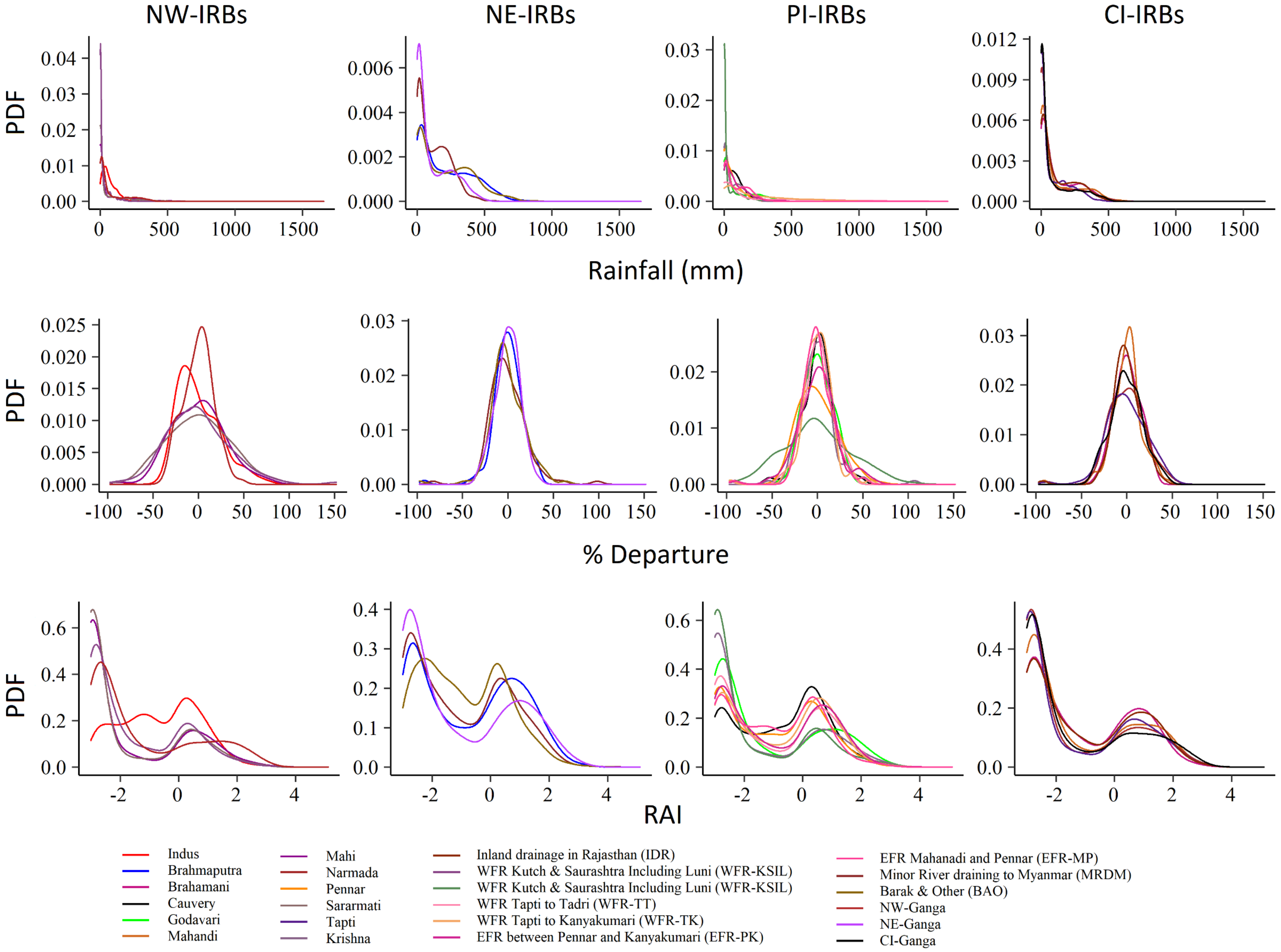


Fig. 2 Probability distribution of monthly sum rainfall, percentage departure, and the rainfall anomaly over the North-West India river basins, North-East India river basins, Peninsular India river basin, and Central-Indian River Basins.

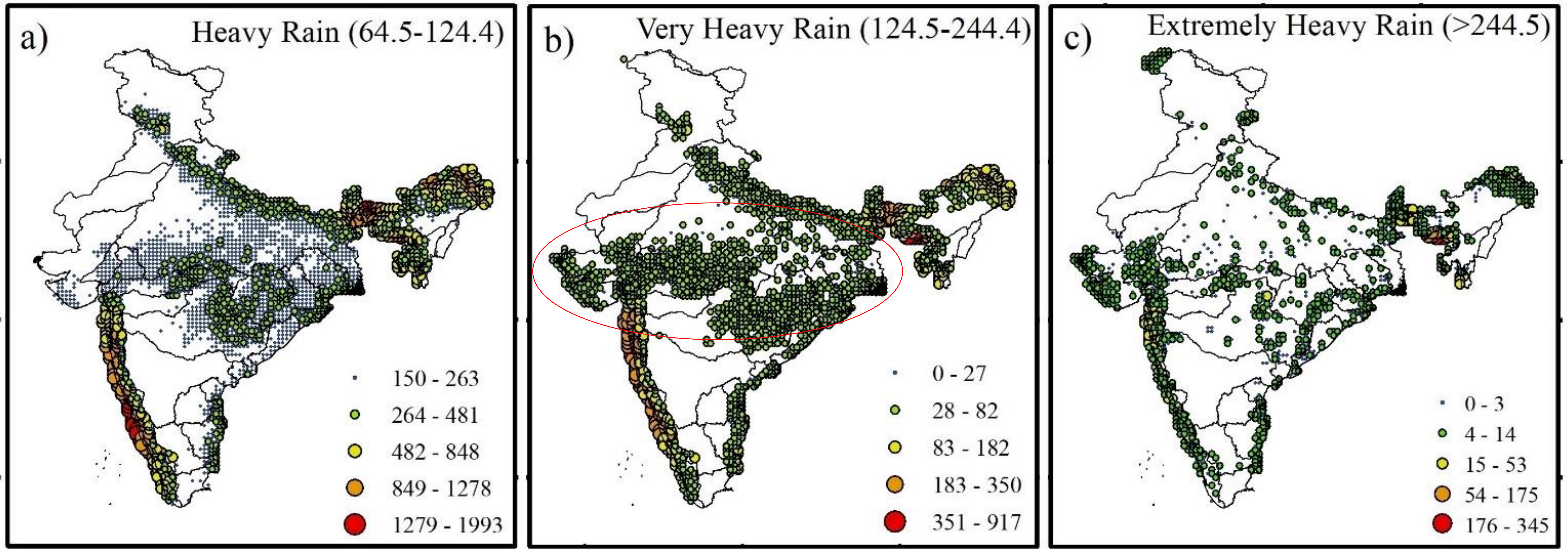


Fig. 3 Long-term (1901-2019) observed a number of extreme rainfall according to Indian Meteorological Department criteria for the intensity of (a) heavy rainfall (HR), (b) very heavy rainfall (VHR), and (c) extremely heavy rainfall (EHR).

- Figures 3 show that the largest number of HR to EHR events are concentrated over the west-flowing river basins of the PI-IRBs, including WFR-TT, WFR-TK, and EFR-PK.
- The CI-IRBs experienced more HR events instead of EHR events, while IDR, Krishna, and Cauvery showed none of the EHR events.

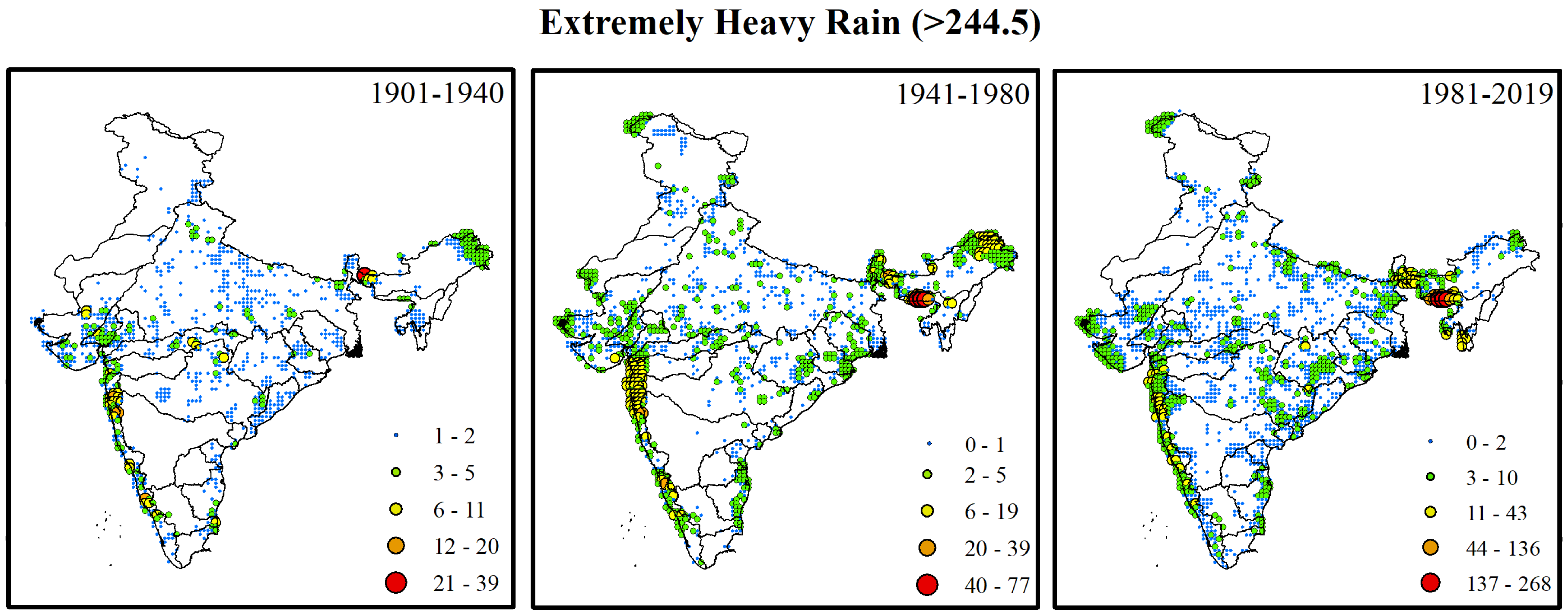


Fig. 4 The number of extreme rainfall events for the extremely heavy rainfall (EHR).

- During the recent period 1981-2019, EHR events have risen spatially in widespread new grids over the WFR-TT and lower Narmada basin (Fig. 4).

