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Variation of temperature and rainfall at Patna

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सार – इस शोध पत्र में, साधारण गैर-प्राचलिक परीक्षणों का उपयोग करके पटना में तापमान और वर्षा में परिवर्तनशीलता का विश्लेषण किया गया है। पटना के अधिकतम और न्यूनतम तापमानों की वार्षिक प्रवृत्तियों, वार्षिक वर्षा, वार्षिक अधिकतम दैनिक वर्षा, वर्ष में वर्षा के दिनों की संख्या, वार्षिक औसत वर्षा प्रति वर्षा वाले दिन तथा प्रति वर्षा के दिन अधिकतम से औसत के अनुपात की जाँच की गई है। वर्ष के प्रत्येक माह की कुल मासिक वर्षा की प्रवृत्ति, माह में अधिकतम दैनिक वर्षा और माह में वर्षा के दिनों की संख्या का भी निर्धारण किया गया है। साधारण मान-कैन्डल परीक्षण का उपयोग करके आँकड़ों की मासिक प्रवृत्ति से शहर में वर्षा के पैटर्न में सांख्यिकीय रूप से महत्वपूर्ण परिवर्तनों का पता चला है।

ABSTRACT. In this paper, the variation of temperature and rainfall at Patna are analysed using simple non-parametric tests. The trends in the annual maximum and minimum daily temperatures, annual rainfall, annual maximum daily rainfall, number of rainy days in a year, the annual average rainfall per rainy day and the ratio of maximum to average rainfall per rainy day at Patna have been examined. Tends in total monthly rainfall, Highest daily rainfall in a month and number of rainy days in a month have also been determined for every month in a year. The monthly trends of data using simple Mann-Kendall test indicated statistically significant changes in rainfall pattern for the city.

Key words – Monsoon pattern, Rainfall pattern, Climate change.

1. Introduction

Climate change and global warming arising from the anthropogenic activity driven emissions of greenhouse gases have emerged as one of the most serious environmental issues in the last two decades confronting humanity. Although the subject of climate change is vast, the changing pattern of precipitation deserves urgent and systematic attention as it will affect the availability of water and subsequently food supply and the occurrence of water related disasters triggered by extreme events. Precipitation is the major driving force in the land phase of the hydrologic system and changes in its pattern could have direct impact on water resources availability.

The IPCC estimates that even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1 °C per decade would be expected (Parry, 2007) and will likely affect global hydrological systems, ecosystems, sea level, crop production and related processes. It is understood that changes in precipitation levels will be accompanied by altered evaporation rates as temperatures rise. The combination of these changes will have a profound effect on soil moisture increasing the likelihood of flooding. Therefore, changes in climatic variables, such as temporal trends of temperature and precipitation, can help in understanding impact of these variables on water resources and hence on societies and ecosystems.

A temporal trend describes the long smooth movement of the variable lasting over a span of observations, ignoring the short term fluctuation. The analysis of trend is primarily estimation of the magnitude of trend along with the statistical significance of the value (*p*-value). Identification of long-term trends in climate change provide information for decision-makers and resource managers that allow them to better anticipate and plan for the potential impacts of climate variability and change.

Various studies have been carried out in different parts in South Asia for detecting possible climate trends (Arora *et al*., 2005; Fowler and Archer, 2006; Hamid *et al*., 2013; Hingane *et al*., 1985; Marco *et al*., 2003; Pant and Kumar, 1997; Shrestha *et al*., 1999;

Singh *et al*., 2008; Zhang *et al*., 2006). Hingane *et al*. (1985) analysed long-term mean annual temperature records from 1901 to 1982 over India and observed that about 0.4 °C warming has taken place over India during the last eight decades mainly due to rise in maximum temperatures. Pant and Kumar (1997) have reported an increase in mean annual temperatures in India at the rate of 0.57 °C per 100 years. Fowler and Archer (2006) examined temperature data of seven climate stations in the Karakoram and Hindu Kush mountains for seasonal and annual trends using regression techniques. Their study showed significant increase in the mean and maximum winter temperatures while mean and minimum summer temperatures showed consistent decline. Arora *et al*. (2005) investigated temperature trend all over India using Mann Kendall non parametric technique and linear regression method. The results showed that mean temperature increased by 0.94 °C per 100 years for the post monsoon and 1.1 °C per 100 years for the winter season. Singh *et al*. (2008) have carried out an extensive analysis of basin wide temperature trends in northeast and central India. A warming trend was observed in seven of the nine river basin studied. The other two basins in their study showed a cooling trend. Hamid *et al*. (2013) carried out the trend analysis using Mann-Kendall non parametric test in meteorological data of Delhi. It was found that the maximum annual temperature has an increasing trend whereas the minimum annual temperature has a decreasing trend. The trends of annual as well as the monsoon rainfalls were also found to be increasing for Delhi. Several studies as mentioned above have indicated that the south Asia region is indeed warming and the trend of warming is broadly consistent with the global warming trend.

