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Variability of rainfall and effective onset and length of the monsoon season over a sub-humid climatic environment

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ABSTRACT

The study has analyzed the variability and trends in monthly, seasonal and annual rainfall and rainy days of four locations over different agro-ecological zones of Bihar, namely Samastipur (zone-I), Madhepura (zone-II), Sabour (zone-IIIA) and Patna (zone-IIIB). The Mann–Kendall nonparametric test was employed for detection of statistical significance and slopes of the trend lines were determined using the method of least square linear fitting. The variability and trends of onset of effective monsoon and length of monsoon period were also analyzed using the same method. The mean annual rainfall varies from 1137 mm at Patna to 1219 mm at Sabour. July is the rainiest month in all the zones followed by August. Maximum increase in annual rainfall was found at Sabour (40.1% of mean/30 years at 95% confidence level) and minimum for Patna (10.1% of mean/30 years). Significant increasing trend of rainfall during July, August and September at rates of 41.9, 83.2, and 112.7% of the mean/30 years, respectively has been noticed at Madhepura. Analysis of rainy days indicates that rainy days increased during winter and annually for all the sites. The mean effective onset of monsoon varies from 18th June at Sabour to 28th June at Patna. The trends in the date of effective onset of monsoon indicate that the date tends to be early in all the sites except Madhepura. But a significant delayed trend in the onset at a rate of 2.8% of the mean/30 years has been observed for Madhepura. The early trend of the effective onset of monsoon and increasing trends of length of monsoon season have been observed for Samastipur, Sabour and Patna.

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1. Introduction

The fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) (2007) indicated with very high confidence (90% probability of being correct) that human activities, since industrialization have caused the planet to warm by about 1 °C and future climate change is likely to affect agriculture, increased risk of hunger and water scarcity. Future projections of climate change using Global and Regional Circulation Climate Models with different IPCC emission scenarios indicate an increase of about 5–10% in summer monsoon rainfall over India (NATCOM, 2004). It is also projected that the number of rainy days may decrease by 20 to 30%, which would mean that the intensity of rainfall is expected to increase. Extreme rainfall may also increase by the end of the year 2100. Another study shows significant increasing trend in extreme rainfall events over central India during the last 50 years (Goswami et al., 2006). Several studies over the region reported that Indian summer monsoon has shown remarkable stability in spite of some decadal variations as well as large inter-annual variability. The long-term series of Indian Summer Monsoon Rainfall (ISMR) has no discernible trends, but decadal departures are found above and below the long time average alternatively for 3 consecutive decades (Kothari and Singh, 1996). There is an increase in the occurrence of extreme rainfall events over northwest India in recent decades (Singh and Sontakke, 2002).

An analysis of the long-term trends in individual monthly mean rainfall over India for the period 1870–2003 from linear fits produces negative slopes (average 0.09 mm/year) for June, July and September, and a significant positive slope of similar value for August (Patra et al., 2005). The long-term changes of

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ISMR have been examined by employing the Mann–Kendall rank test, while the short-term climatic variations have been investigated by applying Cramer's t-test employing 11 year running means. The most striking features are the epochs of above- and below-normal rainfall. The periods 1880–95 and 1930–63 are characterized by above-normal rainfall with very low frequency of droughts. The periods 1895–1930 and 1963–90 are characterized by below-normal rainfall with a very high frequency of droughts. Srivastava et al. (1992) found that there is no trend in all-India rainfall during the monsoon season as well as in annual rainfall. However, they found a decreasing trend in rainfall over some hilly areas of northeast India. In another study a few sub-divisions showed increasing trends in annual rainfall, whereas a few showed decreasing trends. Trends and periodicities in the annual rainfall of 31 meteorological sub-divisions of India during the period 1901–1960 using the Mann–Kendall rank method, low pass filter and power spectrum analysis indicated a positive trend over central India and the adjoining parts of the peninsula and a negative trend in some parts of eastern India (Parthasarthy and Dhar, 1974). There were no long-term trends or periodicities in pre-monsoon season rainfall over Gangetic West Bengal during the period 1901–1992. However, short-term fluctuations were present and a negative tendency from 1915 onwards until the early 1970s and further rise in the 1970s could be observed (Sadhukhan et al., 2000). Results revealed that while there are year-to-year fluctuations of seasonal summer rainfall (June to September) over India, the Mann–Kendall rank statistic suggests no significant long-term trends (Kripalani and Kulkarni, 2001). Sinha Ray and Srivastava (2000) have found that there is a significant decreasing trend in the occurrence of cyclonic storms over Indian seas for the period 1981–1997. They also investigated eleven-year running total frequency of heavy rainfall days for different rain gauge stations and each station was subjected to the Mann–Kendall rank statistic test at 95% level of confidence. There was an increasing trend in the frequency of heavy rainfall over Mumbai during the southwest monsoon and on an annual basis. Vulnerability and agricultural sustainability are primarily local issues and depend critically on the amount and temporal distribution of rainfall received over a region. Thus rainfall patterns need to be examined in a local perspective. Kumar and Jain (2010) reported the trends in seasonal and annual rainfall and rainy days in Kashmir Valley in the last century.

No detailed study on rainfall characteristics and trends for sub-humid (dry) climatic environment of Bihar has been reported in the literature, which is part of the middle part of the Indo-Gangetic Plains. In the present study, monthly, seasonal and annual rainfall and rainy days data of four stations viz., Samastipur, Madhepura, Sabour and Patna districts, representing different agro-climatological zones of Bihar have been analyzed to study the variability and trends of monthly, seasonal and annual rainfall and rainy days. We have also analyzed the date of onset of effective monsoon and the length of monsoon period using the same methodology.