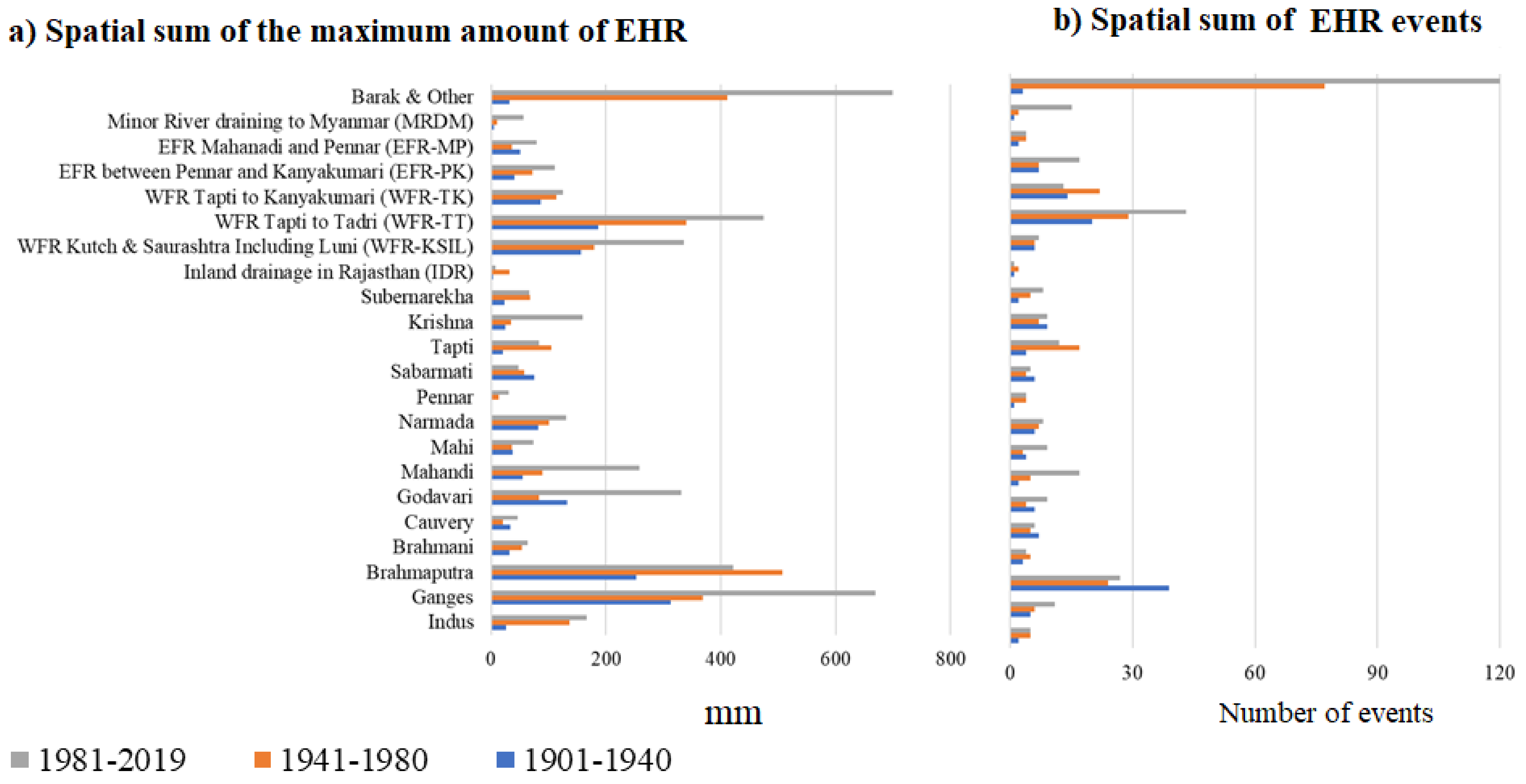


Fig. 5 Calculated spatial sum of the maximum amount and number of the EHR (a-b) events over the 22 major IRBs.

- The spatial distribution of EHR events over the IRBs shows large variability in the total rainfall maxima.
- The largest over the Ganga and the smallest over the Cauvery and Pennar river basins have been observed during 1981-2019 (Fig. 5).

- The figure 6 shows the increasing consecutive 5-day rainfall amount in between 1981-2019.

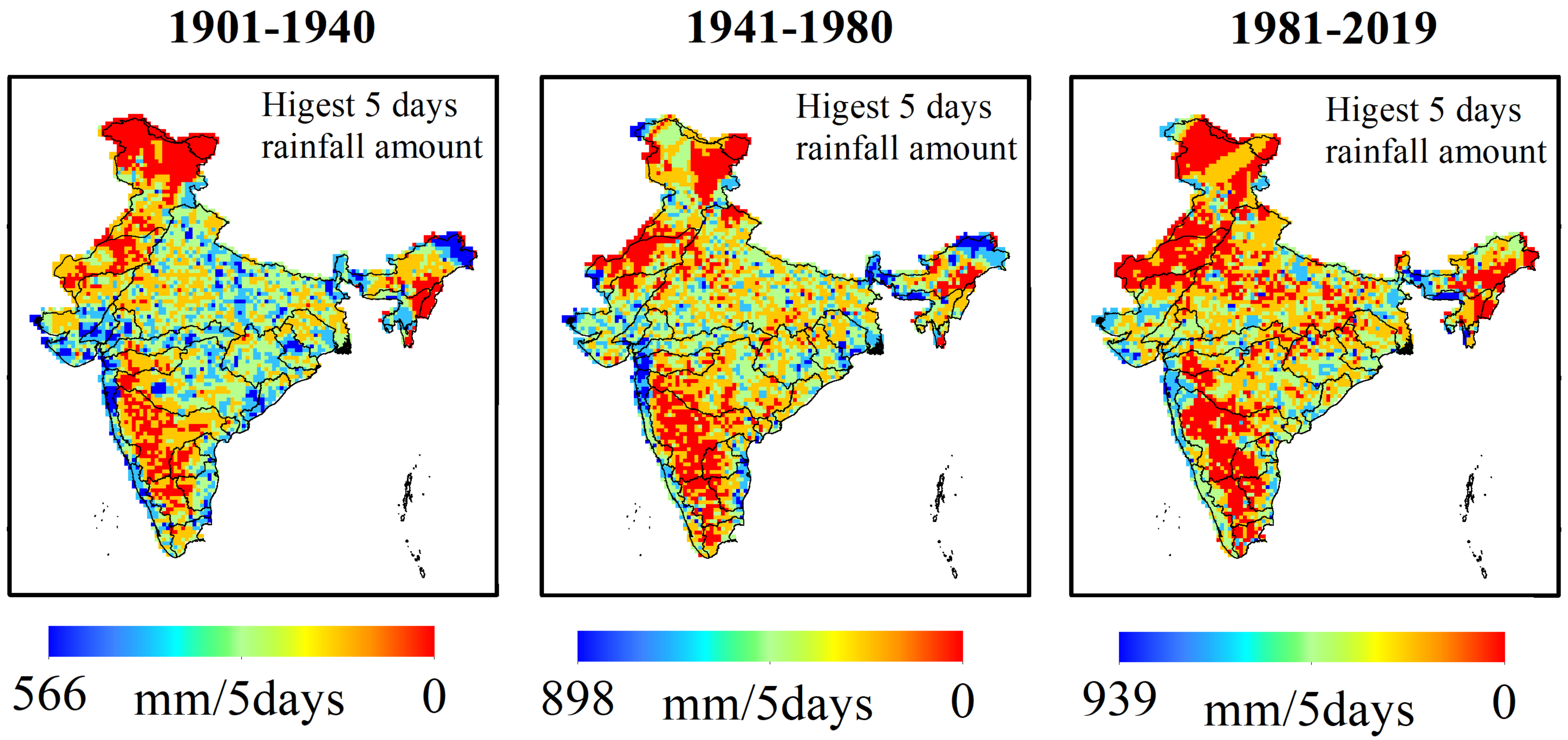


Fig. 6 Spatial variability in the maximum 5-day rainfall estimated by using Expert Team on Climate Change Detection and Indices over the Indian river basins.

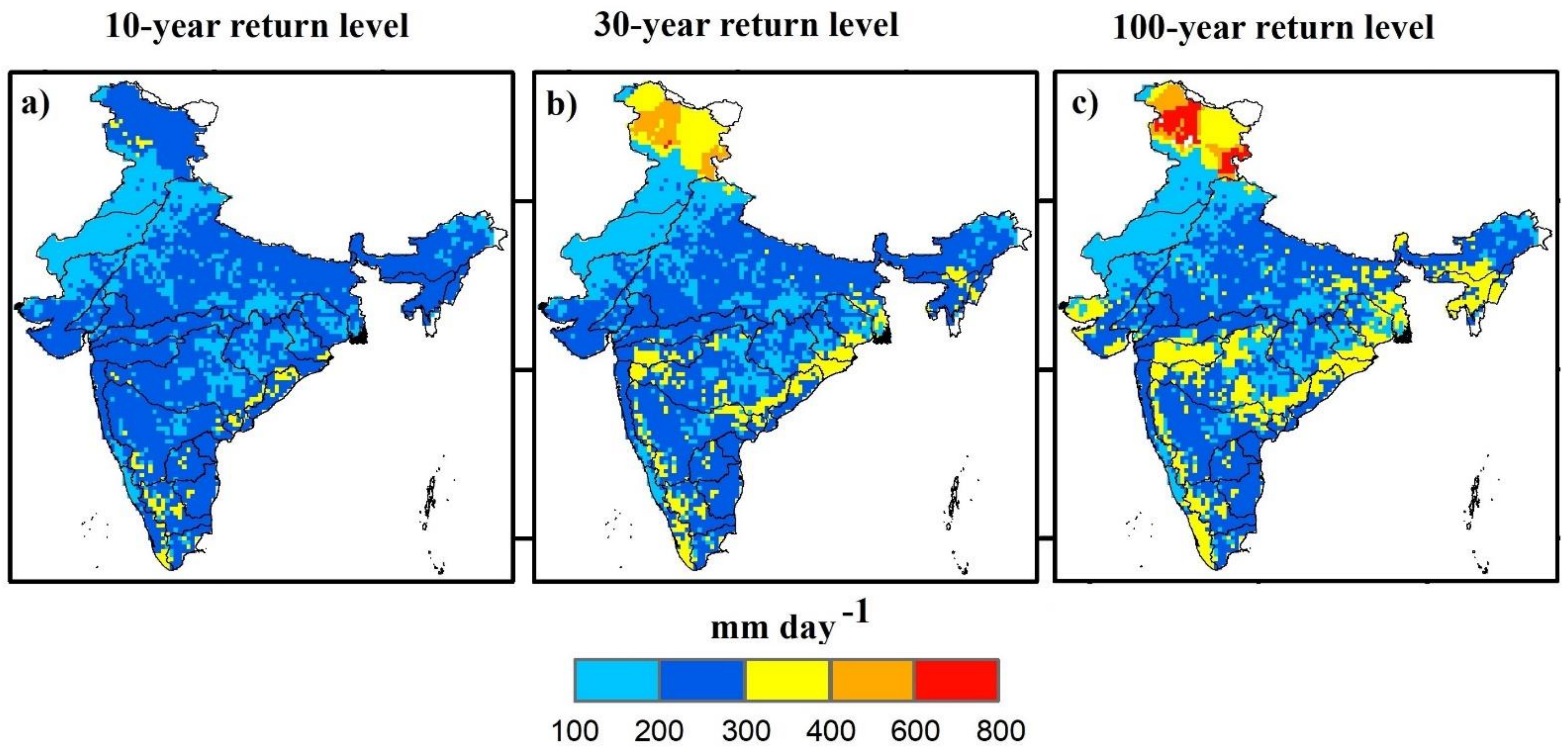


Fig. 7 Spatial grid-based estimation of return level of rainfall extremes over the Indian river basins (IRB) at10-year (a), 30-year (b), and 100-year (c) return levels, using 1901–2019 data.

- The Indus, west-flowing river basins of peninsular India, and north east belt of Ganga and NW-IRBs show the expected 3.3% and 1% probability of extreme rainfall events in 30- and 100-year return level.