Global averaged precipitation is projected to increase, is expected to both increase and decrease at the regional and continental scales resulting due to various climatological factors at these scales (McCarthy, 2001). Similar findings have been reported for rainfall by various authors for the plains of India (Mooley and Parthasarathy, 1984; Parthasarathiy and Dhar, 1976; Singh *et al*., 2008; Srivastava *et al*., 1998). Various authors, such as Pant *et al*. (1999); Shrestha *et al*. (1999); Archer and Fowler (2004) and Kothawale and Rupa Kumar (2005) have made attempts to study rainfall trends over various parts of the Himalayas. The data analysis for seasonal and annual rainfall did not show any significant trend over western Himalaya during the period 1893-1990 (Pant *et al*., 1999). Shrestha *et al*. (1999) found no trend in monsoon precipitation between 1948 and 1994 in the Nepalese Himalaya. Sharma and Chadha (2000) found an increasing trend in rainfall at some stations and a decreasing trend at other stations in the Kosi basin in eastern Nepal and Southern Tibet. A slight downward trend in monsoon rainfall and a slight upward trend in winter rainfall during 1964-1992 was analysed for the Beas catchment by Sen Roy and Balling (2004). Archer and Fowler (2004), who studied the precipitation at 17 stations in the upper Indus Basin, did not find statistically significant long term trends in annual or seasonal precipitation over the last century. In their study on spatial and temporal variation in precipitation in the Upper Indus Basin included only the Srinagar Station from Kashmir valley. The trend of precipitation and runoff has also been studied by Xu *et al*. (2010) in major Chinese rivers in order to find out any human intervention in the trend from 1951 to 2000. They used the Mann-Kendall statistics for the detection in the trends of precipitation. Several precipitation trend studies have also been carried out in the South Asia region. Marco *et al*. (2003) showed that there is an increasing precipitation trend throughout the year in southwest of Xinjiang which is an area adjacent to Northern part of Pakistan and in Jammu-Kashmir which is southwest of Tibet. Zhang *et al*. (2006) detected an upward precipitation trend in middle and lower part of Yangtze basin, China. Jiang *et al*. (2007) investigated temporal trends of annual and seasonal precipitation from 1951 to 2003 in the Hanjiang basin in China using Mann-Kendall and the linear regression methods. Results indicated that precipitation has no significant trend but a significant increasing trend for temperature was seen in most parts of the basin. Further, a decreasing trend was seen in mean annual, spring and winter runoffs in the Danjiangkou reservoir basin. Rana *et al*. (2012) determined long term trends in rainfall by Mann-Kendall rank statistics and linear regression in Delhi and Mumbai, during the period from 1951 to 2004. Precipitation data was studied on the basis of months, seasons and years, and the total period divided in the two different time periods of 1951 to 1980 and 1981 to 2004 for detailed analysis. Jain and Kumar (2012) have reviewed studies pertaining to trends in rainfall, rainy days and temperatures over India. However, no detailed study on, temperature and rainfall tends for Patna has been reported in the literature.

Mann-Kendall test has been the popular method to find the trend in temperature, rainfall and evaporation (both monthly and annual) and in some studies show significant trends in rainfall and temperature (Gocic and Trajkovic, 2013). In the present study, monthly and annual variation of the temperatures and rainfall at Patna have been analysed to study the variability of annual temperature and annual and monthly rainfall to evaluate the existence of long term trends.