2. Study area

Bihar is lying approximately between 21°58′10″ and 27°31′15″N latitudes and 82°19′50″ and 88°17′40″E longitudes in the middle Indo-Gangetic Plains extending 483 km from west to east. Temperature varies from a maximum of 43 °C in summer to a minimum of around 5 °C in the winters. It receives medium to heavy rainfall during the monsoon season. This state embraces some of the most fertile lands of India, squeezed in between West Bengal, Jharkhand and Uttar Pradesh, reaches up to the Himalayas in the north and is completely land locked. Bihar is bounded on the north by Nepal, on the south by Jharkhand, on the east by West Bengal and on the west by Uttar Pradesh. The topography of Bihar can be easily described as a fertile alluvial plain occupying the Gangetic Valley. The plain extends from the foothills of the Himalayas in the north to a few miles south of the river Ganges as it flows through the State from the west to the east. Rich farmland and lush orchards extend throughout the state. The river Ganga flows right across it from west to east. North Bihar is extremely fertile, the land being watered by the rivers Sarayu, Gandak and Ganga. The other rivers are the Sone, Poonpoon, Falgu, Karmanasa, Durgawati, Kosi, Ghaghara, etc. Bihar is traditionally divided into 1) The North Ganga plain and 2) The South Ganga plain. Physiographically the entire state is the part of Ganga Plain. The formation of plains is the sediments deposited by the River Ganga, Gandak and Ghagra. The river system is the lifeline of the state. Every year lakhs of hectares of land comes under the flood of the river. Soil has a number of characteristics, which may be regarded as the aggregate of the physical, chemical and biological properties. The Bihar plain consists of a thick alluvial mantle of drift origin overlying in most part. The siwalik and older tertiary rocks. The soil is mainly young loam rejuvenated every year by constant deposition of silt, clay and sand brought by different streams. This soil is deficient in phosphoric acid, nitrogen and humus, but potash and lime are usually present in sufficient quantity. Basically the economy is rural based with greater dependence on agriculture in which 89.5% of the population is rural based compared to a national average of 72.2%. Out of 70% farmers engaged in agricultural and other allied sectors, 90% are marginal and small farmers. Even though Bihar falls under a high rainfall region, recurrent floods and droughts during the monsoon season are a serious concern. Surprisingly, the occurrence of severe drought/floods in recent years 2003, 2004, 2005, 2008 and 2009 in one or other agro-climatological zones, supports the IPCC (2007) fourth assessment report. Rice (May/June–October/November) followed by wheat (November/December–March/April) is the dominant cropping sequence in this part of the study area. Based on soil characterization, rainfall, temperature and terrain, the state is divided into four agro-climatological zones with zone-I and zone-II corresponding to north Bihar whereas zone-IIIA and zone-IIIB comprising districts of south Bihar. The soil type and topography, and the normal climatic conditions of the agro-climatic zones are reported in Table 1. Four representative districts, viz., Samastipur (zone-I), Madhepura (zone-II), Sabour (zone-IIIA) and Patna (zone-IIIB) – having more or less agro-climatological as well as agro-ecological conditions of the zones – were selected based on data availability (Fig. 1).

3. Data and methodology

3.1. Data

The daily meteorological parameters recorded at the IARI regional station, Pusa, Samastipur; Agricultural College, Sabour; Agricultural Research Institute, Patna and RARS, Rajendra

Table 1
Characteristics of the agro-climatic zones of Bihar.

Agro-climatic zone	Soil and topography	Normal initiation/ cessation of rainfall	Total annual rainfall (mm)	Average annual temperature (°C)	
				Maximum	Minimum
Zone I (North west alluvial plain)	Heavy textured sandy loam to clay, medium acidic, flood prone, pH: 6.5–8.4	12th June/30th September to 10th October	1040–1450	36.6	7.7
Zone II (North west alluvial plain)	Light to medium textured slightly acidic, sandy loam to clay loam with saline/alkaline patches, pH: 6.5–7.8	7th June/30th September to 10th October	1200–1700	33.8	8.8
Zone IIIA (South alluvial plain)	Old alluvium sandy loam to clay, slightly alkaline patches, pH: 6.8–8.0	15th June/30th September to 10th October	990–1240	37.1	7.8
Zone IIIB (South alluvial plain)	Old alluvium sandy loam to clay, slightly alkaline patches, pH: 6.8–8.0	10th June/30th September to 10th October	990–1240	37.1	7.8

Agricultural University, Madhepura were collected. These observatories have been installed long back under the guidance of technically qualified officers and calibrated the instruments according to the IMD/WMO standard. The details regarding geographical features and data period are shown in Table 2.

3.2. Methodology

3.2.1. Trend analysis

For all data sets of monthly, seasonal and annual rainfall, the Mann–Kendall nonparametric test, as described by Sneyers (1990), was applied in order to detect trends. The Mann–Kendal test has been used by several researchers to detect trends in hydrological time series data (Serrano et al., 1999; Brunetti et al., 2000a,b). The slopes of the trends were calculated by fitting the data series into method of least square linear fitting. The Mann–Kendall test basically involves the ranks obtained by each data in the data series. The n time series values (X1, X2, X3, ….., Xn) are replaced by their relative ranks (R1, R2, R3,….., Rn) (starting at 1 for the lowest up to n). (Kundzewicz and Robson, 2000; Subash and Ram Mohan, 2010).

