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FULL-LENGTH RESEARCH ARTICLE

Variability of Monsoon Over Homogeneous Regions of India Using Regional Climate Model and Impact on Crop Production

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Abstract Any alteration in climatic parameter (such as rainfall) governs crop growth and has had a direct impact on quantity of food production. On the complex topographical terrain of Indian subcontinent this work represents the impact of seasonal monsoon rainfall variability on major food crop production over five homogeneous regions of India. The major *Rabi* crops, wheat (*Triticum aestivum*), sorghum (*Sorghum vulgare*), pulses and *kharif* crops rice (*Oryza sativa*), maize (*Zea mays*) and groundnut (*Arachis hypogea*), have a sharp dependency on Indian summer monsoon rainfall (ISMR) over the regions. Trend analysis in production of major food crops has been analyzed along with the dependency on seasonal monsoon rainfall of IMD as well as regional climate model version 4.3. Yearly crop production of *Rabi* and *kharif* has shown a clear decreasing trend with ISMR distribution. This study also shows the worse affected homogeneous regions in agriculture crop production due to rainfall variability. Along with rice–sorghum–maize, wheat and groundnut production is sharply affected by the decreasing trend of monsoon rainfall over the North Central India which is also known as Gangetic plain. The post-monsoonal crop production is also influenced by seasonal monsoon rainfall variability, and the fluctuation in monsoonal and post-monsoonal crop production is indicating alarming situation for food security and becoming the current issue to feed the huge population of India.

Keywords Seasonal rainfall variability · Climate change · Regional climate model · Agriculture · Crop production · Rice · Sorghum · Maize · Wheat · Groundnut

Introduction

India is a country of about 1.25 billion people where more than 70% of the population lives in rural areas with agriculture being their main livelihood. More than 60% of crop area still depends only on the seasonal monsoon rainfall [11]. Hence, food security is an important issue in respect of socioeconomic scenario which directly or indirectly linked to climate change. The alteration in the climatic parameters such as rainfall, temperature, humidity, cloud cover governs crop growth which has had a direct impact on the quantity of food production. Previous study shows that the variation in precipitation, changes in temperature and fertilization effect of CO_2 have a big role in damaging crop yields [1]. Therefore, this study is considered to establish a relationship between crop production and summer monsoon rainfall over various Indian zones. The variability of summer monsoon rainfall over India leads to large-scale drought and flood, resulting in major effect on Indian food grain production [34, 35], and Indian economy is badly affected with this variability [16]. During summer monsoon months of June to September (JJAS), India receives 70% of the total rainfall which has large impact on Indian agriculture [35]. Many scientists have studied the

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long-term variability of monsoon rainfall over the country and its subdivisions [36, 38], but no significant trend is observed for all-India southwest monsoon/annual rainfall [44, 49, 55]. Hence, the long-term variability has studied over small scale [24, 26, 31, 48] and the significant increasing trend is testified during monsoon rainfall over the west coast, north Andhra Pradesh and northwest India along with a significant decreasing trend over Madhya Pradesh and its adjoining area, northeast India and parts of Gujarat and Kerala [46].

Several studies have been conducted to simulate intraseasonal monsoon variability using regional climate model (RCM) [12, 13, 6, 17, 9, 10]. But still, a few of research is focused on agriculture production and its variation due to the monsoon variability in regional level using RCM. In the last few decades, RCMs have become advance to simulate climate over India significantly by demonstrating an advanced skill to predict/simulate India summer monsoon circulation and the association of precipitation over regions [5, 7, 12, 13, 43]. It also has been observed that the RCM has 20% better significant skill than the global circulation model [5]. Few studies show that long-term climate simulation with mixed convection scheme performs better to simulate the summer monsoon characteristics using International Center for Theoretical Physics' (ICTP's) regional climate model (RegCM) [42, 12, 6, 17]. By using version of RegCM, authors have tried to simulate long-term variation of different phases of Indian summer monsoon rainfall (ISMR) with high-resolution dataset [7, 6, 17, 9, 10].

Rainfall and its distribution over different parts of the country have a strong impact on agricultural production [4]. India is a large country with diverse climate and divided into different climatic regions, and the major amount of rainfall is received during southwest summer monsoon which lasts for several months from June to September (JJAS). Monsoon rainfall is mainly influenced by the global and local phenomenon like El Nino, northern hemisphere temperature, sea surface temperatures and snow cover [7, 8]. The year-to-year variation of rainfall and its distribution over different parts of the country have a strong impact on agriculture production. The crops which are more rain-dependent would suffer from the late or early onset of monsoon and from interannual variability of southwest monsoon rainfall [45]. On the basis of cropping seasons, major food crops of India are rice, wheat, maize, pulses, sugarcane and groundnut. *Kharif* crops, mainly rice and maize, are summer crop or monsoon crop. The *Rabi* crop is either winter crop or the spring harvest crop which includes wheat. These crops sow after the summer monsoon and harvest up to the spring or early summer months [27]. Climate changes have been documented for affecting crop growth and development, agricultural water resource and production in broad regions over the world in the last few decades [23, 28, 32, 39, 50, 52, 54]. The crop–climate relationship over Indian subcontinent has been studied by using regional statistics [27], long-term fertility and other conventional field experiments which have explained the historical trends in yields of rice and wheat using crop simulation models [2]. The climate change is also studied by using various climate models over Indian region to find out the impact of increasing temperature and changing patterns of rainfall during the twenty-first century [41, 47]. This ongoing climate change is projected to know the dramatical changes in productivity of essential crops in a wide region over the world although big uncertainties remain in variation in the temporal/spatial pattern of rainfall and its direct impact over the crop and consequently water stress on crop development [23, 33, 50, 51]. Therefore, the foremost objective of this article is to establish a relationship between summer monsoon variability and shifts of crop production over India for long-range prediction. The main focus of the present study is the simulation of ISMR with RegCM-4.3 over five homogeneous regions of India; study on climate change and the variability of ISMR; and the impact of climate change on major agriculture crops over five homogenous regions of India and its variation with seasonal monsoon variation.

Data and Experimental Design

In order to simulate/predict summer monsoon variability and climate change and their impact on crop production, Indian subcontinent with five homogeneous regions is considered. These five homogeneous regions are North West India (NWI), North Central India (NCI), West Peninsular India (WPI), Eastern Peninsular India (EPI) and Southern Peninsular India (SPI) classified over India for regional rainfall studies [48] as shown in Fig. 1.

Description of Data

Observed and Model Data

For the study of rainfall distribution and variability, 25-year daily gridded rainfall data are considered for the period 1986–2010. The high-resolution observed rainfall data with the resolution of $0.25° \times 0.25°$ and reanalyzed wind data with the resolution of $1.5° \times 1.5°$ are obtained from India Meteorological Department (IMD) and European Centre for Medium-Range Weather Forecasts (ECMWF), respectively. High-resolution ($0.5° \times 0.5°$) RegCM-4.3 released by ICTP is considered for simulation purpose [21]. With different convection schemes, RegCM-4.3 has the ability to simulate in combinations of two