- A significant increase in the trend of occurrence of rainfall (94 ± 10 mm/decade) has been observed in WFR-KSIL and WFR-TT at 95% at the end of twentieth and beginning of the 21st century (1981-2019)

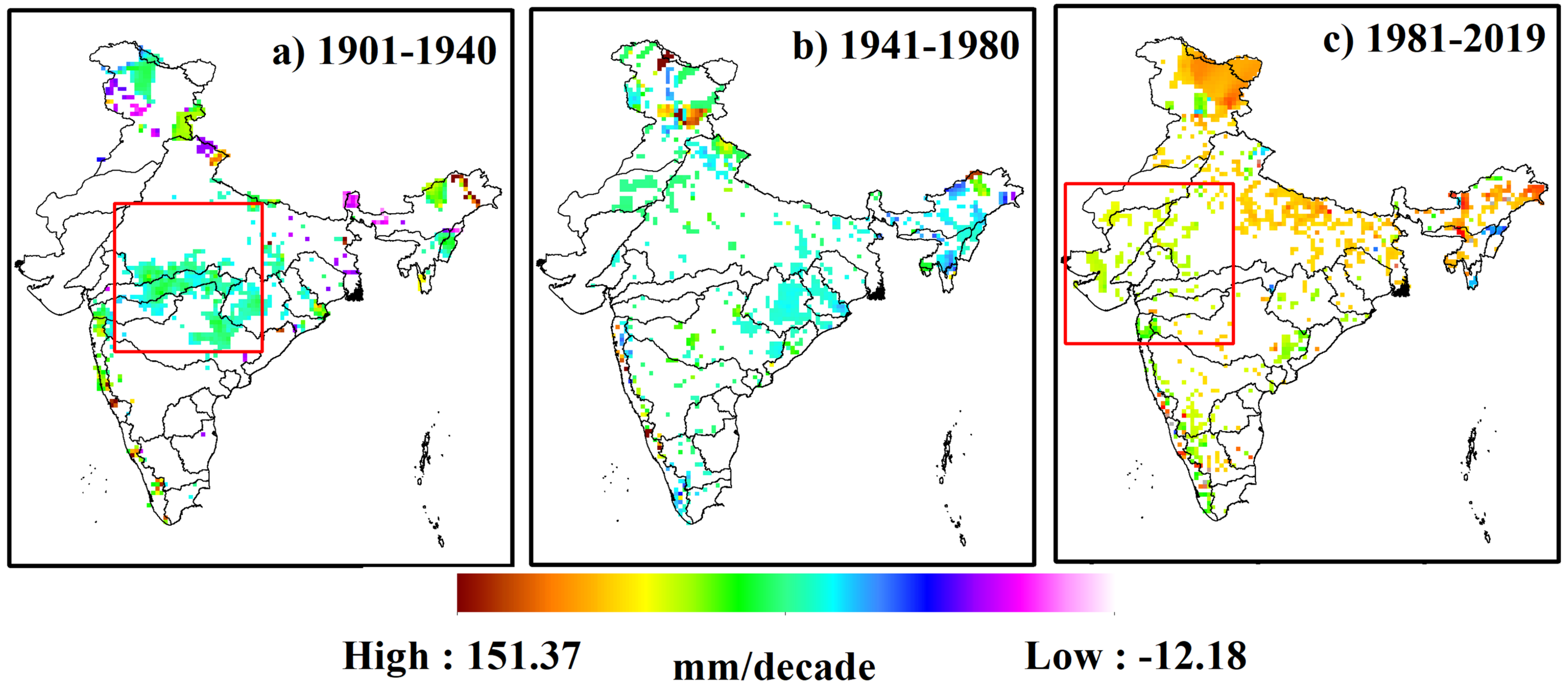


Fig. 9 The decadal trend of spatial rainfall distribution at 40 years's time interval (a–c) in the red box shows the positive trend of rainfall over the Indian River Basins (IRBs). Figures show only those values significant at 95% confidence level are shown.

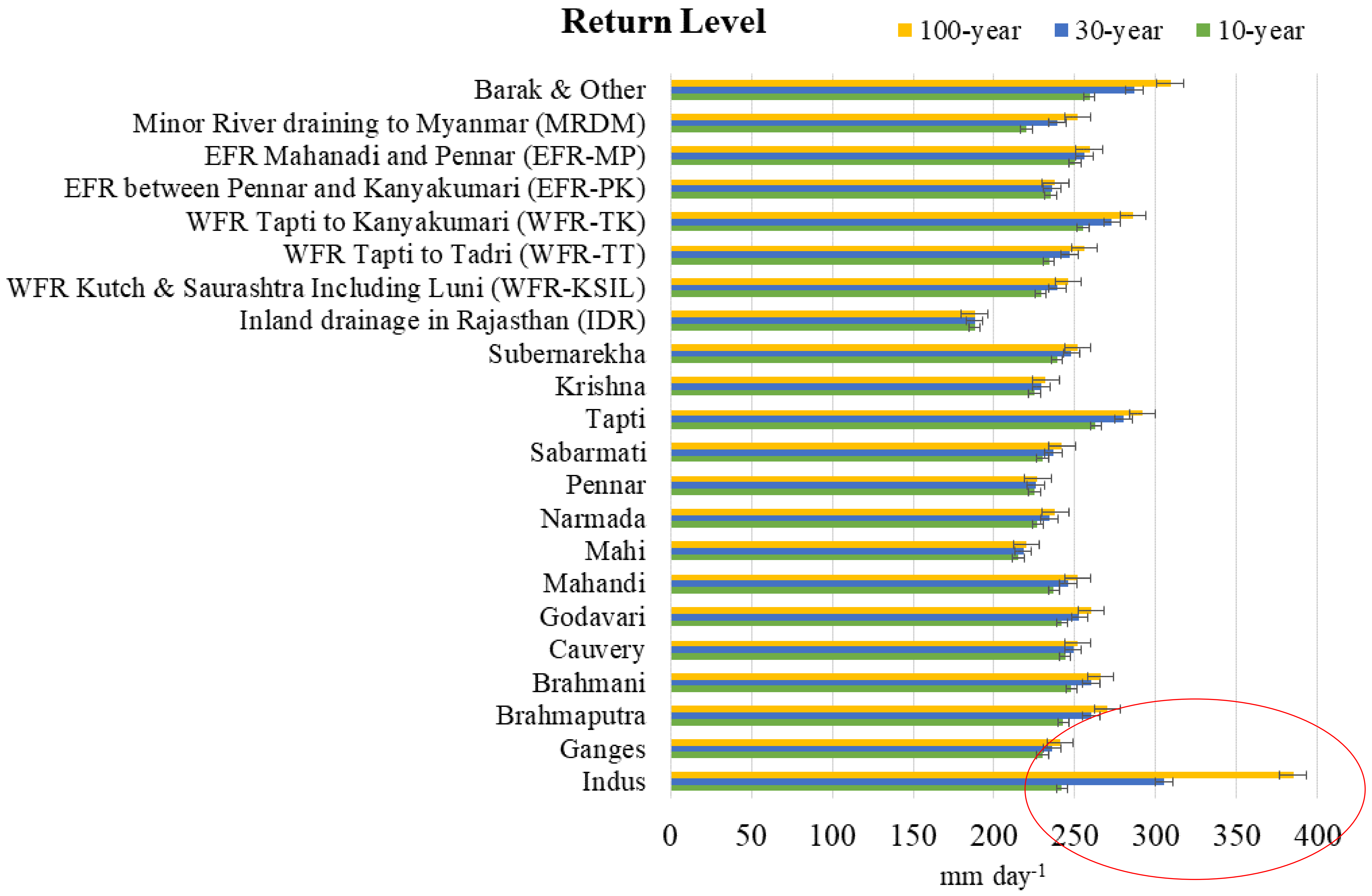


Fig. 8 Spatial mean grid-based estimation of return level distribution of rainfall extremes per day over the 22 major IRBs at 10-years (a), 30-year (b), and 100-year (c) return period, using 1901–2019.

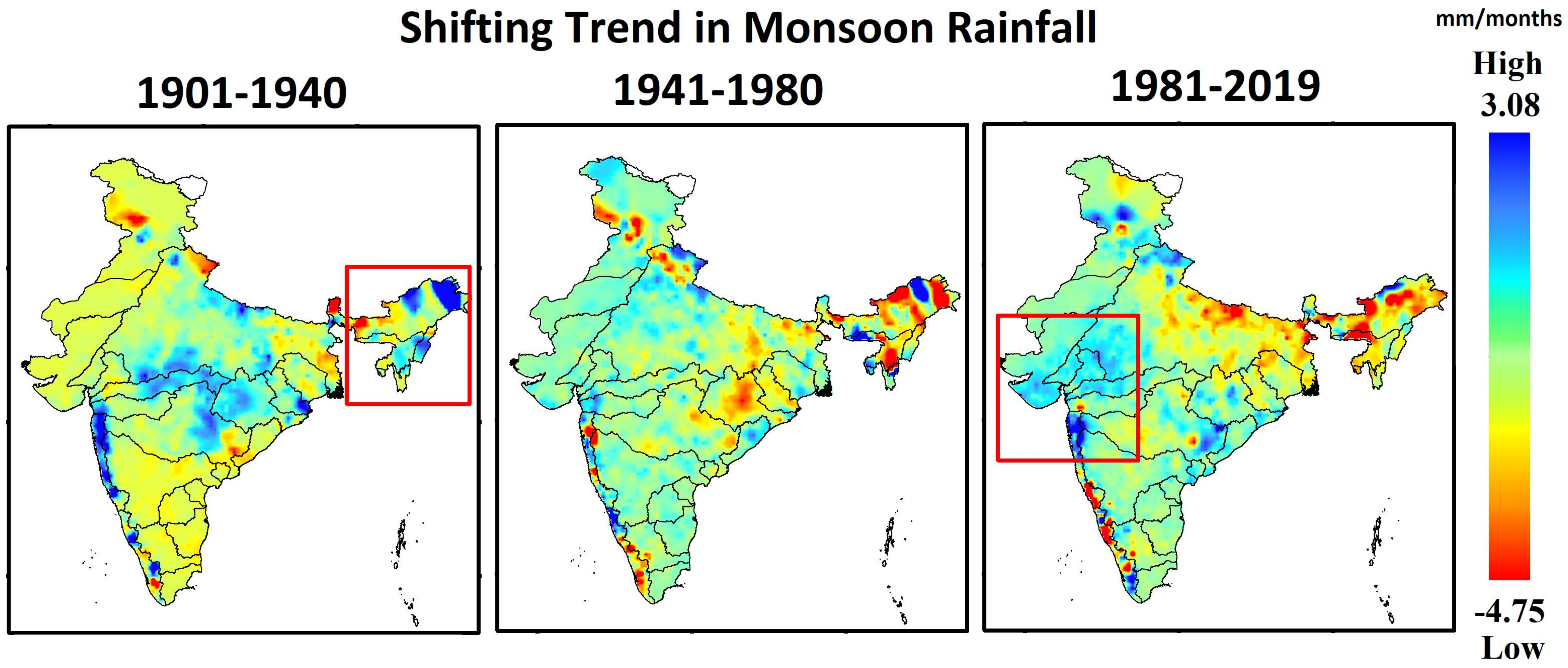


Fig. 10. Shifting trend of the JJAS rainfall at 40-year time interval based on the observed rainfall period (1901–2019), the rectangular red box represents the shifting trend of the rainfall.

- The decades 1941-1950 and 1971-1980 showed moderate wet to a very wet conditions in the Indus and central part of the Ganga river basin having SPI between 1 ≤ SPI ≥ 2, whereas very to extreme wet conditions (1 ≤ SPI ≥ 2) over the WFR-KSIL during decades 1961-1970.

- During 1981-2019, drastic changes in SPI (0 ≤ SPI ≥ 3) were observed, indicating a shift in extreme rainfall events toward the central-western part of the IRBs (Fig. 11).

- The shifting trend of monsoon rainfall toward the NW-IRBs, including WFR-KSIL, Sabarmati, Mahi, and lower part of the Narmada basin (Fig. 10).