The test statistic S is:

$$S = \sum_{i=1}^{n-1}\left[\sum_{j=i+1}^{n} sgn\left(R_j - R_i\right)\right]$$

where
$$sgn(x) = 1 \; for \; x > 0$$
$$sgn(x) = 0 \; for \; x = 0$$
$$sgn(x) = -1 \; for \; x < 0$$

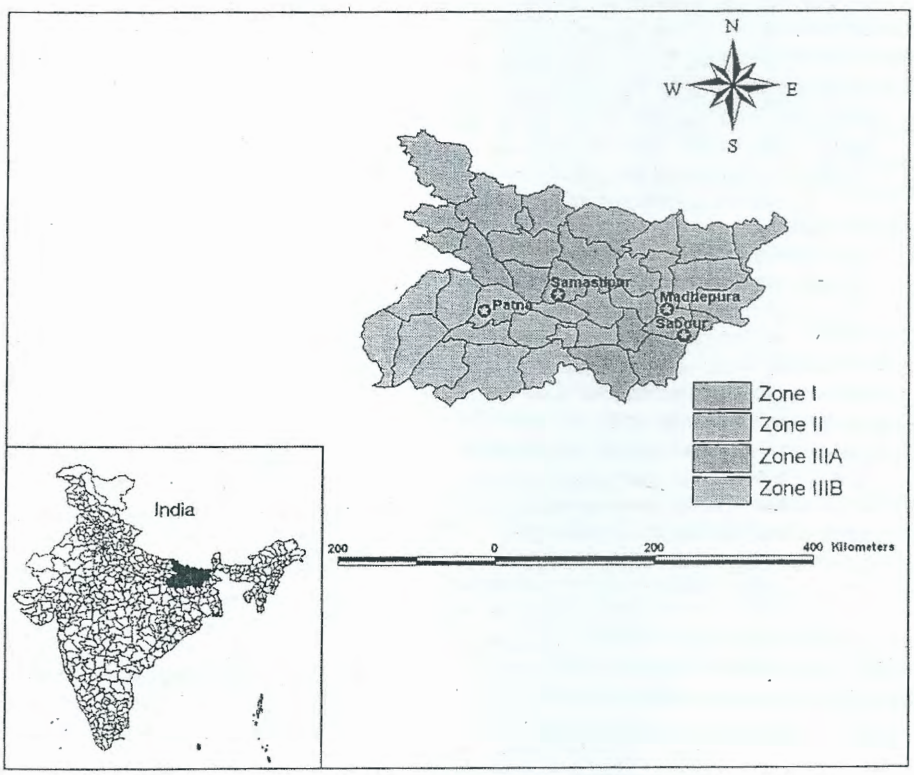

Fig. 1. Agro-ecological zones of Bihar and location of study sites.

Table 2
Characteristics of the study area and data period.

Sl. No.	Agro-climatic zone	Study site	Data period	Latitude	Longitude	Altitude (m)
1	Zone I	Samastipur	1960–2006	25.65°N	85.50°E	52
2	Zone II	Madhepura	1974–2000	25.50°N	86.40°E	42
3	Zone IIIA	Sabour	1972–2003	25.14°N	87.40°E	37
4	Zone IIIB	Patna	1960–2007	25.30°N	85.15°E	52

The trend test was carried out for monthly, seasonal and annual rainfall as well as for rainy days in all the study sites.

3.2.2. Onset of effective monsoon and length of monsoon season

The normal dates of the onset of the monsoon, as determined by the India Meteorological Department (IMD), are based on the sudden increase of the 5-day pentad average of rainfall for all the rain gauge observatories. The middle date of pentad, in which an increase of rainfall occurs from the preceding pentad, is taken as the date of the onset of monsoon. However, from agricultural planning over small areas, above pentad concept has certain limitations. This criterion is not related to the building up of a moisture reserve in the soil, which alone is vital for commencement of sowing operations. Rice is the main kharif (June–November) crop of Bihar and consumes lot of water for field preparation, sowing, and transplanting. Therefore, a rainfall-potential evapotranspiration based concept, suggested by Ashok Raj (1979) is employed, with slight modification for defining the normal effective onset date of rainfall. Since Bihar, as per the climatic classification of

Table 3
Monthly, seasonal and annual distribution of rainfall at different sites in Bihar.

Month/Season	Zone I (Samastipur)			Zone II (Madhepura)			Zone IIIA (Sabour)			Zone IIIB (Patna)		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
January	10.9	14.6	134.5	13.4	17.8	133.2	15.1	16.1	106.8	11.5	10.3	89.9
February	13.1	15.3	116.9	10.0	13.4	134.7	15.1	21.0	139.2	13.4	17.2	128.3
March	7.6	12.5	165.0	21.2	32.6	153.6	11.0	14.2	129.4	9.1	14.2	155.8
April	18.7	22.2	118.9	25.7	23.7	92.1	23.7	28.3	119.3	10.8	13.8	127.4
May	65.9	50.3	76.3	73.0	55.1	75.5	84.3	66.7	79.2	42.8	40.9	95.6
June	159.0	89.5	56.3	181.9	113.2	62.3	186.8	121.4	65.0	140.6	94.0	66.8
July	325.2	160.5	49.3	320.5	198.8	62.0	315.2	119.5	37.9	343.5	164.0	47.7
August	289.8	169.9	58.6	221.2	130.0	58.8	264.5	148.5	56.2	273.3	118.1	43.2
September	225.8	127.4	56.4	202.3	111.3	55.0	196.1	121.0	61.7	202.1	118.4	58.6
October	70.1	91.3	130.3	60.8	64.8	106.6	88.9	99.3	111.6	76.3	86.3	113.2
November	7.8	15.2	194.7	7.9	22.0	277.3	9.5	22.3	233.5	8.2	16.4	199.3
December	5.6	10.1	181.0	7.0	11.7	166.8	8.7	15.5	178.0	5.1	10.7	210.9
JF (Winter)	24.0	21.8	91.0	23.4	26.7	114.4	30.2	28.4	94.3	24.9	21.5	86.2
MAM (Summer)	92.2	55.2	59.8	120.0	79.2	66.1	119.0	74.3	62.4	62.7	45.9	73.2
JJAS (Monsoon)	999.8	312.0	31.2	925.9	291.3	31.5	962.6	261.8	27.2	959.5	266.8	27.8
OND (Post-monsoon)	83.5	90.9	108.9	75.7	70.3	92.9	107.2	98.0	91.5	89.6	85.7	95.7
Annual	1199.4	332.5	27.7	1144.9	288.7	25.2	1219.0	319.1	26.2	1136.8	292.8	25.8

Table 4
Monthly, seasonal and annual distribution of rainy days at different sites in Bihar.