2. Study area

Patna is one of the oldest continuously inhabited places in the world located on the southern bank of the river Ganges. The city is approximately 35 km long and 16 km to 18 km wide. The city is bounded in the north by river Ganga, in the south and east by river Punpun and in the west by river Sone. Patna district is situated between 25º13′ and 25º45′ North latitude and 84º 43′ and 86º 44′ East longitude with a height of 51 meters above mean sea level. Patna is the capital of the Indian state of Biharand is the second most populous city in Eastern India after Kolkata. A characteristic of the geography of Patna is its confluence of its rivers. River Ganga is joined by four other rivers: Ghaghara, Gandak, Sone and Punpun. Patna is unique in having four large rivers in its vicinity. It is a large riverine city and has an entirely alluvial fertile plain and flat region. Patna has a humid subtropical climate with extremely hot summers from late March to early June, the monsoon rainfall from late June to September and a mild winter from November to February.

3. Methodology

To identify the trend in climatic variables, the non-parametric Mann-Kendall (MK) test has been employed by a number of researchers(Gocic and Trajkovic, 2013; Singh *et al*., 2008; Yue *et al*., 2002; Zhang *et al*., 2006; Zhang *et al*., 2000). In the present study, the commonly used nonparametric MK test has also been applied to determine monotonic trends in different variables. The data for analysis of temperature and rainfall at Patna were obtained from India Meteorological Department Patna for the period1975 to 2012. However, the daily data of rainfall was available for the period of 1975-2009 only. The MK test has been applied to the data series without pre-whitening using the wq package in R (Jassby and Cloern, 2014) and the zyp package in R (Bronaugh and Werner, 2013) using two methods for prewhitening described in (Zhang *et al*., 2000) and (Yue *et al*., 2002). The test has been applied to determine the trends in the annual total rainfall data, highest daily rainfall in a year, number of rainy days, maximum temperature and minimum temperatures. The test has also been performed for the average rainfall per rainy day and the ratio of maximum rainfall to average rainfall per rainy day. The average rainfall has been calculated based on the number of rainy days which is indicative of rainfall intensity. The trends in monthly data of total monthly rainfall, highest daily rainfall in a month and number of rainy days in a month have also been determined.

4. Mann-Kendall test

One of the widely used non-parametric tests for detecting a trend in hydro-climatic time series is the Mann-Kendall (MK) test. Kendall (1938) proposed a measure "tau" to estimate the strength of the monotonic relationship between two variables. Mann (1945) suggested using the test for significance of Kendall's tau, where one of the variables is time as a test for trend. The test is well known as Mann-Kendall's test, which is powerful for uncovering deterministic trends. The null hypothesis of randomness against the alternative hypothesis of a monotonic trend can be accepted/rejected using this test. The main advantage of the Mann-Kendall test lies in its dependence on only a few assumptions: the potential trends may be either linear or nonlinear, and no assumptions are made regarding the underlying statistical distribution. Nevertheless, it is well recognised that the Mann-Kendall test is not robust against autocorrelation in the sense that false positive trend identifications get more likely. With a positively auto-correlated series, there are more chances of a series being detected as having a trend while there may be actually none (Bayazit and Önöz, 2007). The case is reverse for negatively auto-correlated series, where trends fail to get detected. This effect depends on the sample size as well as on the magnitude of the trend to be identified. Pre-whitening has been used to detect trend in time series in presence of autocorrelation. Pre-whitening techniques introduced to remove effects induced by autocorrelation may also bias the Mann-Kendall test result (Bayazit and Önöz, 2007).

For pre-whitening, the data series is tested for serial correlation. If the lag-1 auto-correlation (r_1) is found to be non-significant at 95% confidence level, then Mann-Kendall test is applied to the original data series (x_1, x_2,…, x_n), otherwise, Mann-Kendall test is applied on 'Pre-whitened' series obtained as (x_2-r_1x_1, x_3-r_1x_2,…, x_n- r_1x_{n-1}) (Yue *et al*., 2002; Zhang *et al*., 2000).

The MK statistic (S) is defined as follows (Salas, 1993):

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}\left(X_j - X_i\right) \tag{1}$$

where, N is the number of data points. Assuming (X_j - X_i) = θ, the value of sgn (θ) is computed as follows:

$$\operatorname{sgn}(\theta) = \begin{cases} +1 \text{ if } \theta > 1 \\ 0 \quad \text{if } \theta = 1 \\ -1 \text{ if } \theta < 1 \end{cases} \tag{2}$$