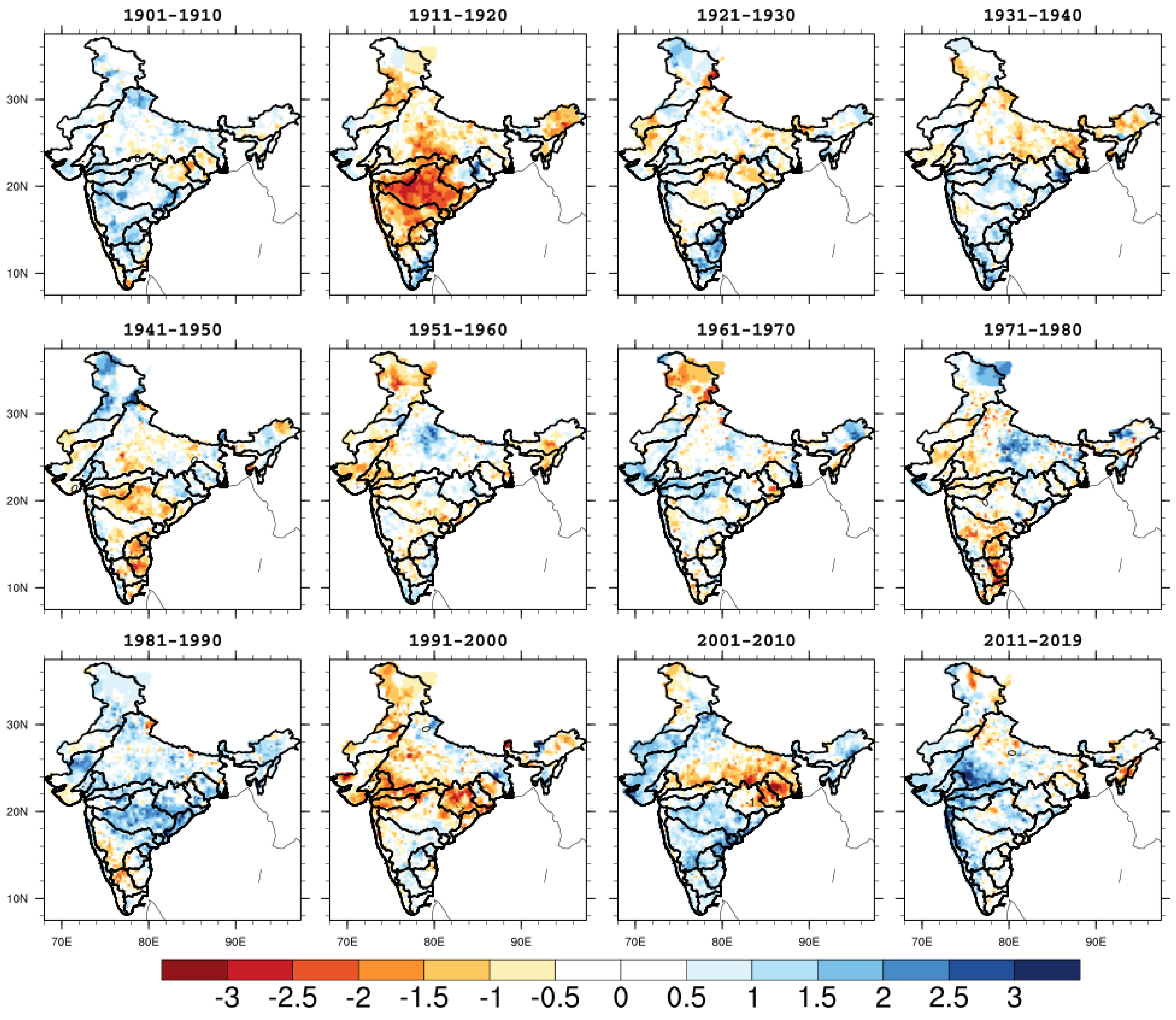
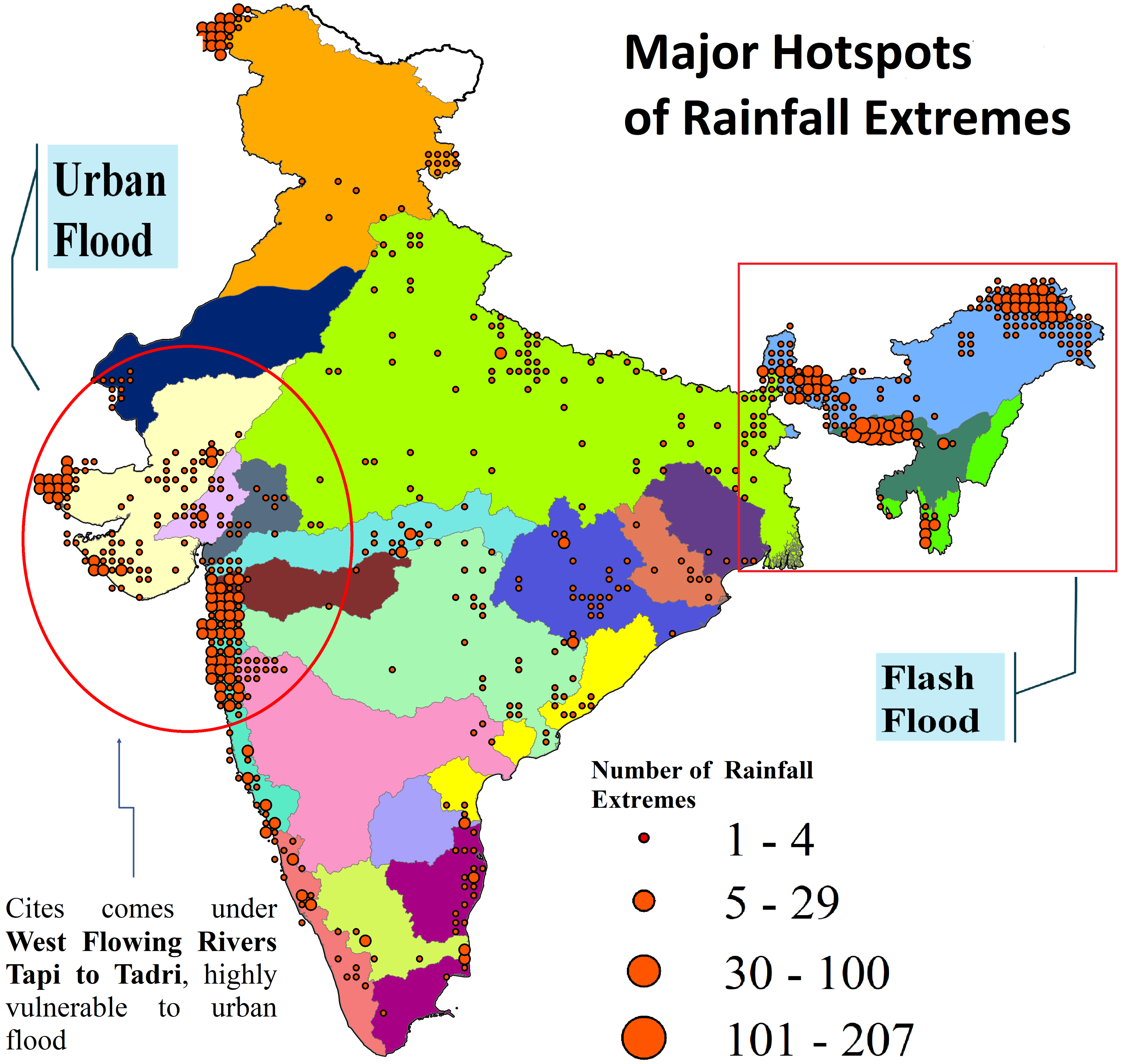


Fig. 11. Decadal changes in average intensity of estimated standardized precipitation indices at a monthly the time spanning over the Indian river basins.



Cites comes under **West Flowing Rivers Tapi to Tadri**, highly vulnerable to urban flood

Fig. 12. Major hotspot region of Indian river basins (IRBs)

- The highly populated cities under the west-flowing river basin, are highly vulnerable to urban flooding also, the northeast part has a flash flood situation (Fig. 12).

- During 1981-2019, drastic changes in SPI (0 ≤ SPI ≥ 3) were observed, indicating a shift in extreme rainfall events toward the central-western part of the IRBs (Fig. 13).

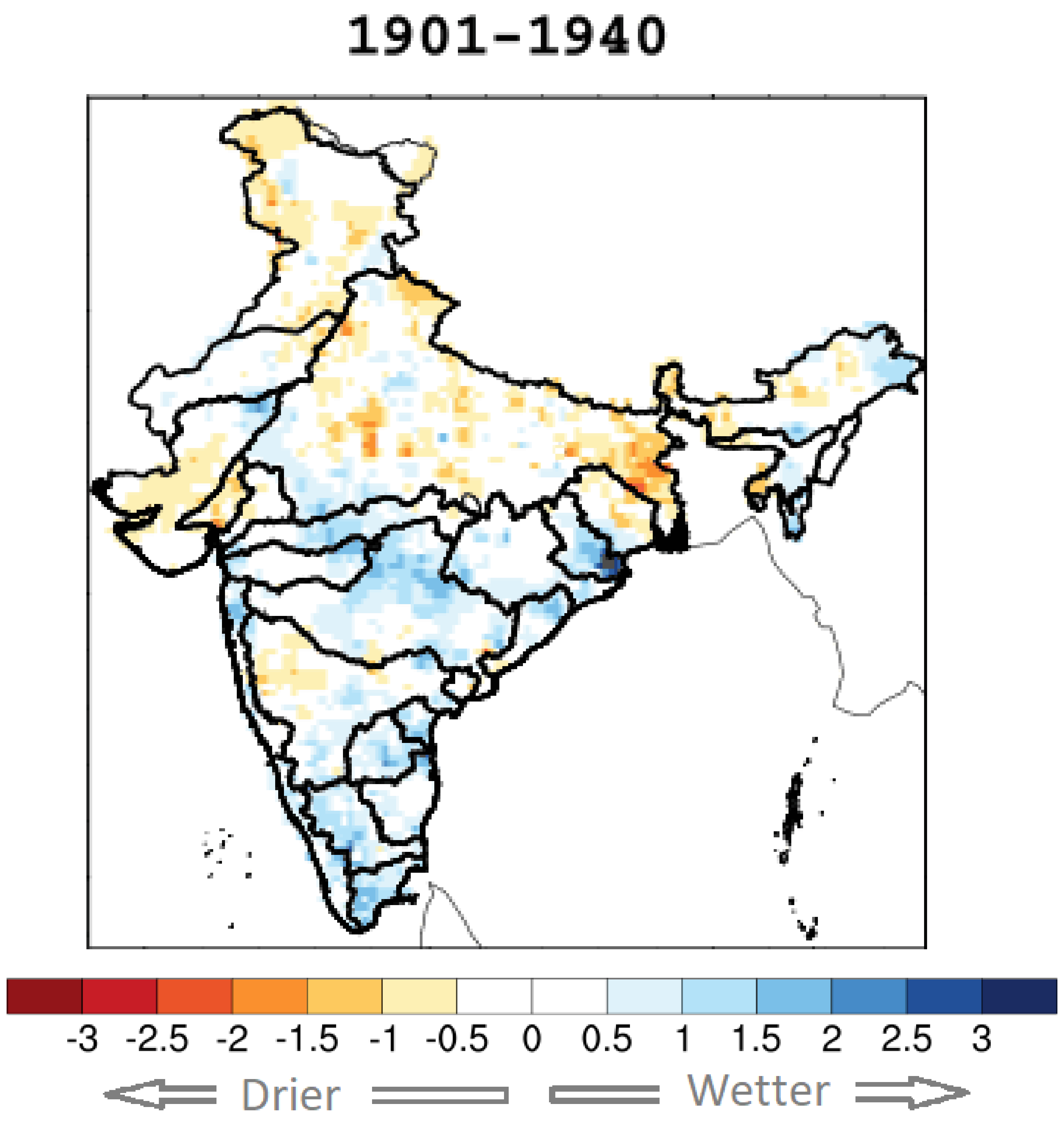


Fig. 13. The average intensity of standardized precipitation indices at a 40-year time spanning over the Indian river basins.