Month/Season	Zone I (Samastipur)			Zone II (Madhepura)			Zone IIIA (Sabour)			Zone IIIB (Patna)		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
January	1.0	1.2	118.2	1.0	1.1	113.3	1.2	1.0	86.7	1.1	1.0	91.1
February	1.2	1.3	108.8	0.7	0.9	121.9	1.4	1.4	96.7	1.2	1.3	111.5
March	0.8	1.2	154.5	1.2	1.6	127.0	1.2	1.3	116.5	0.8	1.1	147.2
April	1.5	1.5	98.5	1.7	1.4	81.1	1.7	1.7	101.6	0.9	1.2	127.5
May	3.5	2.2	62.4	4.2	3.0	71.7	4.7	2.8	60.2	2.5	2.0	79.3
June	7.4	3.0	41.0	8.0	4.3	54.6	9.1	3.6	39.7	6.2	3.2	51.0
July	13.6	3.5	25.9	12.7	5.8	45.5	14.4	3.8	26.3	13.6	3.9	28.5
August	12.1	3.4	28.5	10.1	4.4	43.7	12.9	3.5	27.1	12.4	3.1	25.3
September	10.0	3.0	29.6	9.4	3.8	40.5	10.1	3.4	33.2	9.3	3.5	37.3
October	2.9	2.1	72.2	2.7	2.2	79.4	3.9	2.8	72.1	3.0	2.3	76.7
November	0.5	0.9	172.6	0.4	0.8	207.2	0.6	0.8	127.3	0.5	0.9	179.5
December	0.6	0.9	153.2	0.7	1.2	165.7	0.7	1.0	149.8	0.5	0.9	168.1
JF (Winter)	2.2	1.8	81.6	1.7	1.5	90.4	2.6	1.9	70.9	2.3	1.7	74.7
MAM (Summer)	5.8	2.8	49.0	7.1	4.0	55.8	7.5	4.3	56.9	4.2	2.8	66.8
JJAS (Monsoon)	43.0	6.6	15.3	40.3	9.4	23.4	46.6	6.5	13.9	41.5	7.5	18.1
OND (Post-monsoon)	4.0	2.5	61.2	3.9	3.3	84.5	5.2	2.9	55.9	4.0	2.8	68.3
Annual	55.1	8.0	14.5	53.0	10.4	19.7	61.9	8.8	14.2	52.1	9.2	17.7

NBSS&LUP comes under a sub-humid (dry) climatic environment, potential evapotranspiration follows uni-modal pattern with extreme values during summer months and lowest values in winter months. Hence, instead of daily average potential evapotranspiration, normal potential evapotranspiration of each day is considered to compare rainfall with evaporation; the following criteria were used for defining the normal effective onset date:

1. The first day's rain in the 7-day spell should be more than the normal daily evaporation on that day.
2. The total rain during the 7-day spell should be more than the total normal evaporation of that 7-day spell.
3. At least four of these seven days should have more than 2.5 mm of rainfall.

The potential evapotranspiration has been calculated using the FAO recommended Penman Monteith equation (FAO, 1998). The withdrawal of effective monsoon as the last rainy day of the season as defined by Ashok Raj (1979) is used in this study. The variability as well as the trends of the effective onset and length of monsoon period was also worked out using the Mann–Kendal test.

Based on climatic features, IMD, which is India's nodal agency of WMO, defined four seasons, viz. winter (January–February), pre-monsoon (March–May), monsoon (June–September) and post-monsoon (October–December). The averages for monthly, seasonal and annual rainfall as well as rainy days and its standard deviation (SD) and coefficient of variation (CV) (CV = (standard deviation/mean)*100) were calculated in order to find out the variability during the study period.