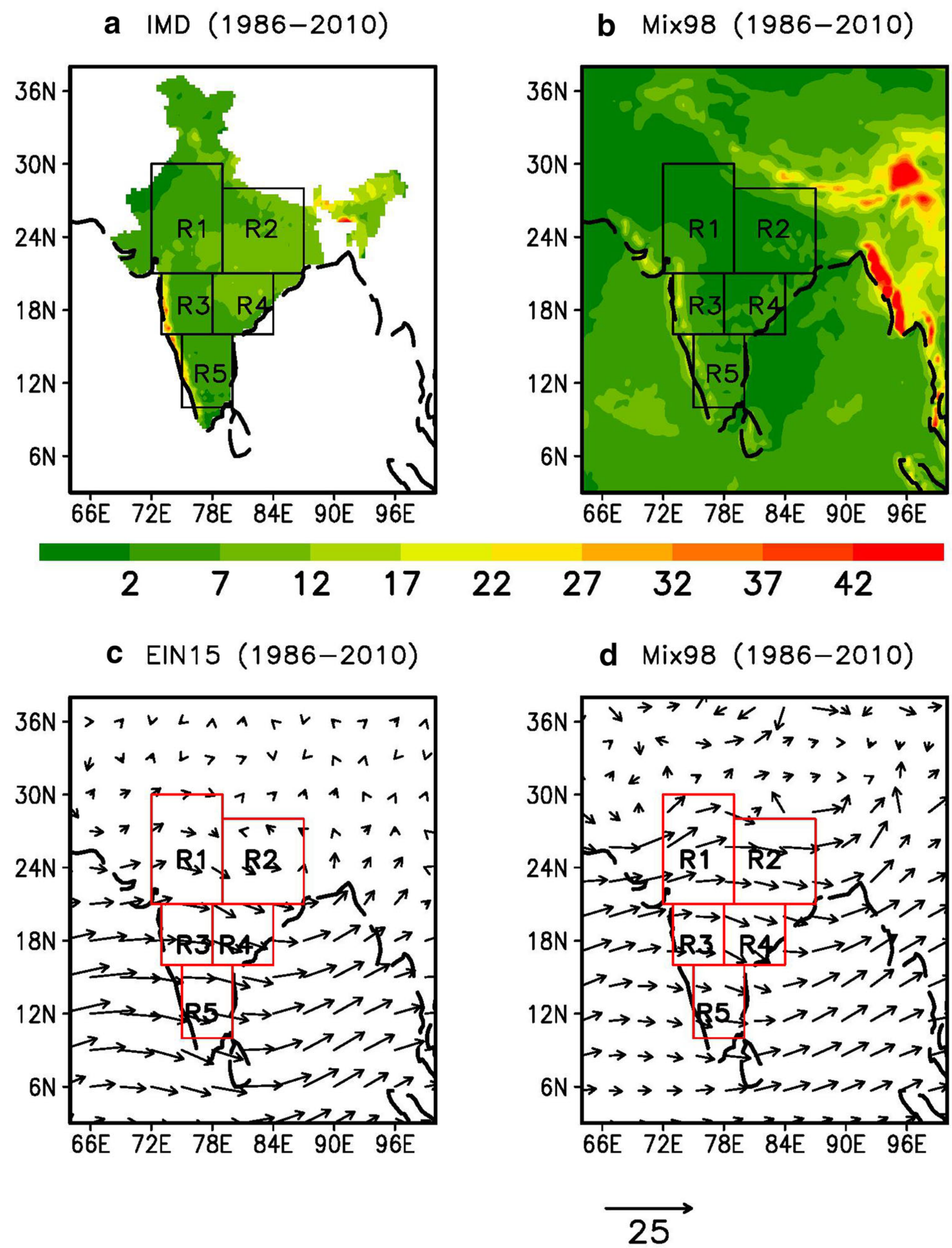


Fig. 1 Observed/reanalyzed and RegCM-4.3 simulated spatial distribution of seasonal (JJAS) rainfall and wind at 850 hPa over homogeneous regions during 1986–2010

convection schemes over land and ocean, called mixed convection schemes. The initial conditions and lateral boundary forcing for the mixed scheme (Mix98) simulations are downscaled from 6 hourly fields of ECMWF ERA Interim (EIN15) datasets, available with a horizontal grid of 1.5° latitude/longitude and 37 vertical levels. The detailed description of model hydrostatic is listed in Table 1. For the foremost study, one mixed scheme (Mix98) is chosen which is a combination of Grell (used over ocean) [22] and Emanuel (used over land) [14, 15]. The detailed description of the different PCSs can be found in [7, 42].

Crop Data

The study uses station-wise crop data (area, production and yield) available from 1986–1987 to 2009–2010 for individual crops: rice (*Oryza sativa*), wheat (*Triticum aestivum*), sorghum (*Sorghum vulgare*), maize (*Zea mays*), pulses and groundnuts (*Arachis hypogea*) over different stations of India. This yearly agriculture data have been obtained from Village Dynamics in SouthAsia International Crops Research Institute in Semi-Arid Tropics (VDSA-ICRISAT-IN). These data also provide the information of shifting in cropping patterns, gains in productivity and regional diversity. In total, 230 agriculture

Table 1 Model configuration of RegCM-4.3 *Source*: Bhatla et al. [7]

Dynamics	Hydrostatics
Model domain	South Asia CORDEX domain (22°S–50°N; 10°E–130°E)
Resolution	50 km horizontal and 18 sigma vertical levels
Initial and boundary conditions	ERA15
SST	OI WK–OISST weekly optimal interpolation dataset
Land surface parameterization	Modified CCM3
Radiation	
Parameterization PBL	Modified Holtslag
Convective parameterization	Mix98 (Emanuel over land and Grell over ocean)

stations all over India are considered for this current study. Among them 61 stations come under NWI, 71 stations are in NCI, 29 stations are in WPI, 21 stations are in EPI, and 48 stations are in SPI zone. The agriculture crop production stations coming in different homogeneous regions are mentioned in Table 2.

Experimental Design

To findout the dependency of crop production on monsoon rainfall the spatial and temporal variability of ISMR in different time epoch (JJAS) are considered. Monthly and yearly correlation analysis of model data is computed with observed data of IMD over five homogeneous regions

Table 2 Domain and stations considered for different homogeneous regions

Region	Homogeneous region	Domain	Crop production stations
R1	NWI	LON 72°–79° LAT 21°–30°	Ajmer, Alwar, Banswara, Bharatpur, Bhilwara, Bikaner, Bundi, Chittorgarh, Churu, Dungarpur, Jaipur, Jaisalmer, Jalore, Jhalwara, Jhunjhunu, Jodhpur, Kota, Pali, Sawai Modhpur, Sikar, Sirohi, Tonk, Udaipur, Saharanpur, Chhindwara, Narsinghpur, Seoni, Sagar, Tikamgarh, Gwalior, Shivpuri, Guna, Datia, Morena, Bhind, Indore, Ratlam, Ujjain, Mandsaur, Dewas, Dhar, Jhabua, W. Nimar, E. Nimar, Sehore, Raisen, Vidisha, Betul, Rajgarh, Shajapur, Hoshangabad, Ahmedabad, Baroda, Bhavnagar, Bulsar, Kaira, Kheda, Mehsana, Surat, Vadodara, Valsad
R2	NCI	LON 79°–87° LAT 21°–28°	Durg, Bilaspur, Raigarh, Hazaribagh, Ranchi, Santhal pargana, Dumka, Palamau, Singhbhum, Nagpur, Allahabad, Azamgarh, Bahraich, Ballia, Banda, Barabanki, Basti, Bhagalpur, Chamoli, Champaran, Darbhanga, Dehradun, Deoria, Dhanbad, Etah, Etawah, Faizabad, Farrukhabad, Fatehpur, Garhwal, Gaya, Ghazipur, Gonda, Gorakhpur, Hamirpur, Hardoi, Hazaribagh, Jalaun, Jaunpur, Kanpur, Lucknow, Mainpuri, Mirzapur, Mungair, Muzzafarpur, Nainital, Patna, Pauri Garhwal, Pithoragarh, Pratapgarh, Rai Bareilly, Saharsa, Saran, Shahabad, Sitapur, Sultanpur, Tehri Garhwal, Unnao, Uttarkashi, Varanasi
R3	WPI	LON 73°–78° LAT 16°–21°	Ahmednagar, Akola, Amaravti, Aurangabad, Beed, Buldhana, Dhule, Dhulia, Kolhapur, Nanded, Nasik, Osmanabad, Parbhani, Pune, Raigarh, Kolaba, Ratnagiri, Sangali, Satara, Solapur, Thane, Yeotmal, Ananatpur, Mahbubnagar, Bidar, Gulbarga, Raichur, Bijapur, Valsad
R4	EPI	LON 78°–84° LAT 16°–21°	Wardha, Yavatmal, Bhandara, Chandrapur, Adilabad, East Godavari, Guntur, Hyderabad, Karimanagar, Khammam, Krishna, Medak, Nalgonda, Nizamabad, Visakhapatnam, Warangal, Bastar, Bolangir, Koraput, Mayurbhanj, Sambalpur
R5	SPI	LON 75°–80° LAT 10°–16°	Alappuzha, Bangalore, Belgam, Bellary, Chennai, Anna, Chengalpattu, Chickmagalur, Chitradurga, Chittor, Coimbatore, Cuddalore/South Arcol, Cuddapah, Dakshin Kannada, Dharwad, Ernakulum, Hassan, Kadapa, Kanyakumari, Kadaga, Kolar, Kollam, Kottayam, Kozhikode, Kurnool, Madurai, Malapupuram, Mandya, Mysore, Nellore, North Arcot, Palakkad, Ramanathpuram, Salem, Shimoga, Srikakulam, Tanjavur, The Nilgiris, Tiruchirappalli, Thiruvananthpuram, Thrissur, Vellore/North Arcot, West Godavari, Tirunelveli, Tumkar, Uttara Kannada