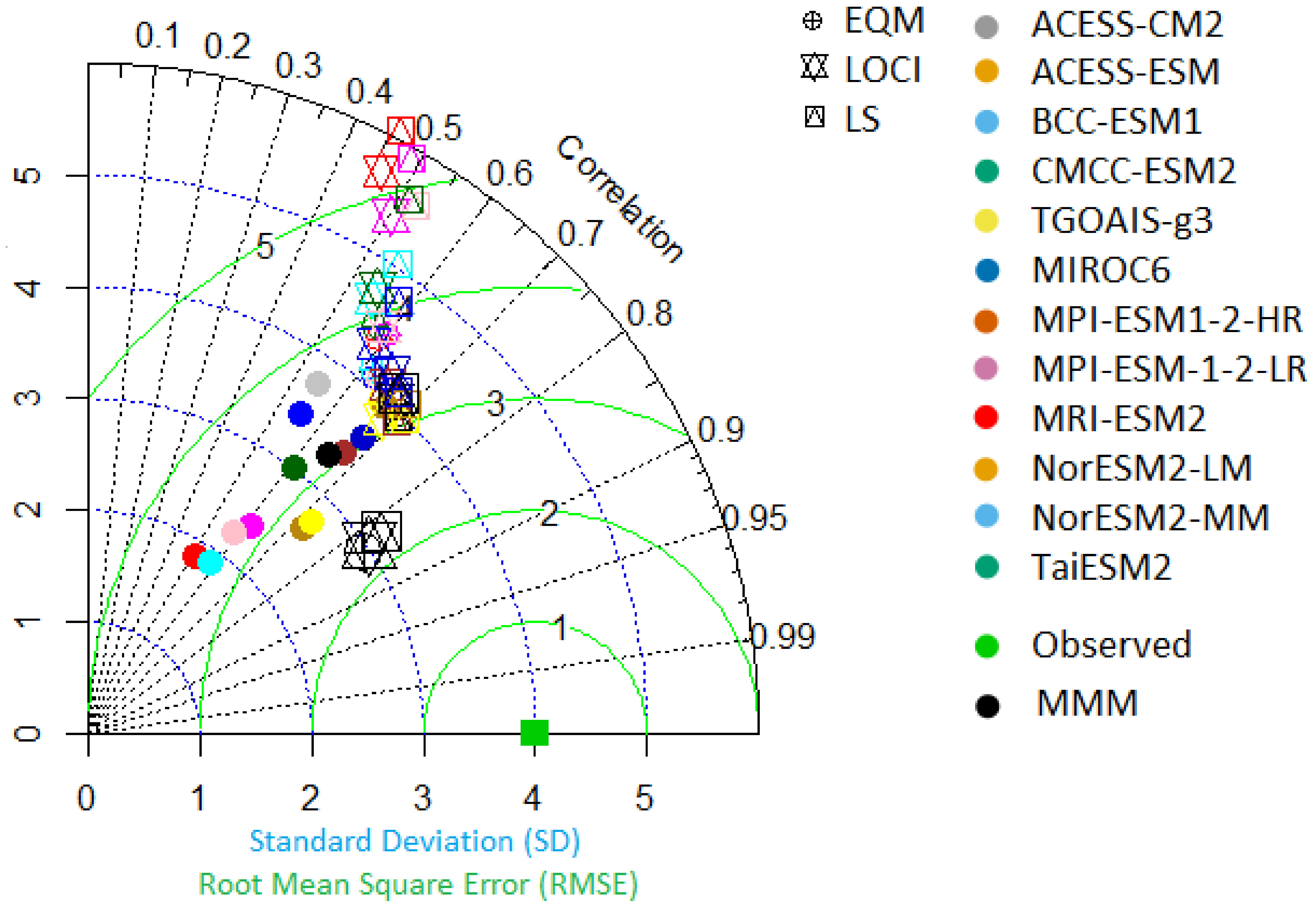


Fig. 14 Taylor diagram for displaying Normalized statistical pattern of projected simulation data of CMIP6 models with the observed IMD data during the period 1951 to 2014. The figure shows the angular axes show spatial correlations between modeled (CMIP6) and observed (IMD) fields; radial axes show spatial standard deviation (root-mean-square deviation), normalized against that of the observations.

- It has been estimated that the Multi-Model Mean (MMM), i.e., the mean of the best 12 models, has a good correlation (0.85) with the observed IMD datasets (Fig. 14).

- The majority of the uncorrected model rainfall data have correlation coefficients (CC) between 0.55 and 0.75.

- The Root Mean Square Error (RMSE) for raw model outputs is likewise aggregated around 3.0 to 3.5, but the Standard Deviation (SD) of various models has a more extended range from 2.0 to 3.5.

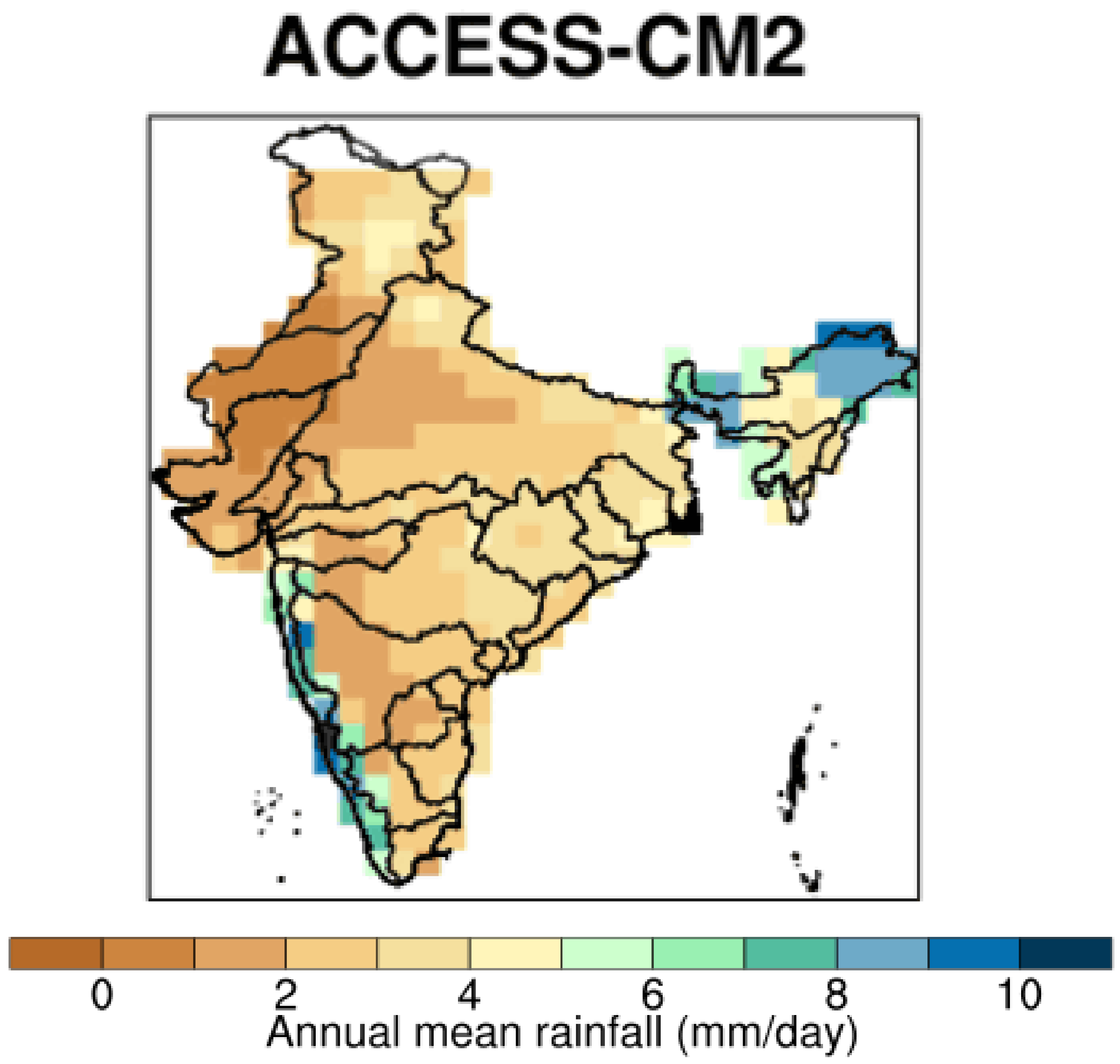


Fig. 15 Spatial pattern of Annual mean Precipitation of corrected climate models

- The uncorrected MMM has high uncertainty with the bias of -3 to 7 mm/day mean precipitation.

- After bias correction, we found that MMM over the has low uncertainty in precipitation with a bias of -0.3 to 0.9 mm/day.

- Uncorrected MMM was underestimated to some extent, with the IMD likely over the northeast river basins

- West-flowing river basins Tapti to and Tadri to Kanyakumari, have overestimated slightly with bias +5 to +7 mm/day.

- Thus MMM makes statistical analysis more feasible and suggests MMM as an optimistic approach to examining future extremes with less uncertainty.

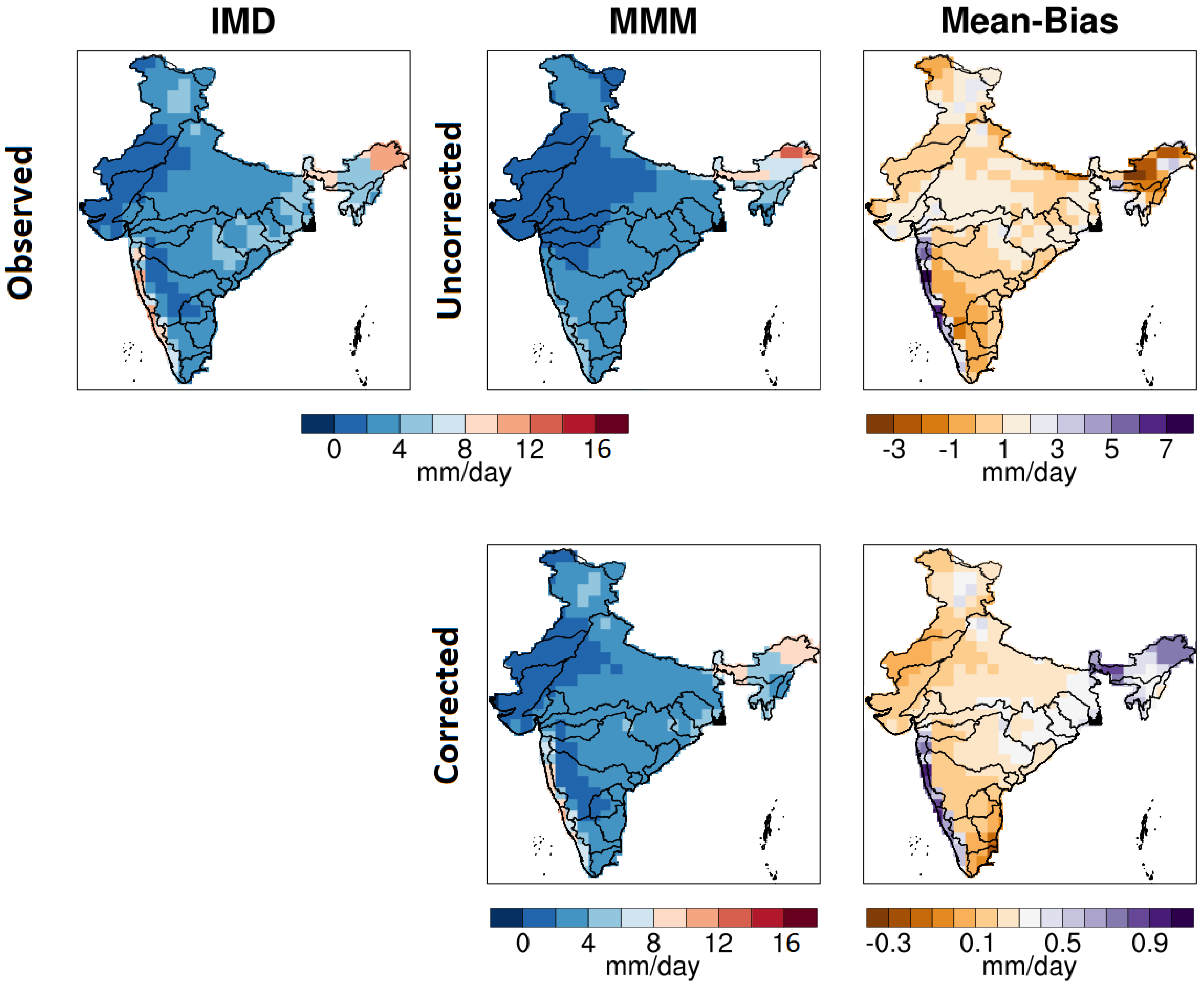


Fig. 16 Spatial pattern of observed rainfall from IMD and Multi-modal Mean (MMM) of simulated outputs CMIP6 and its mean bias for uncorrected and corrected CMIP6 datasets from 1951-2014.