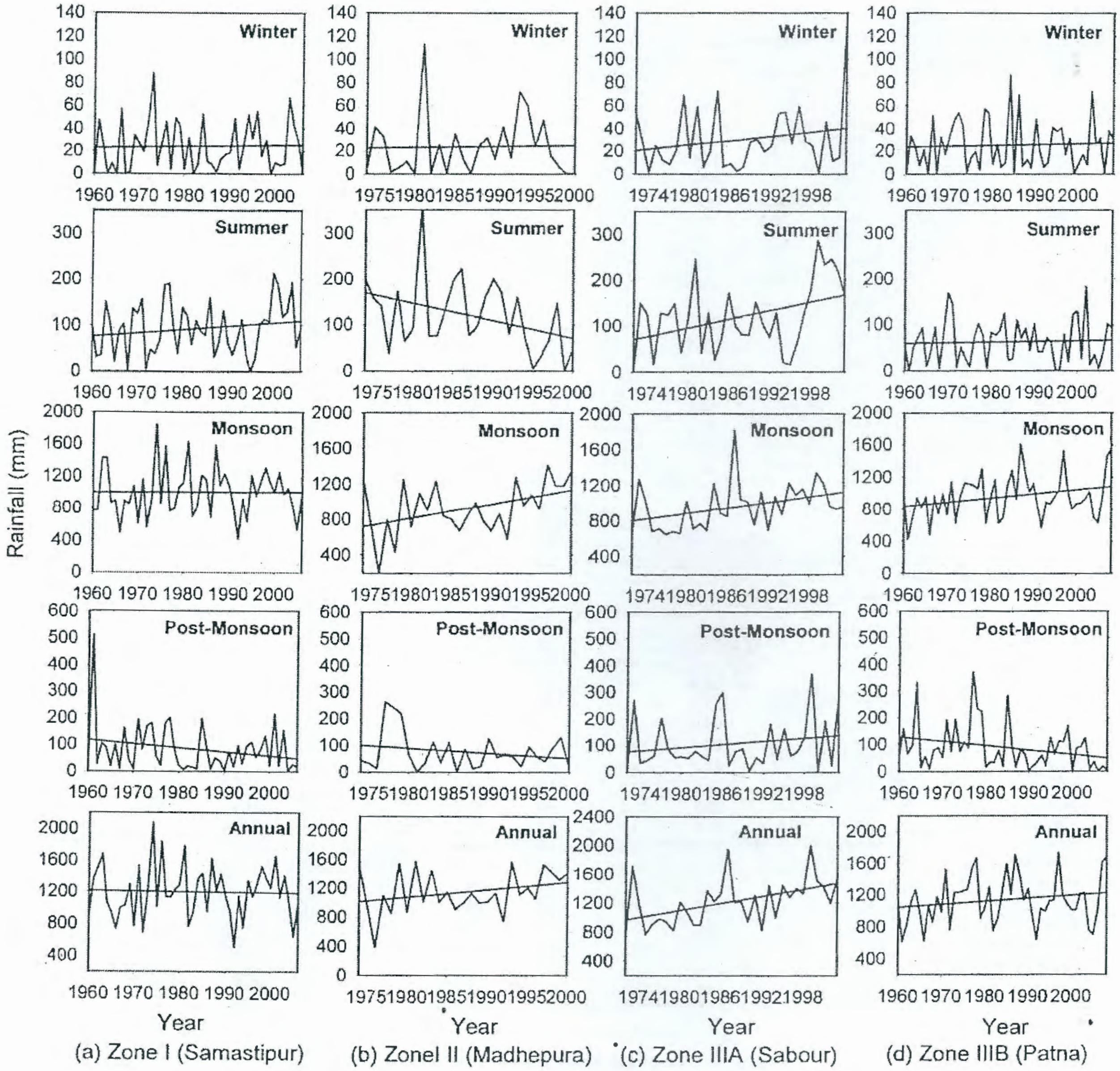

Fig. 2. Seasonal and annual variability of rainfall and its trends at different stations in Bihar.

4. Results and discussion

4.1. General characteristics of rainfall and rainy days

Mean monthly and seasonal rainfall and rainy days and its SD and CV for the selected stations are given in Tables 3 and 4. The mean annual rainfall varies from 1137 mm at Patna to 1219 mm at Sabour. The CV of annual rainfall shows not much difference among the study sites and it was below 30% for all the sites. Even though, the CV during monsoon season was below 35% for all the sites, a higher value of individual months within the monsoon season indicates the large year-to-year variability. The southwest monsoon contributes 79% of annual rainfall at Sabour to 84% at Patna. July is the rainiest month, followed by August in all the sites. However, the per cent contribution of July rainfall to annual rainfall varies from 26% at Sabour to 30% at Patna. The contribution during summer season varies from 6% at Patna to 11% at Madhepura while it varies from 7% at Madhepura and Samastipur to 9% at Sabour during post-monsoon season. Mean annual rainy days vary from 52 (Patna) to 62 days (Sabour). The CV varies from 14.2% at Sabour to 19.7% at Madhepura.

4.2. Trends in monthly, seasonal and annual rainfall

Time series of annual and seasonal rainfall and their linear trends at different stations are shown in Fig. 2. The slopes, r^2 value of linear regression and F-statistic of monthly, seasonal and annual rainfall are presented in Table 5. The annual rainfall at all the sites except Samastipur indicated an increasing trend. Maximum increase in annual rainfall was found at Sabour (40.1% of mean/30 years at 95% confidence level) and minimum for Patna (10.1% of mean/30 years). Even though the higher F-statistic (99% significant level) provides the significance of linear regression; the low values of r^2 prevent the use of linear regression equations for prediction purposes. Rainfall also showed an increasing trend in winter and monsoon seasons for all the sites. Madhepura and Sabour showed a significant increasing trend in monsoon rainfall at rates of 51.3% and 32.8% of mean/30 years, respectively. However Madhepura indicated a decreasing trend in summer and all other sites showed an increasing trend. During the post-monsoon season, all sites except Sabour, indicated a decreasing trend in rainfall. Patna showed a significant (90% confidence level) decreasing trend of rainfall at a rate of 55.8% of the mean/30 years. As far as monthly variation is concerned, significant increasing trend of rainfall during July, August and September at rates of 41.9, 83.2, and 112.7% of the mean/30 years, respectively has been noticed at Madhepura. The significant decreasing trend of rainfall at a rate of −209.3% of the mean/30 years has been noticed during March. This indicates that the wheat crop, which will be in the milky/ripening stage, may be subjected to terminal water stress. At Sabour, significant increasing trend of rainfall at rates of 128.3% and 53.2% of the mean 30 years, respectively has been observed during April and June. The higher summer (April) rainfall may be beneficial to vegetables and other crops, but it will affect the wheat crop, wherever the harvesting of wheat crop is delayed. The increasing trend of rainfall during June will be highly beneficial to rice crop, if the rice planting had been completed with the onset of monsoon. At Patna, significant increasing trend of June rainfall at a rate of 44.5% of the mean/30 years and decreasing trend of October rainfall at a rate of −64.5% of the mean/30 years were noticed. The decreasing trend of October and November rainfall may affect the germination of wheat crop during November–December.