NWI North West India, *NCI* North Central India, *WPI* West Peninsular India, *EPI* East Peninsular India, *SPI* South Peninsular India individually. The EIN15-derived downscaled rainfall is being signified with the IMD dataset by measuring the statistical score: correlation coefficient (CC) with 1%, 2%, 5%, 10% and 20% significant level, standard deviation (SD), root-mean-square error (RMSE), empirical cumulative distribution function (ECDF) and box plot are taken into account for performance measurement. To analyze the observed and model simulated monsoon variability and its changing pattern, the long-term monthly and accumulated (JJAS) rainfall anomalies are computed in respect of IMD rainfall. These anomalies are considered in respect of time, and the trends are examined by fitting a linear regression line over the respected time series. The linear trend represents the slope of least square regression line which depicts the increasing and decreasing trend of the rainfall by using Mann–Kendall statistical test [25, 30]. It is a nonparametric test used to identify trend in time series data which compares the relative magnitudes of the respective data series [20]. Here, $(x_1, x_2, \ldots, x_n)$ represent n data points where x_j represents the data point at time j. Then, the Mann–Kendall statics (S) is given by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sign}(x_j - x_k)$$

where

$$\operatorname{sign}\left(x_j - x_k\right) = \begin{cases} +1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases}$$

Values of S are the indicator of trend, i.e., very high positive value of S indicates the increasing trend and very low negative value of S indicates the decreasing trend. The probability associated with S and n computes the statistical quantification of significance of the trend. Here the significance level alpha (α) is considered in 5% level.

For variability on crop production, some statistics such as empirical cumulative distribution function (ECDF), box plot, correlation coefficient (CC) and Student's t test are applied between agricultural production and summer monsoon rainfall over five homogeneous regions. Crop yield percentage is also computed for every respective year to investigate trend of production changes in yearly basis. The crop production (P) is calculated using:

$$P = \frac{1}{n} \sum [y_1 + y_2 + \cdots + y_n] \times \sum [a_1 + a_2 + \cdots + a_n]$$

where y is the average yield on a particular agriculture station and a is the area of respective agriculture station, i.e., crop production is the product of average yield per unit area and cultivated area.

Results and Discussion

Rainfall Distribution Over India and Its Homogeneous Region

The impact study of summer monsoon variability over crop production is considered using the composite observed/reanalyzed and model simulated rainfall and wind distribution during the seasonal climatology of Indian summer monsoon (JJAS) for 25-year time duration (1986–2010). In spatial pattern, the rectangle boxes are representing the different homogeneous regions, i.e., (R1–R5) over the Indian subcontinent (Fig. 1). The model simulated Mix98 rainfall and wind distribution for the monsoon season have been analyzed and have been compared with the observed/reanalyzed datasets. It has been observed that the following convection scheme follows the observed pattern of rainfall. Figure 1a–d represents the spatial pattern of observed/reanalyzed and model simulated seasonal (JJAS) rainfall and wind distribution during summer monsoon over India and its subdivisions. During the season, IMD rainfall distribution (Fig. 1a) over most of the region of R1 is indicating 2–7 mm of rainfall/day and some parts of south-east region of R1 are indicating up to 12 mm of rainfall/day. Except for the hilly regions, the northwest part of R2 region is representing the rainfall amount of 7 mm/day and all the remaining area is accounting for the rainfall up to 12 mm/day. R4 region indicates the lack of rainfall at the lower part, and the regions of R3 and R5 are enjoying heavy amount of rainfall. Model simulated Mix98 rainfall (Fig. 1b) is following the pattern with overestimating over the regions. The westerly wind circulation pattern in EIN15 (Fig. 1c) is in good agreement with Mix98 (Fig. 1d). This is the regular circulation pattern of seasonal rainfall distribution over the regions, and these features are well simulated by Mix98 convection scheme. Table 3 represents the Mann–Kendall statistics in which a sharp negative slope is represented over R2 region by IMD rainfall distribution although the Mix98 scheme is simulating positive over the region. It is also observed that in R1 and R2 regions, IMD rainfall is indicating decreasing trend at 5% significant level and no trend is found in observed rainfall in R3 and R4 regions. Model simulated Mix98 region is depicted a decreasing trend at 5% significant level over R3 region. Over R5 region, a negative slope in summer monsoon rainfall is observed in IMD as well as Mix98 rainfall with the higher (5%) significant level. The above analysis of seasonal rainfall variability of ISMR is shouting the decreasing trend during 25-year climatology period. Thereafter, it also has been tried to analyze the monthly variability for the considered period over the different homogeneous regions.

Table 3 Mann–Kendall trend analysis with 5% significant level during monthly and seasonal monsoon rainfall climatology over Indian homogeneous regions

Monsoon season and epoch										
	JJAS		June		July		August		September	
	IMD	Mix98	IMD	Mix98	IMD	Mix98	IMD	Mix98	IMD	Mix98
R1	D				D		D	D		
R2	D		D		D	D	D		D	D
R3		D	D	D		D		D		D
R4			D	D	D	D	D			
R5	D	D	D	D	D	D				