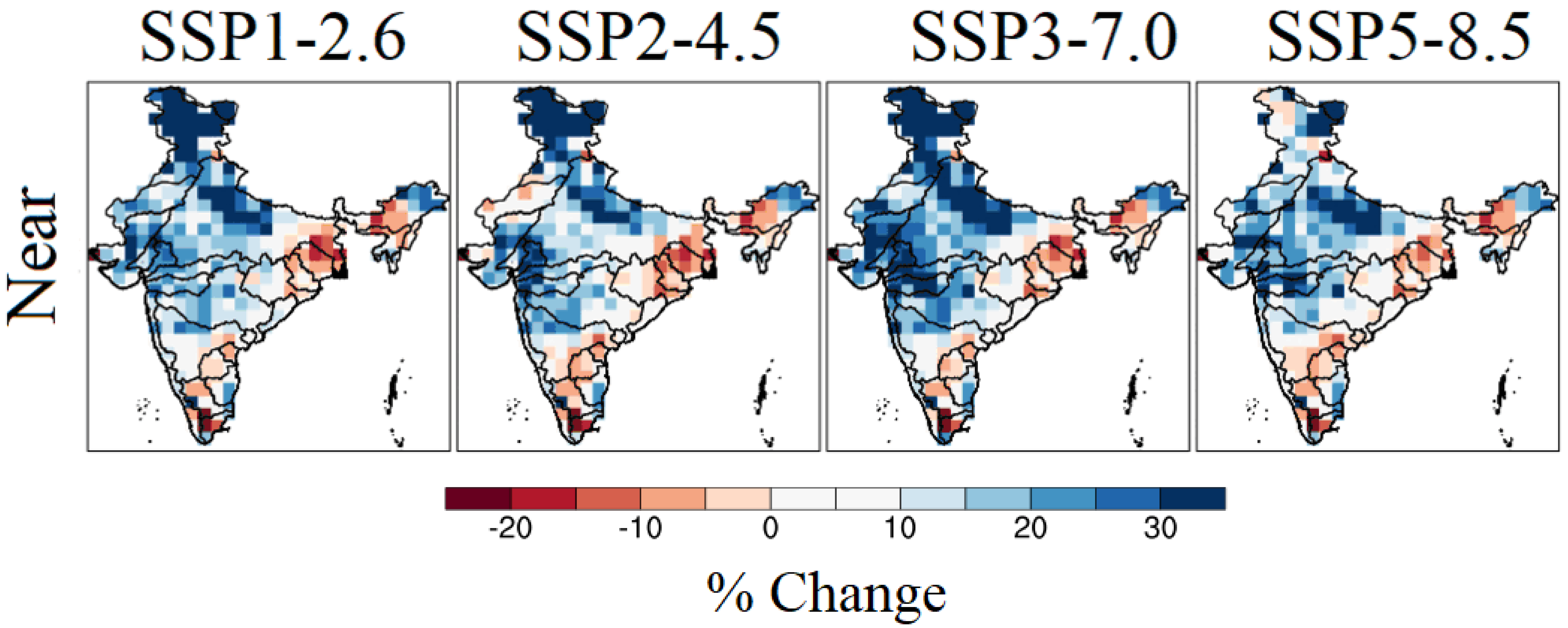


Fig. 17 Annual mean precipitation change (%) for Near- (2021-2040), Mid- (2041-2060), and Far-future (2081-2100) relative to 1995–2014.

- In the near future, the upper Ganga and Indus river basin found to be 10 to 30 mm/day change in precipitation (Fig. 17).
- The projected daily precipitation is highly concentrated over the western and central Indian river basins.

- The lower Ganga river basin is found to be a decrease in monthly mean precipitation of approximately 7 to 11 mm/day in the near future.
- However, in the September south-peninsular Indian river basins Cauvery, the East-flowing River (EFR) between Mahanadi and Kanyakumari projected mean precipitation from 4 to 9 mm/day (Fig. 18).

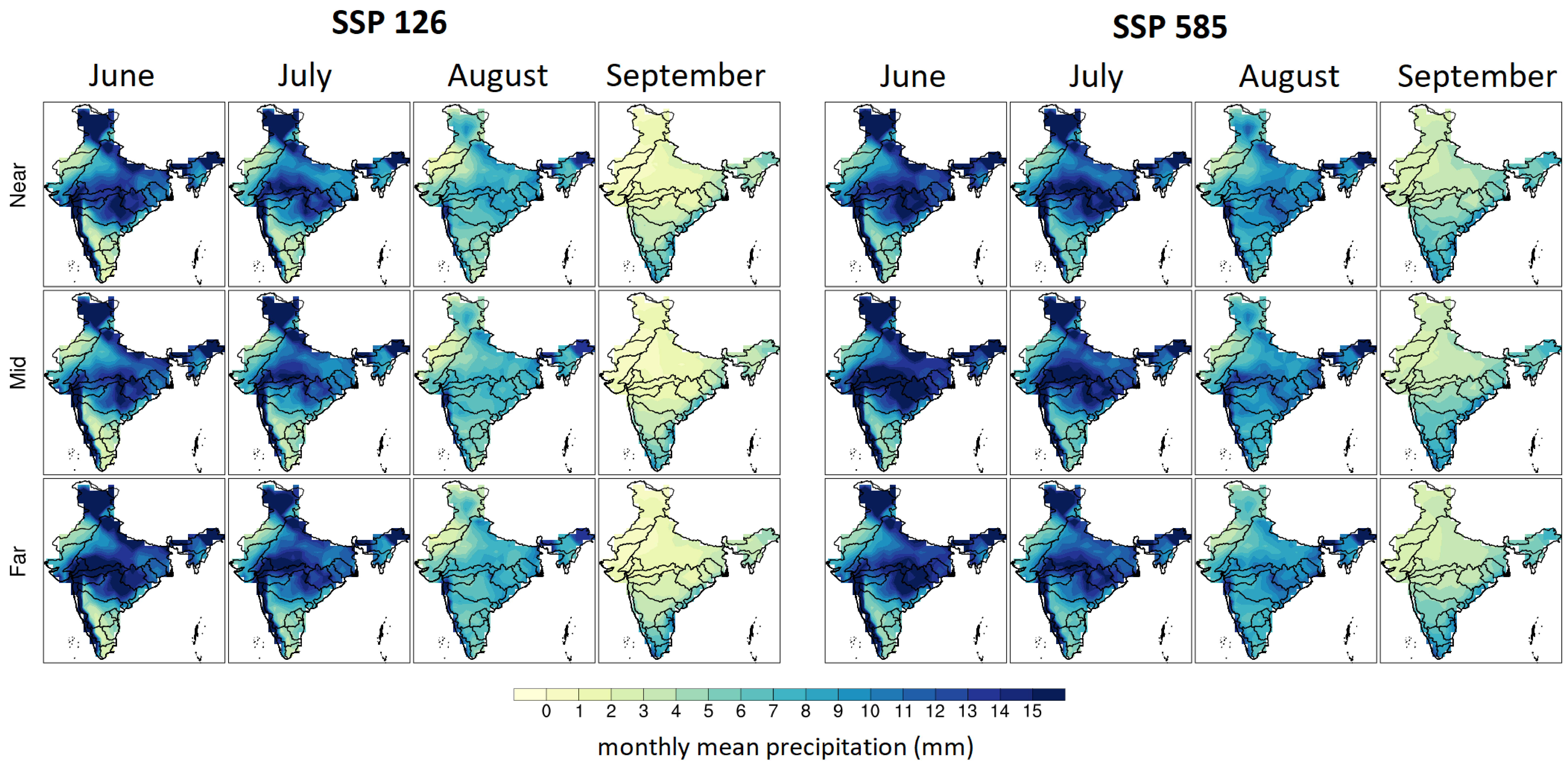


Fig. 18 Monthly mean precipitation climatology for monsoon season over the IRBs at low (SSP1-2.6) and high (SSP5-8.5) emission scenarios.

Intensity of Extremes Events

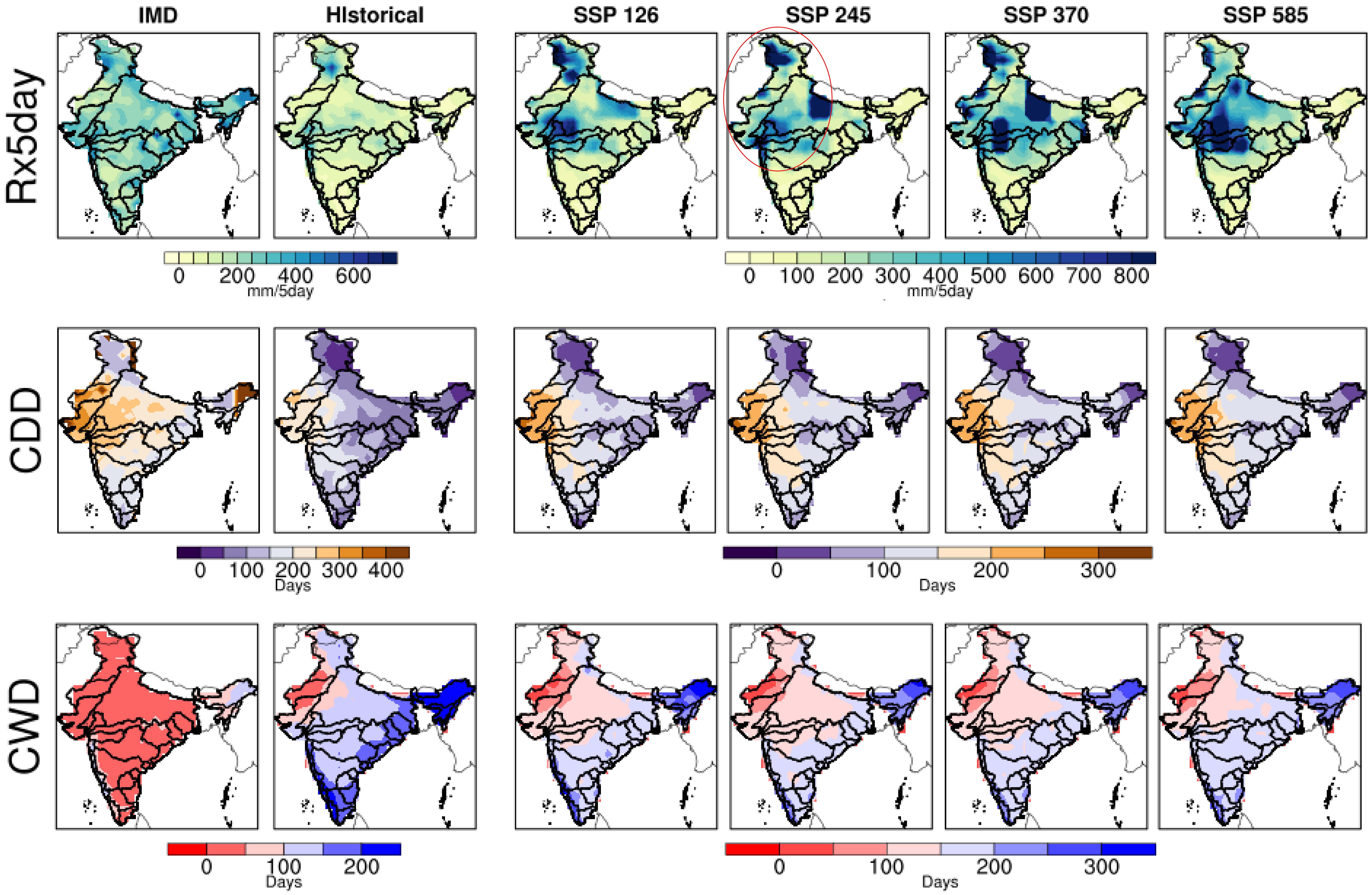


Fig. 19 Spatial changes in the intensity of extreme precipitation events from observed (1951-2021), historical (1951-2014), and projected (2021-2100) for all SSP scenarios.