4.3. Trends in monthly, seasonal and annual rainy days

Analysis indicates that rainy days increased during winter and annual seasons for all the sites. However rainy days were found to be increasing during the monsoon season in all the sites except Samastipur. A significant (at 95% confidence level) increasing trend of annual rainy days at a rate of 24.0% of mean/30 years has been observed for Sabour (Table 6). The low values of r^2 prevent the use of these linear equations for prediction purposes. During monsoon, rainy days were found to be increasing in all the sites, except Samastipur. A significant increasing trend of rainy days at a rate of 21.3%

Table 5
Linear trends in rainfall (% of variation over mean), r^2 and F-statistic during the study period.

Month/Season	Zone I (Samastipur)			Zone II (Madhepura)			Zone IIIA (Sabour)			Zone IIIB (Patna)		
	% Var	r^2	F	% Var	r^2	F	% Var	r^2	F	% Var	r^2	F
January	−18.1	0.004	0.171	26.6	0.003	0.070	17.7	0.003	0.081	−7.7	0.002	0.079
February	27.6	0.012	0.532	−11.4	0.001	0.013	109.9	0.061	1.947	21.6	0.006	0.306
March	−94.8	0.069	3.334	−209.3*	0.130	3.736	33.3	0.006	0.196	−49.2	0.023	1.090
April	40.3	0.024	1.108	−88.0	0.064	1.706	128.3**	0.113	3.829	23.2	0.008	0.356
May	32.4	0.038	1.764	−64.9	0.052	1.363	71.8	0.080	2.624	14.9	0.006	0.261
June	31.1	0.064	3.072	−39.0	0.027	0.706	53.2*	0.066	2.105	44.5*	**0.100**	**5.246**
July	8.6	0.006	0.288	41.9*	0.032	0.824	24.7	0.041	1.296	12.4	0.015	0.735
August	−12.3	0.009	0.417	83.2**	0.140	4.077	23.1	0.016	0.503	22.0	0.059	2.934
September	−17.8	0.021	0.958	112.7**	0.294	10.40	39.7	0.040	1.265	−3.7	0.001	0.043
October	−65.7	0.053	2.525	−112.7	0.078	2.120	50.1	0.020	0.603	−64.5**	0.074	3.735
November	−17.6	0.002	0.077	−19.5	0.000	0.009	144.2	0.037	1.162	−23.3	0.003	0.146
December	34.5	0.008	0.344	189.4	0.090	2.482	12.7	0.000	0.015	22.1	0.002	0.118
Winter	6.9	0.001	0.054	10.3	0.001	0.014	63.9	0.045	1.409	8.1	0.002	0.093
Summer	23.6	0.032	1.509	−95.4*	**0.146**	**4.269**	79.5*	***0.159***	***5.653***	7.0	0.002	0.098
Monsoon	0.2	0.000	0.000	51.3**	**0.186**	**5.723**	32.8**	**0.143**	**4.934**	16.4	0.079	4.052
Post-monsoon	−54.5	0.052	2.485	−74.8	0.045	1.190	55.4	0.036	1.118	−55.8*	0.077	3.924
Annual	−1.7	0.000	0.036	26.8	0.079	2.140	40.1**	***0.230***	***8.962***	10.1	0.035	1.682

**Significant at 95% confidence level, *at 90% confidence level as per the Mann–Kendall test.
Figures in bold indicate 95% significant level and bold and italics indicate 99% significant level.

Table 6
Linear trends in rainy days (% of variation over mean), r^2 and F-statistic during the study period.

Month/Season	Zone I (Samastipur)			Zone II (Madhepura)			Zone IIIA (Sabour)			Zone IIIB (Patna)		
	% Var	r^2	F	% Var	r^2	F	% Var	r^2	F	% Var	r^2	F
January	−22.3	0.008	0.341	26.5	0.004	0.097	20.5	0.005	0.163	−2.6	0.000	0.009
February	55.1	0.053	2.541	39.7	0.007	0.186	63.4	0.042	1.321	2.8	0.000	0.007
March	−51.3	0.023	1.056	−169.4	0.124	3.552	3.4	0.000	0.002	−72.0*	0.054	2.686
April	55.6*	0.067	3.209	−68.9	0.050	1.326	96.3**	0.088	2.891	1.3	0.000	0.001
May	46.6**	0.117	**5.941**	−51.6	0.036	0.942	59.4	0.095	3.161	29.9	0.032	1.564
June	17.6	0.038	1.798	−32.9	0.025	0.6652	35.7*	0.079	2.567	17.3	0.026	1.264
July	−2.6	0.002	0.092	29.2	0.029	0.740	10.9	0.017	0.518	−3.7	0.004	0.185
August	−10.1	0.026	1.213	64.4*	0.152	**4.486**	26.4	0.093	3.070	−4.6	0.008	0.359
September	−8.4	0.017	0.767	15.0	0.010	0.243	16.4	0.024	0.735	7.5	0.009	0.429
October	−27.7	0.031	1.431	0	0.000	0.000	−9.2	0.002	0.048	−23.0	0.020	0.976
November	−8.2	0.000	0.021	103.1	0.017	0.444	−39.9	0.010	0.290	−5.3	0.000	0.010
December	−17.0	0.003	0.114	98.8	0.025	0.639	−6.5	0.000	0.005	−23.7	0.005	0.212
Winter	19.3	0.012	0.532	32.2	0.009	0.225	44.0	0.038	1.172	0.1	0.000	0.000
Summer	36.1**	0.113	**5.734**	−76.0	0.130	3.736	59.2*	0.106	3.548	4.8	0.001	0.056
Monsoon	−2.6	0.006	0.265	22.5	0.064	1.723	21.3**	0.229	***8.925***	1.6	0.002	0.089
Post-monsoon	−23.6	0.031	1.441	29.7	0.009	0.218	−12.3	0.005	0.144	−20.9	0.021	1.013
Annual	0.8	0.001	0.032	10.1	0.018	0.470	24.0**	0.280	***11.770***	0.1	0.000	0.000