D decreasing trend

The temporal distributions of 25 years monthly accumulated IMD and model simulated rainfall over different homogeneous regions are considered in Fig. 2a–t. Time series analyses are considered for understanding the monthly rainfall variability and its changing pattern during the months of summer monsoon. Therefore, anomalies of monthly rainfall climatology for the monsoon month of June, July, August and September are considered for IMD as well as model simulated Mix98 scheme. Mann–Kendall trend test at 5% statistical significant level is applied to measure the presence of trend and is placed in Table 3. Figure 2a–e represents the monthly rainfall variability over five homogeneous regions for the month of June in which Fig. 2a shows the rainfall distribution over region R1 with the positive slope in IMD as well as in Mix98 rainfall. Except Mix98 model simulated rainfall distribution over the R2 region (Fig. 2b), all the remaining regions (Fig. 2b–e) are representing negative slopes in IMD as well as model simulated rainfall distribution during June. The Mann–Kendall trend is also indicating a negative trend in IMD rainfall over the R2 region at 5% significant level (Table 3). With the large deviation in IMD rainfall, model simulation has a peak during the month of June. Figure 2c illustrates rainfall slope over R3 in which IMD shows a slide negative slope and Mix98 shows sharp negative fall in rainfall distribution. A noticeable negative slope is also found in IMD and Mix98 rainfall trend over the R4 and R5 regions (Fig. 2d, e). Figure 2f–j shows the rainfall distributions for the month of July over regions R1 to R5, respectively. In this representation, IMD rainfall is indicating negative slopes for all regions (Fig. 2f, g, i, j) except R3 (Fig. 2h). Among Fig. 2f–j, IMD rainfall over regions R2 (Fig. 2g) and R4 (Fig. 2i) region and Mix98 simulated rainfall over R5 (Fig. 2j) region are indicating a sharp negative slope. At the same time another negative trend is indicating over the R2, R4 and R5 regions for IMD and Mix98 rainfall at 5% significant level. Along with it the negative trends are also observed over R1 and R3 regions in IMD and Mix98 simulation, respectively (Table 3). For the month of August, the rainfall distributions are considered in Fig. 2k–o. During this month, the strong negative slope is observed in IMD rainfall over the R1 (Fig. 2k), R2 (Fig. 2l) and R4 (Fig. 2n) homogeneous regions along with a negative slope in Mix98 rainfall distribution over R1 (Fig. 2k) and R3 (Fig. 2m) regions. Over the regions R1 and R2, Mix98 is performed well and the negative slopes are altered into the decreasing trend over the same regions at 5% significant levels (Table 3). The variability of summer monsoon for the month of September is considered in Fig. 2p–t. IMD rainfall during this month is depicting the negative slope along with the decreasing trend at 5% significant level over the R2 region (Table 3). It is also noticed that the withdrawal month (September) does not show much negative slope over the Indian regions except R2 region which represents the NCI region basically known as Gangetic plain.

The performance of Mix98 schemes has also been measured with the statistical score correlation coefficient (CC), root-mean-square error (RMSE) and standard deviation (SD) (Table 4). These scores are calculated with 25-year mean rainfall and have been compared with IMD observed. For a significant analysis, Student's t test is applied at the significance of 1–20% level in respect of CC. In all cases, the RMSE and the SD are shown as the closeness with IMD. Hence, during the monsoon month of June, the CC over the regions R1, R3 and R4 is indicating the magnitude of 0.6, 0.6 and 0.55, respectively, at 1% significance level. The R5 region is indicating the CC 0.33 at 10% significant interval for the considered month. The CC for R1 (0.51), R2 (0.42) and R4 (0.63) for the month of July is signified at 1, 2 and 1% significant level, respectively. During the month of August, CC 0.31, 0.24 and 0.5 represent the regions R1, R2 and R3 at 10%, 20% and 1% statistical significance, respectively. The month of

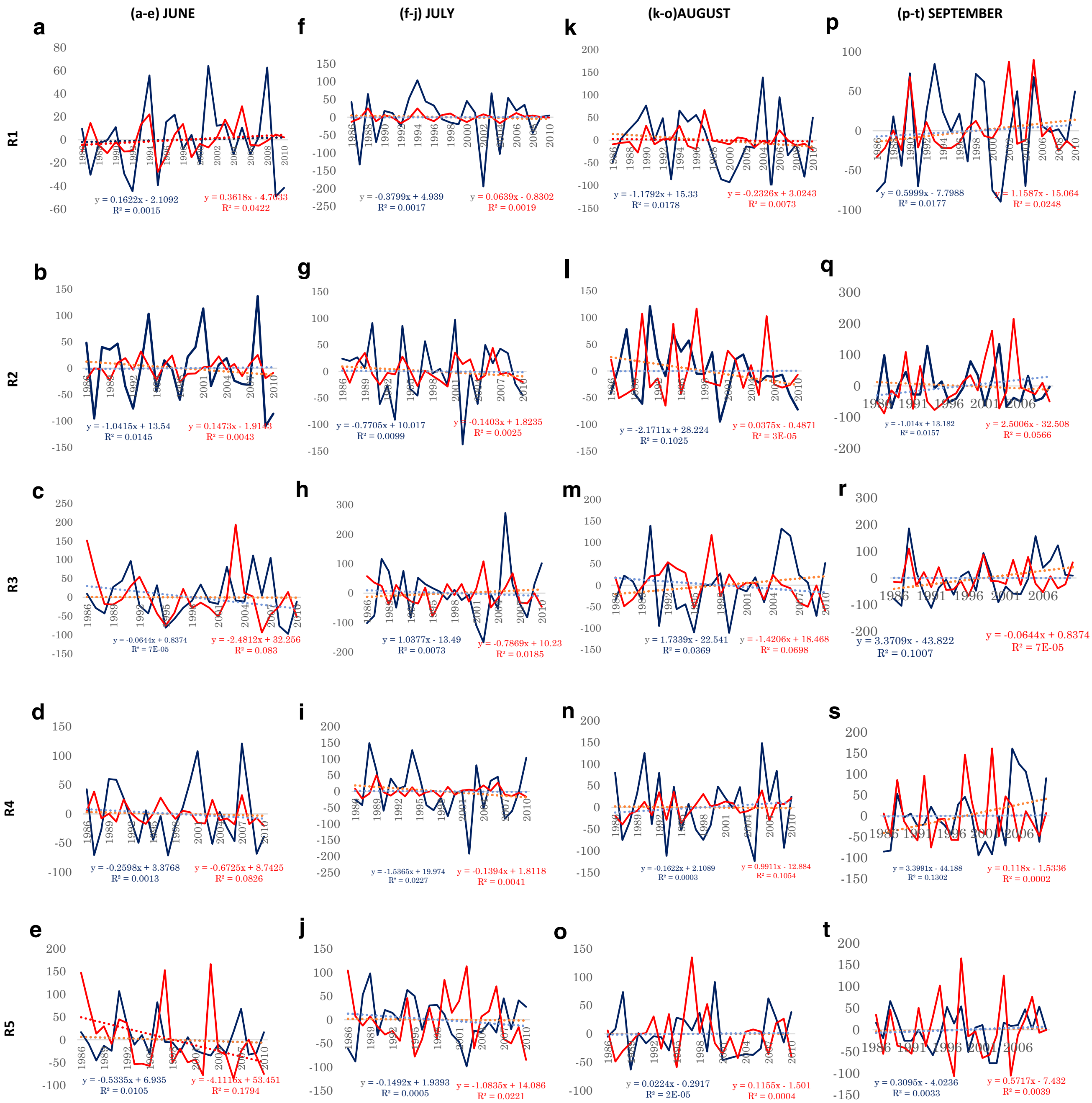


Fig. 2 Temporal distribution of IMD and RegCM-4.3 simulated rainfall distribution for the monthly climatology (June, July, August and September) during 1986–2010 over five homogeneous regions of India

September is basically known as withdrawal month of Indian summer monsoon, and the rainfall withdrawal starts from the Rajasthan (comes in the region R1) and completely withdraws itself up to the end of this month. Therefore, in the month of September, the monsoon rainfall found to become weaker which are perfectly captured by Mix98 schemes. During long-term duration Mix98 is performing with a high CC of 0.8, 0.7 and 0.62 over the regions of R1, R2 and R5, respectively, at 1% significant levels. The regions R3 and R4 are having CC of the magnitude 0.4 and 0.31 CC at 5% and 10% significant level, respectively.