The statistic represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N>10), the test is conducted with normal distribution assumption (Helsel and Hirsch, 1992) provided there are not many tied values within the data set. The test entails calculation of S as described in equation (1) and the variance as follows:

$$Var(S)=\frac{1}{18}\left[N(N-1)(2N+5)-\sum_{k=1}^{n} t_k(t_k-1)(2t_k+5)\right] \quad (3)$$

where, n is the number of tied (zero difference between compared values) groups, and t_k is the number of data points in the k^{th} tied group. The standard normal test statistic, Z, is then computed as (Hirsch *et al*., 1992):

$$Z=\begin{cases}\frac{S-1}{\sqrt{Var(S)}} & \text{if} \quad S>0\\ 0 & \text{if} \quad S=0\\ \frac{S+1}{\sqrt{Var(S)}} & \text{if} \quad S<0\end{cases} \quad (4)$$

If the value of Z lies within the limits of ± 1.96, the null hypothesis of having no trend in the series cannot be rejected at 95% level of confidence.

5. Sen's slope estimator

The magnitude of trend in a time series can be determined using non-parametric Sen's estimator (Sen, 1968). This method assumes a linear trend in the time series and the slopes (T_i) of all data pairs are calculated as follows:

$$T_i=\frac{X_j-X_k}{j-k} \quad \forall i=1,...N \quad (5)$$

where, X_j and X_k are data values at time j and k ($j>k$) respectively. The median of these N values of T_i gives the Sen's estimator of slope β. A positive value of β indicates an upward trend and a negative value indicates a downward trend in the time series (Sen, 1968).

6. Results and discussion

The time series of annual rainfall has been presented in Fig. 1. The solid black line in this figure represents the annual rainfall variation and the solid grey line at the bottom represents the variation of the highest daily rainfall in that year. From Fig. 1 it can be seen that the highest value of annual rainfall is in the year 2007 and the lowest value is in the year 1982. Also, the highest daily rainfall occurred in the year 2007. The time series of number of rainy days and the ratio of maximum to average rainfall intensity is also shown in Fig. 2. The average rainfall is

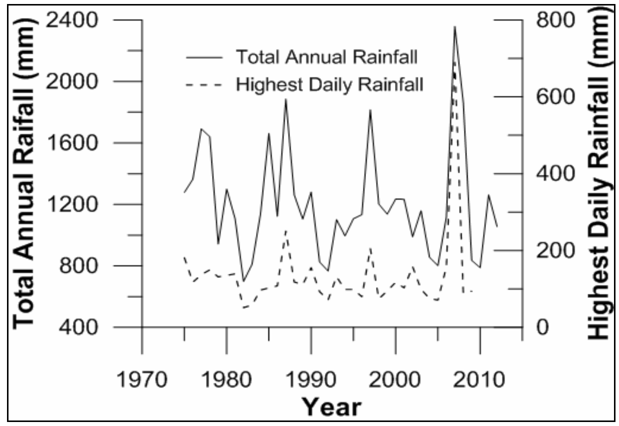

Fig. 1. Time series of annual total and highest daily rainfall at Patna

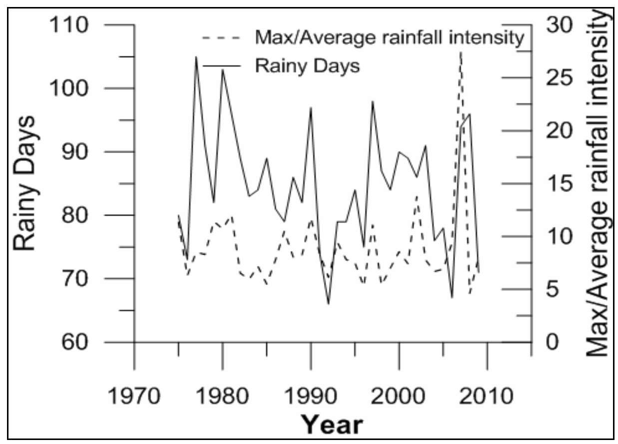

Fig. 2. Time series of number of rainy days in a year and the ratio of maximum to average rainfall intensity (The average rainfall is calculated by dividing the total annual rainfall by number of rainy days)