**Significant at 95% confidence level, *at 90% confidence level as per the Mann–Kendall test.
Figures in bold indicate 95% significant level and bold and italics indicate 99% significant level.

of the mean/30 years has been noticed for Sabour during monsoon. At Samastipur, a significant increasing trend of rainy days at rates of 55.6% and 46.6% of the mean/30 years has been noticed during April and May, respectively. An increasing trend of rainy days at a rate of 64.4% of the mean/30 years was noticed for Madhepura during August, which indicates the possibility of occurrence of floods. An increasing trend of rainy days during April (96.3% of the mean/30 years) and June (35.7% of the mean/30 years) (significant) has been noticed for Sabour. But as far as Patna is concerned, a significant decreasing trend of rainy days during March may trigger the possibility of occurrence of water stress in wheat crop.

4.4. Variability and trends in the onset of effective monsoon and length of monsoon season

The mean effective onset of monsoon, SD and CV over different sites are given in Table 7. The mean effective onset of monsoon varies from 18th June at Sabour to 28th June at Patna. There is not much variation in SD and CV among the study sites. Time series of effective onset of monsoon and their linear trend at different sites are shown in Fig. 3. The trends in the date of effective onset of monsoon indicate that the date tends to be early in all the sites except Madhepura. But a significant delayed trend in onset at a rate of 2.8% of the mean/30 years has been observed for Madhepura (Table 8). However, the low values of r^2 indicate the scattering of points and thus these trend equations might not be useful for prediction purposes. The time series of the length of monsoon season and their linear trend at different sites are shown in Fig. 4. The length of the monsoon season varies from 89 days at Patna to 100 days at Sabour. The CV is less (10%) for Sabour and higher (13%) for Madhepura. Linear trends show that all the study sites, except Madhepura, showed an increasing trend. A significant decreasing trend at a rate of 5.7% of the mean/30 years has been observed for Madhepura. The low value of r^2 in all the linear regression reveals that these equations are not suitable for prediction purposes.

Table 7
Statistics of the date of the effective onset of monsoon and length of monsoon season in Bihar.

Agro-climatic zones	Date of the effective onset of monsoon			Length of monsoon season		
	Mean	SD days	CV %	Mean (days)	SD days	CV %
Zone I (Samastipur)	24th June	12	6.7	95	12	12.4
Zone II (Madhepura)	19th June	12	7.0	98	13	12.7
Zone IIIA (Sabour)	18th June	11	6.6	100	10	10.2
Zone IIIB (Patna)	28th June	11	6.2	89	12	13.4

5. Conclusion

The present study deals with an examination of variability and trend in monthly, seasonal and annual rainfall and rainy days for the four sites of agro-ecological zones of Bihar. The study also investigated the variability and trends in the effective onset of monsoon and length of monsoon season in these sites. Annual rainfall at three stations, namely Madhepura (zone-II), Sabour (zone-IIIA) and Patna (zone-IIIB) was found to be increasing. Samastipur (zone-I) experienced a decreasing trend in annual rainfall. As far as the monsoon season is concerned, all the sites experienced an increasing trend in monsoon rainfall. The increasing trend at Madhepura and Sabour was found to be statistically significant at 95% confidence level. If this widespread increasing trend in rainfall is sustained, it will adversely affect the rice crop and there is a need to increase/improve drainage facilities/structures to remove/store excess water, so that this can be utilized during the critical pheno-phases of the crop. The study also provides some scenarios of the pattern of rainfall and rainy days change, which may be useful for sensitivity analysis of water availability in middle Indo-Gangetic Plains of Bihar. The moving of "sowing window" at three sites, namely Samastipur (zone-I), Sabour (zone-IIIA) and Patna (zone-IIIB) indicates the importance of identifying suitable