Here, it has been tried to emphasis the negative trend for monthly and seasonal climatology because more than 60% significant trends are strongly negative over 25-year time periods. The frequent lack rainfall condition causes drought over the country and its subdivisions. Along with that the decreasing trend of rainfall might have impact on crop

Table 4 Statistical scores of IMD and Mix98 rainfall distribution over five different homogeneous regions of India during 1986–2010

	June		July		August		September	
	IMD	Mix98	IMD	Mix98	IMD	Mix98	IMD	Mix98
R1 region								
COR		− 0.6*		0.51*		0.31⁺⁺		0.8*
RMSE		12.5		9.8		10.4		8.5
SD	15.27	2.04	11.28	2.65	10.81	1.53	14.36	3.66
R2 region								
COR		0.1		0.42**		0.24#		0.7*
RMSE		30.6		13.46		16.21		14.73
SD	30.21	14.6	16.41	19.57	2.74	3.84	6.31	6.44
R3 region								
COR		− 0.6*		0.09		0.5*		0.4⁺
RMSE		19.55		15.08		13.41		8.55
SD	23.87	14.87	15.16	9.10	6.71	5.38	8.37	5.40
R4 region								
COR		− 0.55*		0.63*		0.13		− 0.31⁺⁺
RMSE		21.00		12.94		17.81		14.99
SD	24.80	16.32	17.95	15.48	3.28	2.93	3.90	6.68
R5 region								
COR		− 0.33⁺⁺		0.19		− 0.01		0.62*
RMSE		8.84		7.00		6.04		5.44
SD	9.21	7.06	5.89	6.83	17.36	8.04	5.14	16.61

*1% significant; **2% significant; ⁺5% significant; ⁺⁺10% significant; #20% significant

production over India and its different homogeneous regions. Apart from this, the crops which are sowing after monsoon period may lead to crop damage for the whole year. In terms of agricultural production and food security over regional scale, the vulnerabilities and risks from these changes have taken considerable attention over the globe [23, 51, 53] and these facts of food security become a current issue for this country [45]. Therefore, the crops which are sowing during monsoon and post-monsoonal season are also considered for the further study.

Crop Production Over Homogeneous Regions

The major food crops of India are rice, wheat, maize, pulses and groundnut. On the basis of cropping season, it has been divided into *Kharif* and *Rabi*. *Kharif* crops are mainly rice and maize which are also known as summer/monsoon crop. These crops are grown during the summer monsoon period, i.e., JJAS, and harvested in early winter or in autumn. The *Rabi* crop is the winter crops or the spring-harvested crops which include wheat. Winter crops (*Rabi* crop) which indirectly depend on monsoon rainfall are also influenced by healthy monsoon [40]. These crops are sown after the summer monsoon and continue its growth and harvest in the spring or early summer month [27], and the seasonal rainfall provides the soil moisture for these crops during the post-monsoonal season [40]. Therefore, summer monsoon rainfall plays an important role for crop production in India during monsoon and post-monsoonal period [37]. Total crop cultivation area (unit in million hectares; Mh), average yields (unit in tonnes/hectares) and production (unit in million tonnes; MT) of rice, wheat, sorghum, maize, pulses and groundnut over Indian subcontinent are given in Table 5. It indicates that rice, wheat and maize are among the most cultivated food grains in this country. The average of rice, wheat and maize yield is 70.75 tonnes/hectares, 65.21 tonnes/hectares, 64.72 tonnes/hectares over the area 54.06 Mh, 218.89 Mh and 48.41 Mh with the production of 3.82 MT, 14.27 MT and 3.13 MT, respectively. Average yields of sorghum, pulse and groundnut are also good in tonnes/hectares. Sorghum production over India is 1.49 MT with the average yield 31.52 over the area 47.39 Mh. Productions (in MT) of pulse and groundnut are 4.39 and 0.69 with the average yields (in ton/hect) 26.72 and 38.18 over the area (Mh) 164.43 and 18.20, respectively. Also, the percentage contribution of all crops over five different homogeneous regions is also considered in Fig. 3a–e. From this figure it is observed that

Table 5 Total crop cultivated area, average yield and production over all India region [production in million tonnes (MT) and area in million hectares (Mh)]

Crop	Area	Average yield (tonnes/hectares)	Production
Rice	54.06	70.75	3.82
Wheat	218.89	65.21	14.27
Sorghum	47.39	31.52	1.49
Maize	48.41	64.72	3.13
Pulse	164.43	26.72	4.39
Groundnut	18.20	38.18	0.69

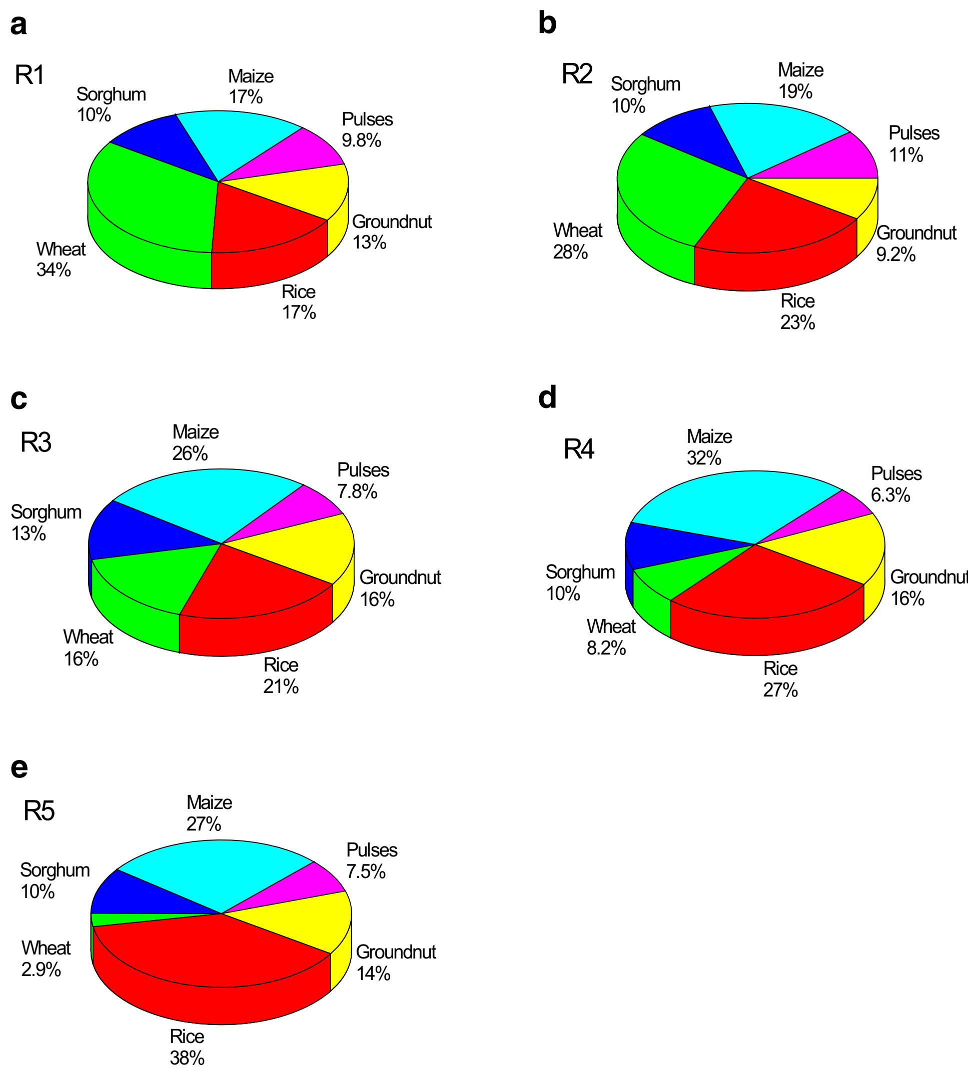


Fig. 3 Crop productions and percentage contributions over different homogeneous regions

rice, wheat and maize are the major food crops over most of the homogeneous regions, as these crops account for maximum percentage among all selected crops. The R1 region (Fig. 3a) deals with NWI where the major crop is wheat (34%) and the second major crops are rice (17%) and sorghum (17%). The production distribution of wheat, rice, maize, pulse, sorghum and groundnut is 28%, 23%, 19%, 11%, 10% and 9.2% over R2 region (Fig. 3b), respectively, which covers the Gangetic plain of India. Region R3 (Fig. 3c) accounts maximum production of maize (26%) and sorghum (13%) which are not prominent in any other homogeneous regions. Production of rice