- The intensity of 14 % was found to be increased under SSP2-4.5 over the upper Ganga and Indus river basins.
- The maximum intensity of dry days is found over the Inland drainage of Rajasthan, West-flowing river basin Tapti to Tadri.
- Moreover, the projected dry days increased by about 100 to 150 days/86 years. On the other hand, during the period 1951-2021, observed rainfall shows the intensity of wet days increases approximately 100 to 250 days/71 years over the Brahmaputra and Barak and Other, eastern and western ghats river basins, including Mahanadi, Brahmani, Subarnarekha over the IRBs.
- However, the projected wet days are increased in similar basins, including Northeast river basins, by approximately 150 to 350 days/86 years.

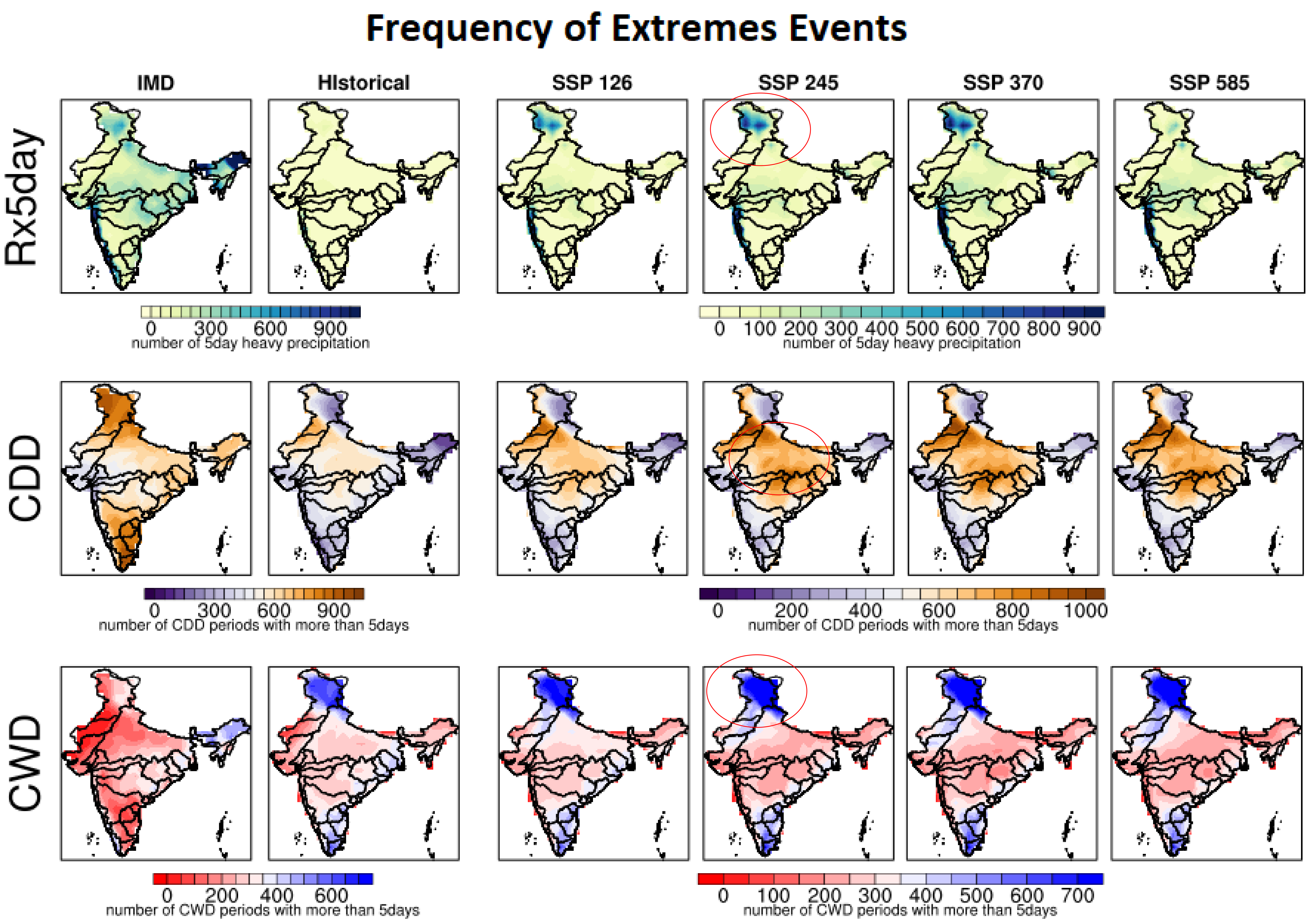


Fig. 20 Spatial changes in the frequency of extreme precipitation events from observed (1951-2021), historical (1951-2014), and projected (2021-2100) for all SSP scenarios.

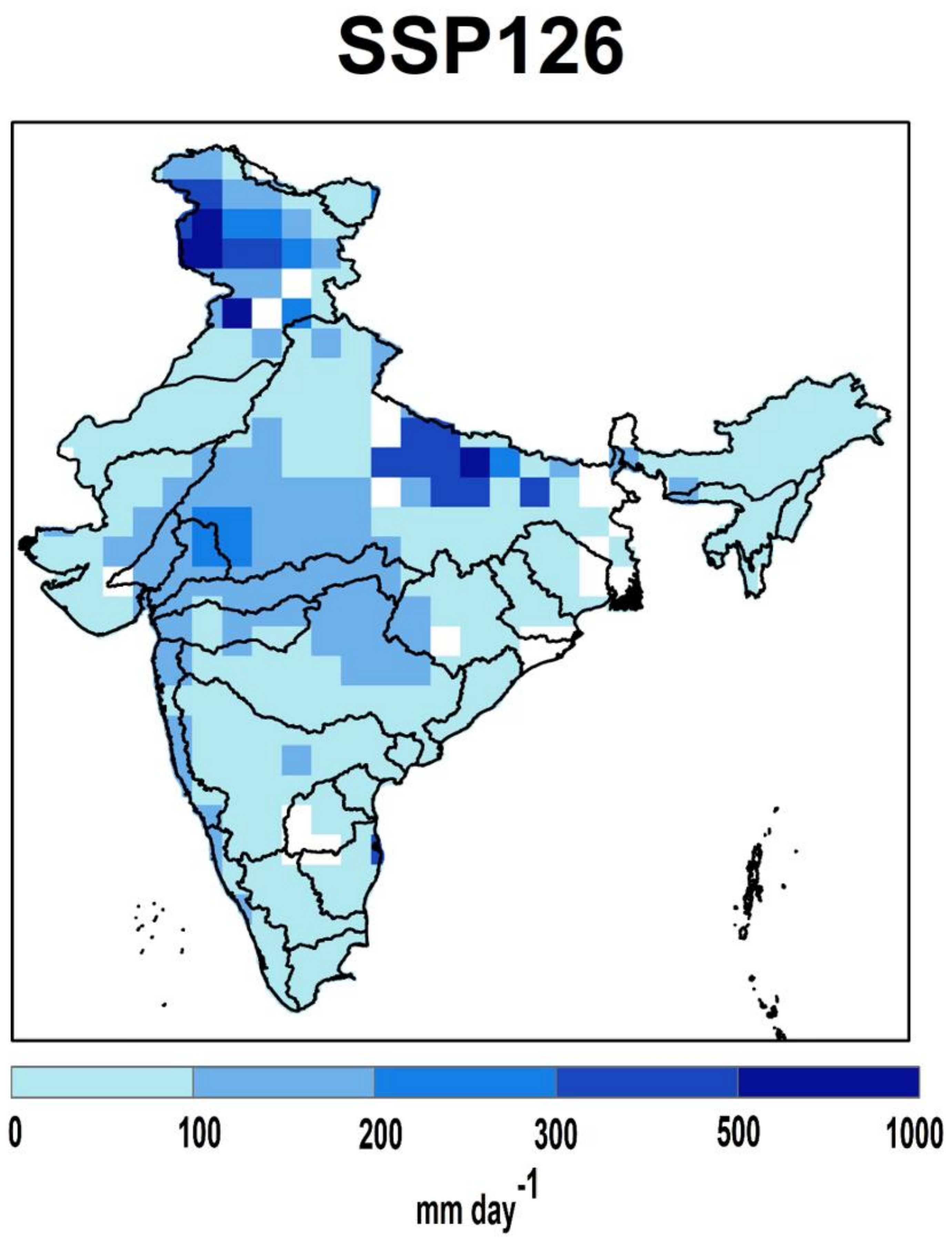
- And the frequency of 5-days heavy rainfall is mostly dominated over the Brahmaputra and west-flowing river basins from Tapti to Kanyakumari River basins from 1951-2014, with approximately 600 to 900 events.

- The projected maximum number of 5-days of heavy precipitation events is approximately 700 to 1000, mainly concentrated over the Indus and Western Ghats.

- The projected frequency of consecutive dry days (i.e., number of CDD more than 5-days) was found to increase (600 to 800 events) in the middle to lower Ganga basins, Mahanadi, lower Indus basin, Brahmani, and Subarnarekha.

- Projected frequency of consecutive wet days (i.e., number of CWD more than 5-days) resulted in approximately 350 to 700 days over the Upper Ganga basin, inland drainage of Rajasthan, Cauvery, and East flowing river basin Mahanadi to Kanyakumari.

Fig. 21 Spatial estimation of return level of precipitation extremes over the Indian river basins (IRBs) at 10-year return levels (10%, probability storms), using 2021–2100 projected SSP scenarios. The white color represents the unprocessed data sets.



- The IRBs show changes in wet to dry conditions, in which western river basins (Surplus, 0 ≤ SPI ≥ +2) while northern east river basins (Deficit, 0 ≤ SPI ≥ -1.5) in the last 71 years from 1951-2021 (Fig. 22).

- The precipitation extremes are found to be increased in the central Indian river basins, including the central Ganga basin, Narmada, Sabarmati, Mahi, and northwest part of the Godavari basin, with approximately 100 to 500 mm/day return level.

- The highest probability of precipitation extremes was found in the upper Ganga and Indus River basins at 500 to 1000 mm/day at 10-year return period.