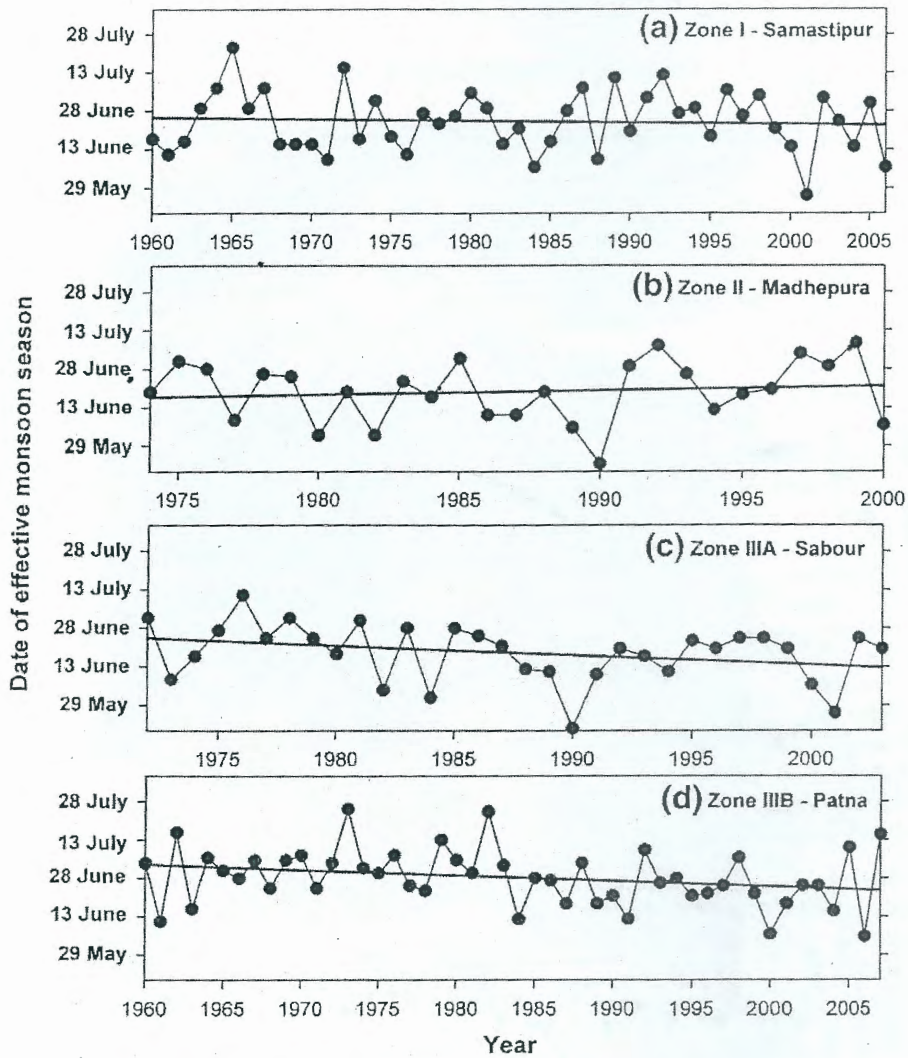

Fig. 3. Variability and trends in the effective onset of monsoon at different stations in Bihar.

Table 8
Trends and magnitude of change by linear regression (% of mean/30 years), r^2 and F-statistic in the effective onset of monsoon and length of monsoon season.

Sl No	Agro-climatic zones	Effective onset of monsoon			Length of monsoon season		
		% Var	r^2	F	% Var	r^2	F
1	Zone I (Samastipur)	−1.12	0.006	0.266	0.80	0.001	0.039
2	Zone II (Madhepura)	2.83*	0.011	0.289	−5.67**	0.014	0.352
3	Zone IIIA (Sabour)	−6.54	0.095	3.165	11.88	0.133	**4.615**
4	Zone IIIB (Patna)	−3.64	0.076	3.801	6.10	0.045	2.163

**Significant at 95% confidence level, *at 90% confidence level as per the Mann–Kendall test.
Figures in bold indicate 95% significant level.

varieties and water resources experts to adopt suitable water management/irrigation practices to minimize the adverse impacts of climate changes on agricultural productivity.

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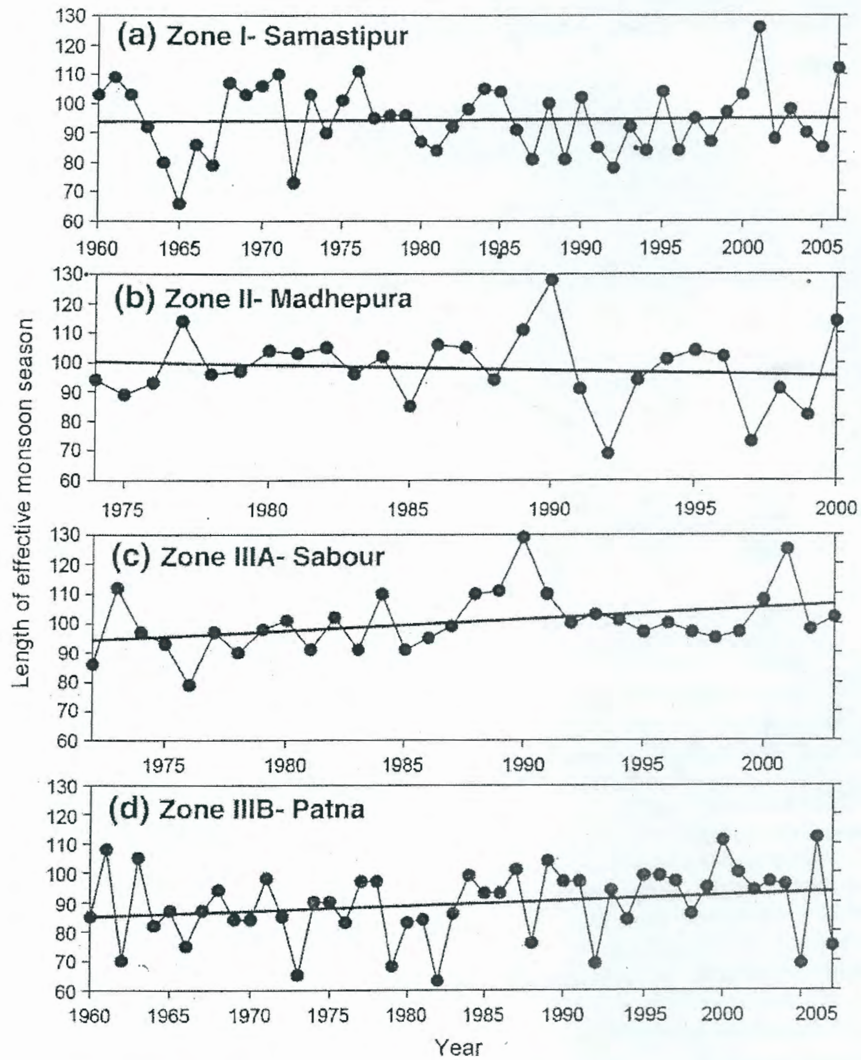

Fig. 4. Variability and trends in the length of monsoon season at different stations in Bihar.

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