Table 6 Correlation coefficient (CC) between crop production and monsoon rainfall over five Indian homogeneous regions during 1986–2010

Crops	Seasonal rainfall (JJAS)									
	R1		R2		R3		R4		R5	
	IMD	Mix98	IMD	Mix98	IMD	Mix98	IMD	Mix98	IMD	Mix98
Rice	**0.6***	**0.3**$^{++}$	**0.3**$^{++}$	0.23	0.23	− **0.52***	**0.46****	− 0.10	**0.3**$^{++}$	− 0.25
Wheat	**0.3**$^{++}$	0.05	0.10	0.08	**0.40**$^{+}$	− **0.58***	**0.60***	− 0.06	0.23	− 0.05
Sorghum	**0.40**$^{+}$	0.10	0.02	**0.3**$^{++}$	0.006	− **0.43**$^{+}$	**0.3**$^{++}$	− 0.23	**0.66***	− 0.08
Maize	0.17	0.02	0.16	0.17	**0.32**$^{++}$	− **0.44**$^{+}$	0.25	0.05	**0.31**$^{++}$	− **0.36**$^{+}$
Pulses	**0.65***	0.18	0.07	0.24	**0.40**$^{+}$	− **0.51***	**0.34**$^{++}$	− 0.02	0.17	− 0.23
Groundnut	**0.40**$^{+}$	0.02	− 0.18	0.06	**0.3**$^{++}$	− **0.49****	**0.32**$^{++}$	− 0.01	**0.5****	− **0.51***

Bold is showing the highly significant data

*1% significant; ** 2% significant; $^{+}$5% significant; $^{++}$10% significant

Table 7 Mann–Kendall trend analyses on crop production over homogeneous regions with 5% significant level

	Crop production					
	Rice	Wheat	Sorghum	Maize	Pulses	Groundnut
R1	D	D	D	D	D	
R2	D	D	D	D	D	D
R3	D	D	D	D	D	D
R4	D			D		D
R5	D					D

D decreasing trend

(21%) is indicating second largest crop over R3. Figure 3d depicts important crop distribution in R4 which accounts two major crops rice (27%) and maize (32%). The production of groundnut over R4 region is the same as R3 region but is prominent over the other regions. And Fig. 3e signifies rice as a major crop for the southern peninsular India comes under R5. In this region the crops are benefited by both southwest and northeast monsoon.

Dependency of Crop Production on Monsoon Rainfall

India is the second largest producer of rice and wheat in the world (https://www.csc.gov.in/index.php?option=com_content&view=article&id=218&Itemid=362), placed first in pulses production and fourth in coarse grain [3]. This historical mile stone is achieved by high yielding variety (HYV) seeds, availability of fertilizers, changing crop pattern and agricultural practice, expanded irrigation, institutional support and minimum support price policy. The alteration in the precipitation pattern due to climate change shows a direct or indirect impact over crop production [29] which has been documented from the last few decades [23, 28, 32, 39, 52, 54]. Figure 4a–j illustrates the graphical representation of major crop yield with observed and model simulated rainfall over the respective regions during time period of 1986–2010. These figures basically represent the total monsoon rainfall over homogeneous regions and the crop yield production over the respective regions for the respective years. From the initial analysis we found rice, wheat and maize as the major and prominent crops over the regions. Therefore, in the section we mainly concern for the prominent crop of respective regions which represents a strong relationship between summer monsoon and crop production (Fig. 4a–j, Table 6). Rice production in R1 region is strongly correlated with observed data of IMD with correlation coefficient of 0.6 at 1% significant level. R1 region accounts for the 17% of rice production among the selected crop (Fig. 4a), but Mix98 rainfall data show CC 0.3 with 10% significant level. For R1 wheat is prominent crop with highest percentage of production, but IMD data show the genuinity of the relation at 10% level of significance. Similarly, sorghum and groundnut show good CC of 0.4 with IMD observed and the pulses show strong relation with significance of 1%. Hence, an overall analysis of IMD and model simulated rainfall analysis over R1 is considerably valid and good for rice, sorghum, pulses and groundnut production. A significant CC on rice (with IMD CC of 0.3 at 10% significant level) and sorghum (with Mix98 CC of 0.3 at 10% significant level) is observed over R2 region, and rice (with Mix98 CC − 0.52 at 1% significant level), wheat (with IMD CC 0.4 at 5% significant