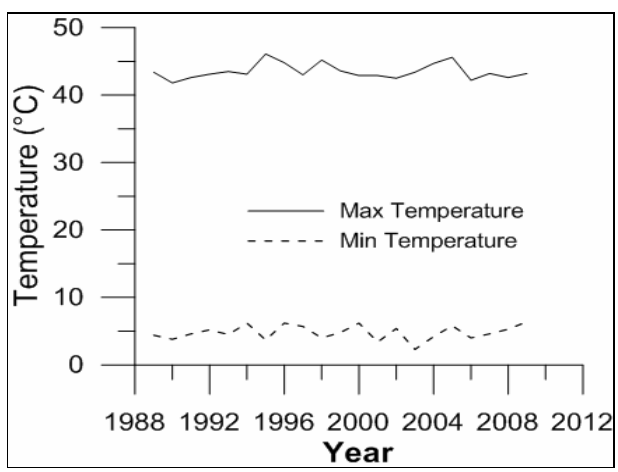

Fig. 3. Variation of the maximum and minimum values of temperature at Patna

TABLE 1

Results of Mann-Kendall test and estimated Sen's slope for trends of rainfall and temperature at Patna assuming no autocorrelation

Description of data	MK statistic	Variance of MK statistic	p-value	Sen's slope
Maximum Temperature (1989-2009)	-3	1091	0.95 (Insignificant)	0
Minimum Temperature (1989-2009)	23	1091	0.51 (Insignificant)	0.024
Annual Rainfall (1975-2012)	-83	6327	0.30 (Insignificant)	-3.788
Number of Rainy Days in a year (1975-2009)	-54	4943	0.45 (Insignificant)	-0.167
Average Rainfall per rainy day (1975-2009)	-15	4958	0.84 (Insignificant)	-0.009
Highest daily rainfall (1975-2009)	-86	4957	0.23 (Insignificant)	-0.871
Ratio of Maximum Daily to Average Rainfall per rainy day (1975-2009)	-53	4958	0.46 (Insignificant)	-0.030

TABLE 2

Results of Mann-Kendall test and estimated Sen's slope for trends of rainfall and temperature at Patna using method proposed by Yue *et al*. (2002) in columns (2)-(4) and (Zhang *et al*., 2000) in columns (5) - (7)

Description of data	MK statistic	*p*-value	Auto corr. of detrended time series	MK Statistic	*p*-value	Auto corr. of detrended time series
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Maximum Temperature (1989-2009)	0.04	0.82 (Insignificant)	0.180	0.04	0.82 (Insignificant)	0.179
Minimum Temperature (1989-2009)	0.09	0.58 (Insignificant)	-0.241	0.11	0.50 (Insignificant)	-0.252
Annual Rainfall (1975-2012)	-0.06	0.63 (Insignificant)	0.256	-0.06	0.63 (Insignificant)	0.257
Number of Rainy Days in a year (1975-2009)	-0.11	0.36 (Insignificant)	0.019	-0.09	0.45 (Insignificant)	0.047
Average Rainfall per rainy day (1975-2009)	0.03	0.84 (Insignificant)	0.355	0.02	0.86 (Insignificant)	0.348
Highest daily rainfall (1975-2009)	-0.12	0.33 (Insignificant)	0.028	-0.14	0.23 (Insignificant)	-0.006
Ratio of Maximum Daily to Average Rainfall per rainy day (1975-2009)	-0.03	0.84 (Insignificant)	-0.094	-0.08	0.46 (Insignificant)	-0.121

TABLE 3

Monthly trends of rainfall in Patna (1975-2009) with *p*-values based in Mann-Kendall statistic

Month	Monthly rainfall		Highest daily rainfall in the month		Number of rainy days	
	Sen's slope	*p*-value	Sen's slope	*p*-value	Sen's slope	*p*-value
January	0	0.898	-0.05	0.639	0	0.896
February	-0.15	0.062	-0.06	0.117	-0.05	0.091
March	0.01	0.557	0.04	0.39	0	0.218
April	1.22	0.01*	0.55	0.017*	0.13	0.02*
May	5.32	0.001*	1.56	0.006*	0.29	0.001*
June	8.19	<0.001*	1.33	0.033*	0.39	<0.001*
July	-5.35	0.044*	0.07	0.865	-0.09	0.102
August	-2.96	0.201	-0.07	0.91	-0.17	0.024*
September	-7.31	<0.001*	-1.9	<0.001*	-0.42	<0.001*
October	-1.95	<0.001*	-1.18	<0.001*	-0.18	<0.001*
November	0	0.936	0	0.91	0	0.859
December	0.09	0.262	0.07	0.227	0	0.977