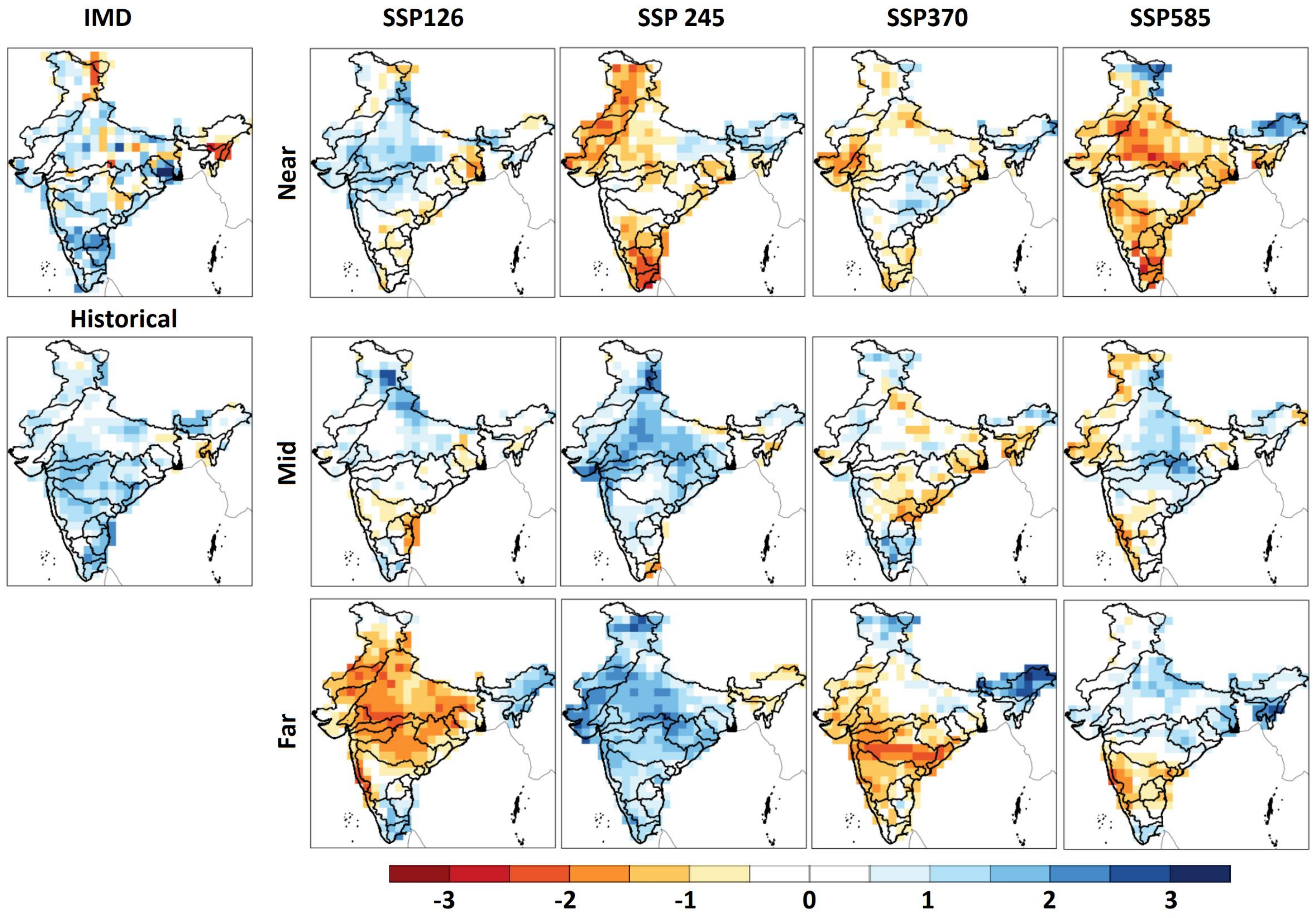


Fig. 22 Changes in average intensity of estimated wet to dry stage at a monthly time spanning over the Indian river basins.

Conclusions

- The extreme events (15%–58.74%) increased over the western ghats in the west-flowing river basins of IRBs in the last 119 years.

- A shift in extreme rainfall events over the western river basins of the central India homogeneous climate region.

- The Multi-model Mean suggests an optimistic approach to examining future extremes with less uncertainty.

- The CMIP6 projection indicates that extreme rainfall will continue to increase and intensify throughout the 21st century, with even greater magnitudes of change expected after the 2040s. As a result of this intensification, the western Ghats, Indus, and central Indian river basins are highly vulnerable to extreme rainfall events.

- In the near future, the June-July months of the monsoon season will see heavy rainfall with high intensity over the Indus, western, and central IRBs. Moreover, the peninsular IRBs will experience heavy rainfall leading to new hotspots for urban flooding in highly populated.

- The findings presented here support basin-wise climate adaptation and mitigation strategies, including water and emergency services policies to minimize risk due to hydroclimate extremes.

Earth's Future

RESEARCH ARTICLE
10.1029/2023EF003556

Special Section:
CMIP6: Trends, Interactions, Evaluation, and Impacts

Key Points:

- Extreme rainfall is projected to intensify in future but decrease in areal mean rainfall in near and far future
- Central and west Indian river basins will be more vulnerable
- The finding support flood and emergency policies to mitigate the extreme rainfall impacts

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:
Chaubey, P. K., & Mall, R. K. (2023). Intensification of extreme rainfall in Indian river basin: Using bias corrected CMIP6 climate data. *Earth's Future*, *11*, e2023EF003556. https://doi.org/10.1029/2023EF003556

Received 1 FEB 2023
Accepted 8 AUG 2023

Intensification of Extreme Rainfall in Indian River Basin: Using Bias Corrected CMIP6 Climate Data

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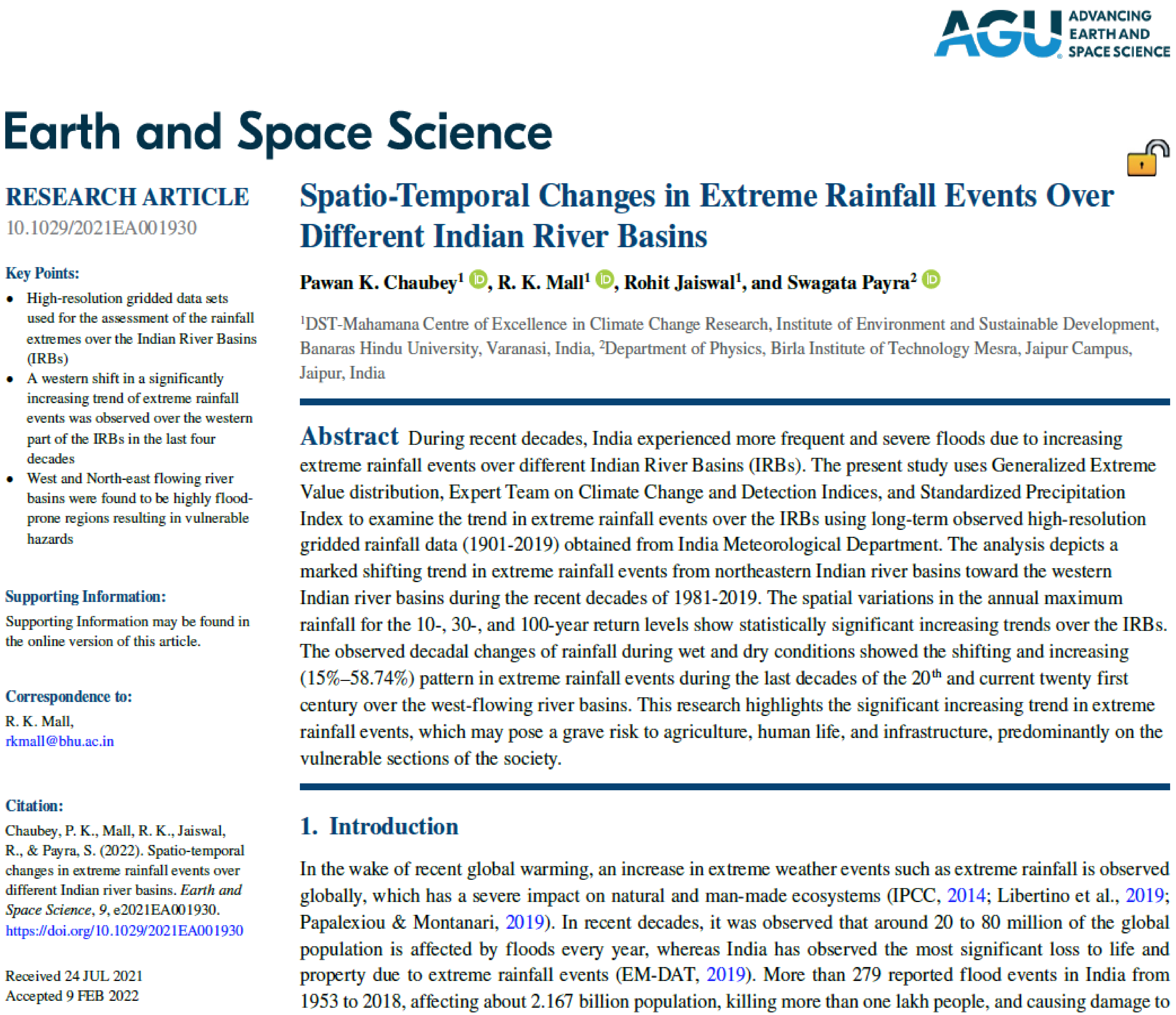
Abstract The changing frequency of extreme rain events in the past few dec
river basins (IRBs) contributed to floods and drought and resulted in economic l
product. In this study, we evaluated the performance of 12 Global Circulation M
Model Intercomparison Project Phase 6- experiment with India Meteorological I
sets to reproduce the extreme rainfall events as well as project the changes in fre
hydroclimate extremes in future. We found that under low emission scenarios (S
of extreme rainfall is going to increase over the western ghat and northeast IRBs
in heavy rainfall intensity (14.3%) noticed under SSP2-4.5 in the upper Ganga a
approximately 4%–10% of the heavy rainfall is projected to increase over the we
the Near (2021–2040) and Mid (2041–2060) future. The study explored the new
urban flooding due to increasing pattern of heavy rainfall in future. Moreover, th
experience agricultural drought in near future due to decreasing areal mean rain
policymakers for managing the excess (less) water. Also, India's northern, centra
experience more extremes under high-emission (SSP5-8.5) scenarios that indica
findings of this study highlight the importance of developing long-term adaptati
aimed at reducing hydroclimate vulnerability. It emphasizes the need to implem
resilience and minimize risks associated with hydroclimate extremes at the basi

Plain Language Summary Global warming increases the risk of hy
floods and droughts worldwide. The increasing rate of atmospheric heat increas
the leading cause of extreme events. The widespread variability in extreme even
natural systems. The study shows the changes in the extreme precipitation event
scenarios of the CMIP6 climate model. The uncertainty in the different climate
study by applying performance tests using linear and quantile bias correction ap

Chaubey & Mall (2023)

Chaubey et al. (2022)



Earth and Space Science

RESEARCH ARTICLE
10.1029/2021EA001930

Key Points:

- High-resolution gridded data sets used for the assessment of the rainfall extremes over the Indian River Basins (IRBs)
- A western shift in a significantly increasing trend of extreme rainfall events was observed over the western part of the IRBs in the last four decades
- West and North-east flowing river basins were found to be highly flood-prone regions resulting in vulnerable hazards

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:
Chaubey, P. K., Mall, R. K., Jaiswal, R., & Payra, S. (2022). Spatio-temporal changes in extreme rainfall events over different Indian river basins. *Earth and Space Science*, *9*, e2021EA001930. https://doi.org/10.1029/2021EA001930

Received 24 JUL 2021
Accepted 9 FEB 2022

Spatio-Temporal Changes in Extreme Rainfall Events Over Different Indian River Basins

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Abstract During recent decades, India experienced more frequent and severe floods due to increasing extreme rainfall events over different Indian River Basins (IRBs). The present study uses Generalized Extreme Value distribution, Expert Team on Climate Change and Detection Indices, and Standardized Precipitation Index to examine the trend in extreme rainfall events over the IRBs using long-term observed high-resolution gridded rainfall data (1901-2019) obtained from India Meteorological Department. The analysis depicts a marked shifting trend in extreme rainfall events from northeastern Indian river basins toward the western Indian river basins during the recent decades of 1981-2019. The spatial variations in the annual maximum rainfall for the 10-, 30-, and 100-year return levels show statistically significant increasing trends over the IRBs. The observed decadal changes of rainfall during wet and dry conditions showed the shifting and increasing (15%–58.74%) pattern in extreme rainfall events during the last decades of the 20th and current twenty first century over the west-flowing river basins. This research highlights the significant increasing trend in extreme rainfall events, which may pose a grave risk to agriculture, human life, and infrastructure, predominantly on the vulnerable sections of the society.

1. Introduction

In the wake of recent global warming, an increase in extreme weather events such as extreme rainfall is observed globally, which has a severe impact on natural and man-made ecosystems (IPCC, 2014; Libertino et al., 2019; Papalexiou & Montanari, 2019). In recent decades, it was observed that around 20 to 80 million of the global population is affected by floods every year, whereas India has observed the most significant loss to life and property due to extreme rainfall events (EM-DAT, 2019). More than 279 reported flood events in India from 1953 to 2018, affecting about 2.167 billion population, killing more than one lakh people, and causing damage to

Thank You

Suggestions are most welcome