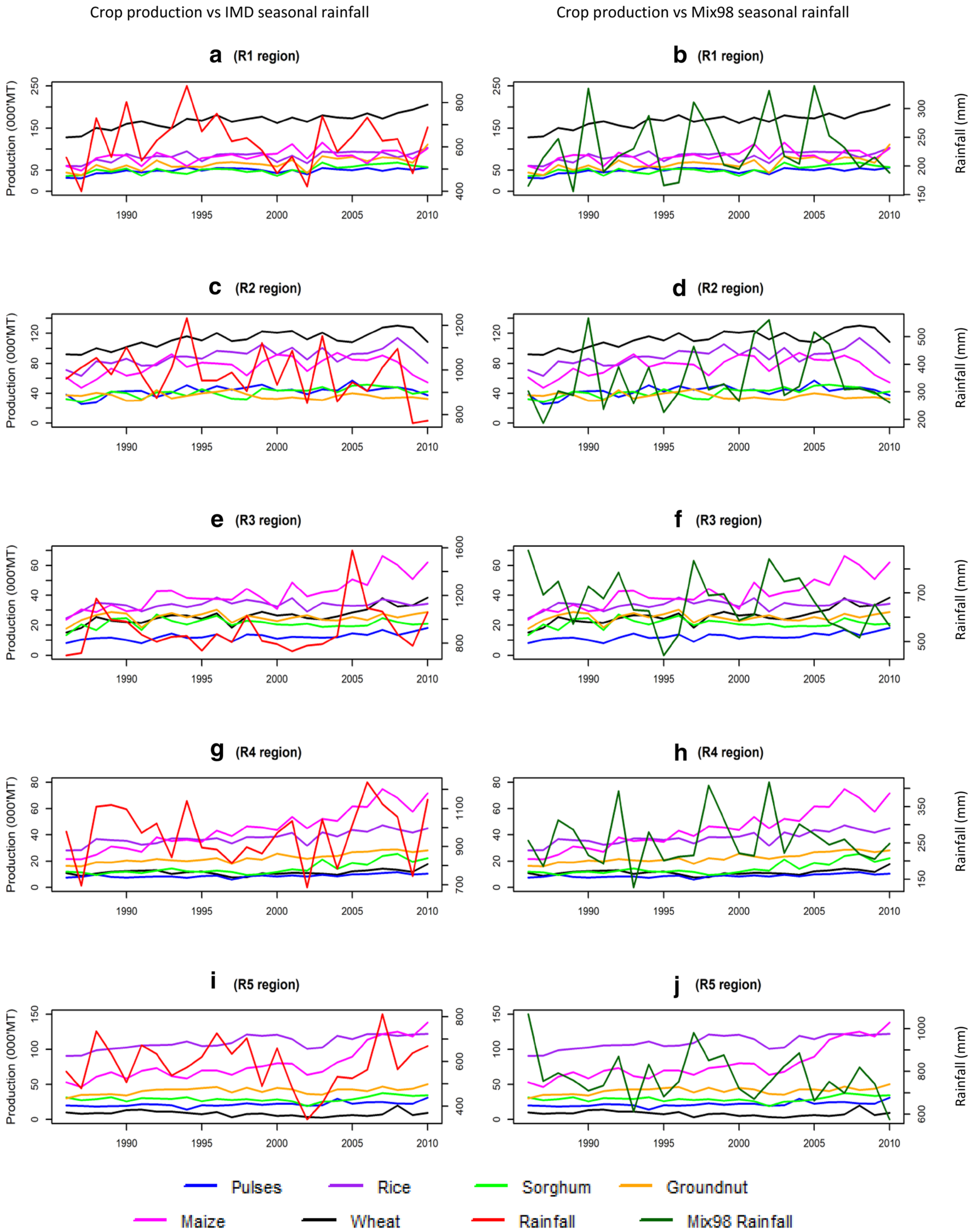
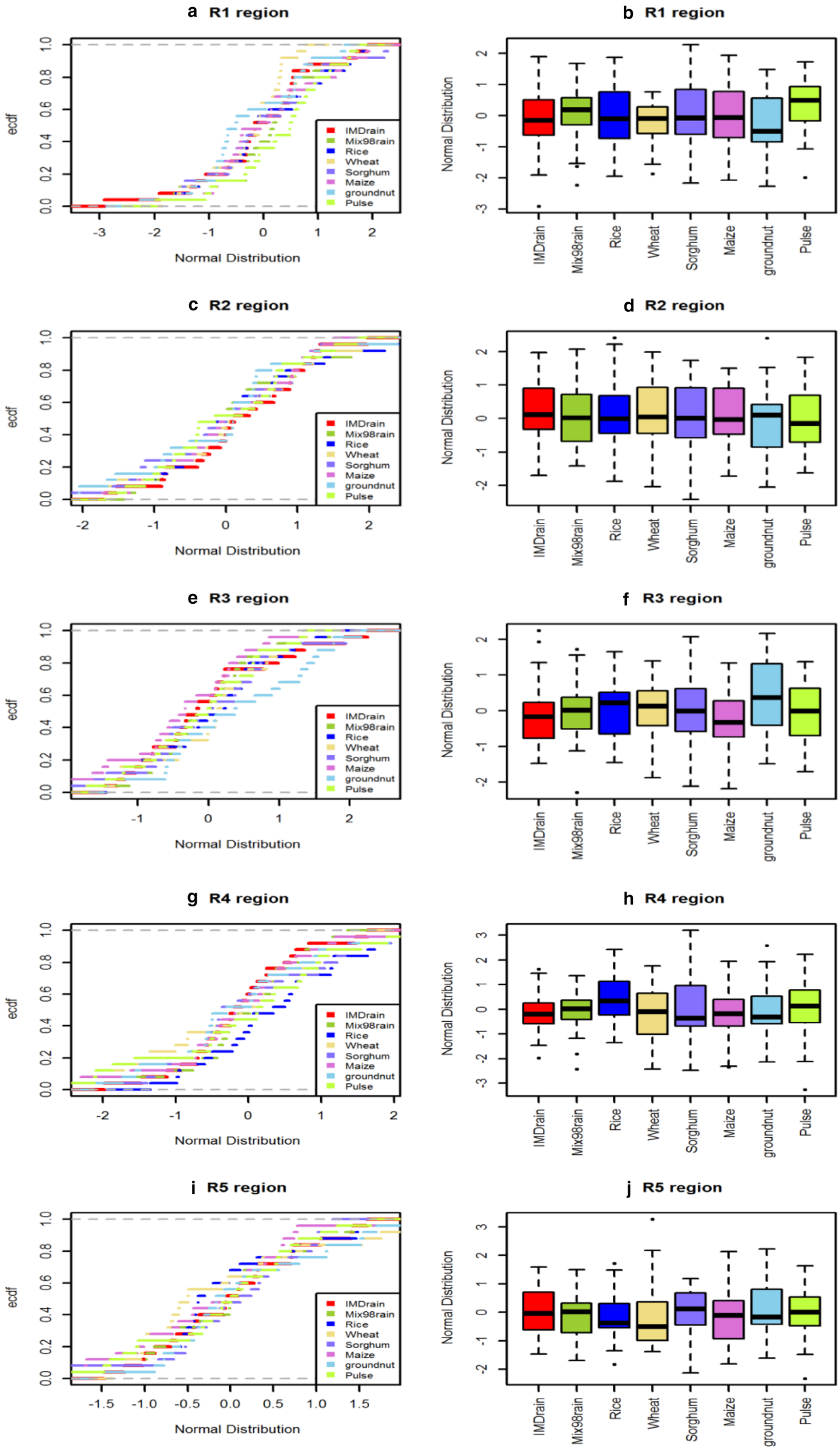


Fig. 4 Variation of crop production with IMD and RegCM-4.3 simulated rainfall during 1986–2010 over five Indian homogeneous regions


a R1 region
b R1 region
c R2 region
d R2 region
e R3 region
f R3 region
g R4 region
h R4 region
i R5 region
j R5 region
ecdf
Normal Distribution
IMDrain
Mix98rain
Rice
Wheat
Sorghum
Maize
groundnut
Pulse

◀ **Fig. 5** Empirical cumulative distribution function (ECDF) and box plots of observed (IMD) and model simulated (Mix98) rainfall along with major crop production over different homogeneous regions of India

level; with Mix98 CC − 0.58 at 1% significant level), pulses (with IMD CC 0.4 at 5% significant level; with Mix98 CC − 0.51 at 1% significant level), groundnut (with IMD CC 0.3 at 10% significant level; with Mix98 CC − 0.49 at 2% significant level), maize (with IMD CC 0.32 at 10% significant level; with Mix98 CC − 0.44 at 5% significant level) and sorghum (with Mix98 CC − 0.43 at 5% significant level) over R3 region have also been depicted. In R4 region, a good CC is observed in production of rice (with IMD CC 0.46 at 2% significant level), wheat (with IMD CC 0.6 at 1% significant level), sorghum, pulses and groundnut (with IMD CC 0.32 at 10% significant level). R5 region shows the strong relationship between rainfall and production of rice, sorghum, maize and groundnut at 1–10% significant levels. This CC signifies that the crop productions are strongly dependent on summer monsoon rainfall and any spatial and temporal variation in rainfall may affect the crop production over Indian region.

ECDF and box plots of observed and model simulated rainfall along with major crop productions over five homogeneous regions are considered in Fig. 5a–j. ECDF is a nonparametric statistical estimator tool which interprets the similar group of random dataset by their own distributions [18, 19]. The box plot represents the upper and lower limit of data along with its deviation from mean with 25 and 75 percentiles. Here, these statistics are used to verify the data distribution and distribution pattern between rainfall and crop production with their normal. With the ECDF estimator, it is possible to visually gauge the data series distribution by the slope of the line. With the increases of ECDF from 0 to 1, plotting of key points of the data series is plotted. The ECDF fitted results of the distributions for every region are presented in separate plot. The normal distributions of model simulated rainfall and major crop production over every region are showing their closeness with IMD rainfall distribution. Most of the major crops production rate is following the pattern of observed rainfall for every ECDF quantiles. However, pulses and groundnut production are showing a little deviation in ECDF (Fig. 5b) as well as box plot (Fig. 5b) over the R1 region. A goodness of fit between rainfall and crop production data distribution is illustrated over R2 region (Fig. 5c, d). A slide deviation in groundnut, rice and wheat has also been observed over R3 (Fig. 5e, f), R4 (Fig. 5g, h) and R5 (Fig. 5i, j) regions, respectively (Table 6).