*Trends are significant at 95% confidence level; Negative values of Sen's slope are indicative of decreasing trend and *vise-versa*

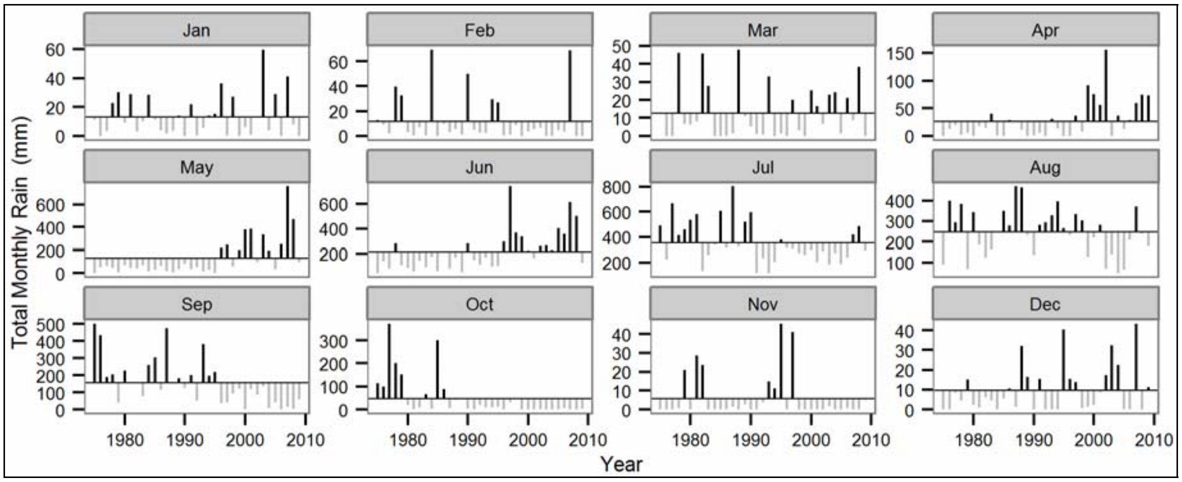

Fig. 4. Total monthly rainfall (mm); The grey bars denote monthly rainfall less than mean monthly rainfall and black bars denote monthly rainfall more than mean monthly rainfall

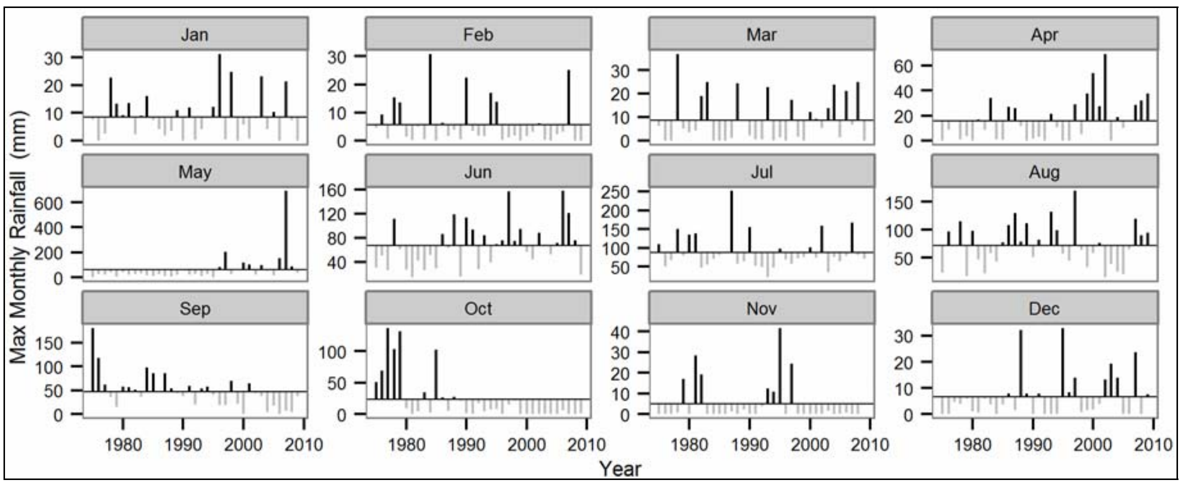

Fig. 5. Highest daily rainfall in a month (in mm); The grey bars denote highest daily rainfall in a month less than mean highest daily rainfall in a month and black bars denote more than mean maximum daily rainfall in a month