Figure 6a–e illustrates the percentage changes of annual crop yield over five different homogeneous regions of India during the time period of 1986–2010. To find the significance of trend, Mann–Kendall trend analysis with 5% significance is considered (Table 7). Except groundnut, all the crops (rice, wheat, sorghum, maize and pulses) are showing decreasing trend in percentage changes of crop yield over R1 region (Fig. 6a). Having a significant decreasing trend for all crops (except groundnut) in region R1 (Table 7), sorghum production has a sharp decreasing slope of − 0.31. Figure 6b, c illustrates the percentage changes of crop yield over R2 and R3 for 25-year climatology period. These regions show a significant decreasing trend for the entire crops (Table 7). NCI (R2 region) which contributes a large amount of food grain for Indian population is representing a significant decreasing trend in percentage changes in crop yield and is the subject for concern. Figure 6d illustrates yield percentage changes for the crops over region R4. During 1986–2010, crop production is found to have a decreasing trend for all crops except wheat and sorghum (Table 7). Figure 6e shows the trend analysis of all major food crop production over R5 region. It has been showing a decreasing trend in rice and pulses (Table 7). In R5 region, all crops become benefited by both the monsoon rainfall: southwest monsoon and northeast monsoon. Therefore, it may be the possible cause not getting a significant trend in most of the crops over R5 region.

Conclusions

Study concludes a direct impact of summer monsoon variability on crop production over Indian homogeneous regions and is well simulated by RegCM's mixed convection scheme in which Grell scheme is used over land surface and Emanuel is considered over sea surface as a mixed mode. Rainfall distribution over the homogeneous regions has been decreased for monthly and seasonal climatology during the monsoon period, and an immense variation is observed during the peak monsoon months (July and August). The immense decreased climatology particularly during July and August has a deep association with the prominent monsoonal and post-monsoonal crop production over five homogeneous regions. Out of five homogeneous regions NCI and WPI are critically affected for all the major food crops, and the crop failure is depicted over NWI region. Production of rice (*Oryza sativa*), wheat (*Triticum aestivum*) and maize (*Zea mays*) is mainly affected over the respective regions. Soil moisture budget during the monsoon season and year is basically maintained by peak monsoonal rainfall which is the chief causative factor for healthy crop production. The lack of peak monsoon rainfall leads to down moisture budget over the year and might be the causative factors behind weak

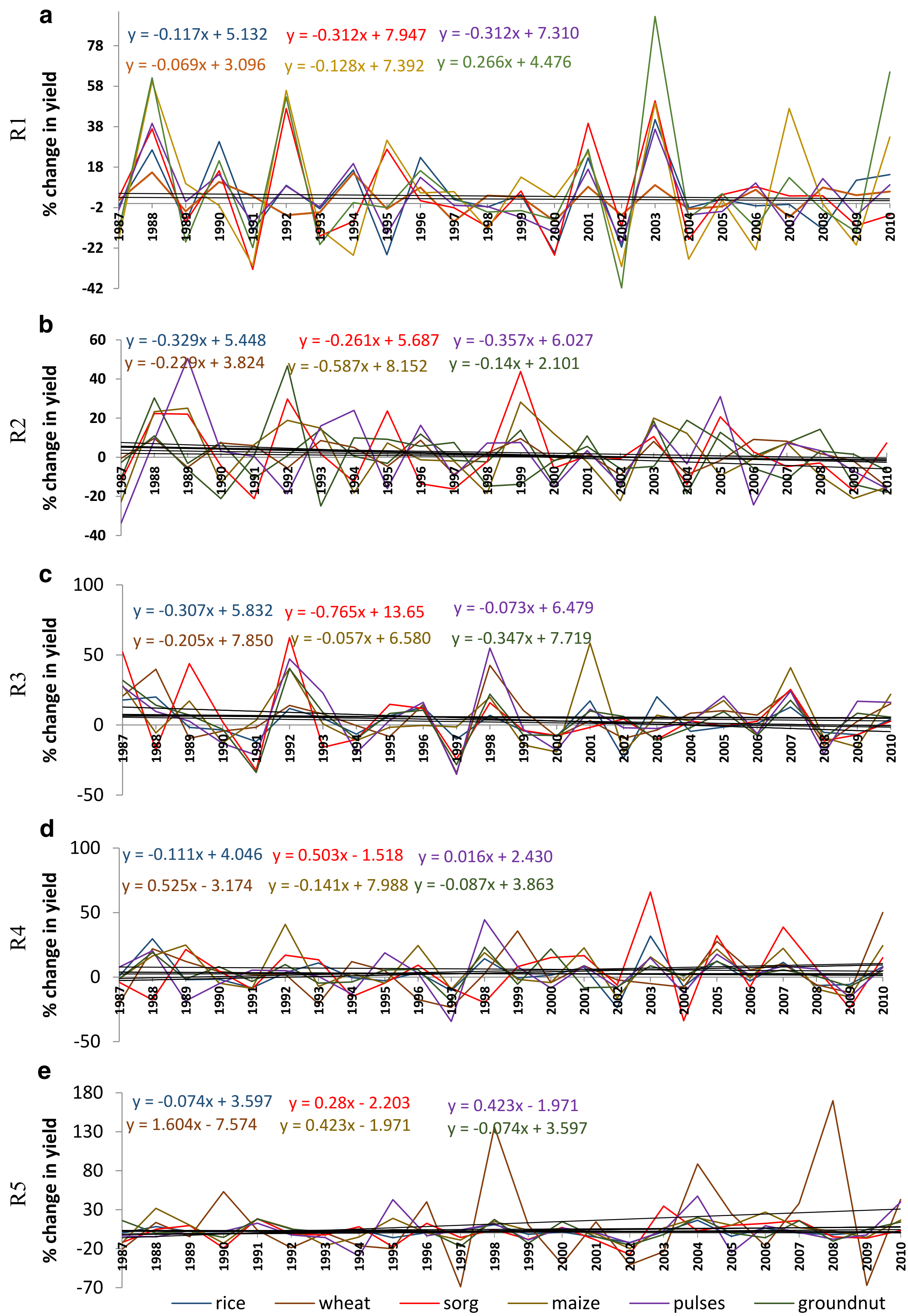


Fig. 6 Crop yield percentage changes for the major food crops over different homogeneous regions

monsoonal and post-monsoonal along with annual crop production. Study shows that the weak monsoon disturbs the monsoonal crop production and crop sows after monsoon period is leading the crop damage/failure due to insufficient moisture in the soil. India is the world's second largest producer of rice (*Oryza sativa*) and wheat (*Triticum aestivum*), first in pulse and fourth in coarse grain [e.g., maize (*Zea mays*), sorghum (*Sorghum vulgare*)], and has a big contribution to world's food security. Consequently, these alterations in crop production (crop damage/failure) are showing the fact of food security by becoming the current issue to feed the huge population of India and giving alarming threat to the Indian economy. Therefore, this study might have provided a better long-range planning for irrigation, water harvesting crop production as a precaution for climatic change over India.

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Author's Contributions RB and SG are conceived the study. SV, SG and GG have analyzed the data. RKM has guided in agriculture section. SG, SV and RB have written the manuscript.

Compliance with Ethical Standards

Conflict of interest The authors declare no conflict of interest.

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