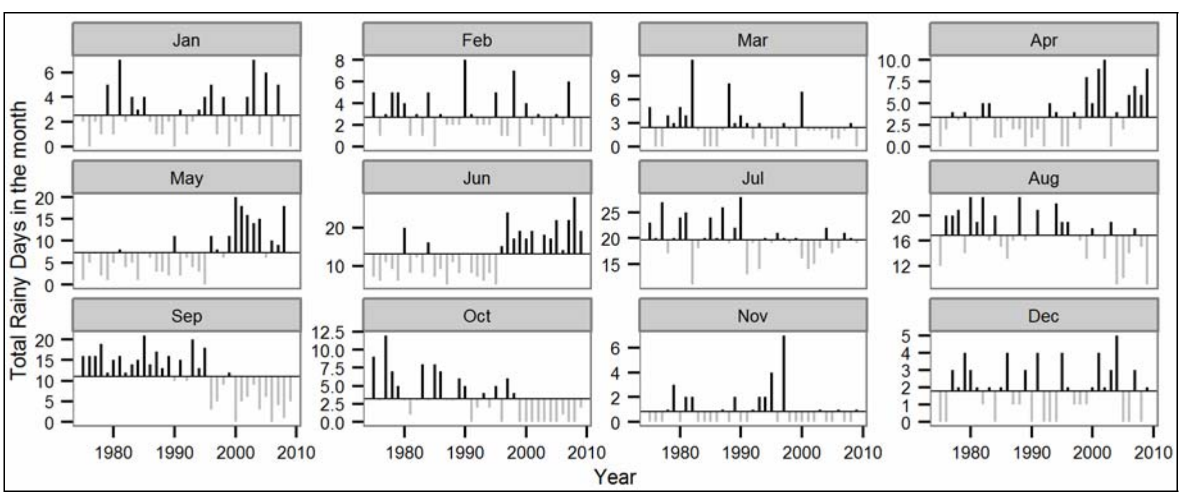

Fig. 6. Number of rainy days for the month; the grey bars denote number of rainy days in the month less than mean number of rainy days for the month and black bars denote number of rainy days in the month more than mean number of rainy days for the month

calculated by dividing the total annual rainfall by number of rainy days in that year. These data have been analysed for the trends of number of rainy days in a year and the highest daily rainfall in a year in comparison to the average daily rainfall in a year based on the number of rainy days.

The annual maximum and minimum value of temperature have been presented in Fig. 3. It can be seen that the extreme maximum value of temperature at Patna occurred in the year 1995 and extreme minimum occurred in the year 2003.

The MK test has been applied to the annual total rainfall data, highest daily rainfall in a year, number of rainy days, the average rainfall per rainy day, the ratio of maximum to average rainfall per rainy day maximum temperatures and minimum temperatures and the results have been presented in Tables 1& 2. The value of normalised test statistic indicates no significant trend at 95% level of significance using the time series data without pre-whitening (Table 1) and the time series data with pre-whitening (Table 2) in all the cases.

Further analysis of the time series of total monthly rainfall, highest daily rainfall in a month and monthly rainy days were carried out for each month in order to determine the monthly trends. Firstly, the deviations from the mean of monthly rain fall, highest daily rainfall in a month and monthly rainy days were plotted (Figs. 4-6). Then the Sen's slope for the trends of each month were computed using wq package in R (Jassby and Cloern, 2014). The levels of significance of the monthly trends were calculated using the MK statistic and the results are presented in Table 3. The monthly trends of total monthly rain fall, highest daily rainfall in a month and monthly rainy days showed increasing trend in the months of April, May and June and decreasing trends in September and October with high level of significance (p-values < 0.05). This is indicative of shift in the monsoon season towards the pre-monsoon season. Absence of annual trends and significant monthly trends in April, May, June, September and October indicate changes in monthly rainfall pattern for the city of Patna. The non-homogeneity of monthly trends were also tested using the method suggested by van Belle and Hughes (1984) and implemented in wq (Jassby and Cloern, 2014) for the three time series of total monthly rain fall, highest daily rainfall in a month and monthly rainy days and they were found to be significant with *p*-values of <0.001 in all the cases. Such changes in rainfall pattern may affect the agricultural activity around the city as it is one of the major contributors to the economy of the city as well as the state of Bihar.

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