Atmospheric Research 180 (2016) 211–225

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Precipitation and temperature changes in eastern India by multiple trend detection methods

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ARTICLE INFO

Article history:
Received 9 October 2015
Received in revised form 25 April 2016
Accepted 28 April 2016
Available online 9 May 2016

Keywords:
Eastern India
Precipitation
Temperature
Seasonal
Trend detection
Correlation

ABSTRACT

The present study deals with spatial and temporal trend analysis of precipitation and temperature (1970–2004) in eastern India. Long-term trend direction and magnitude of change over time (annual and seasonal) were detected and analyzed by Mann–Kendall test, Sen's slope estimator, Least square linear regression, Spearman rank correlation and Sequential Mann–Kendall test. In addition to it, correlation analysis was also performed. Trend analysis of annual rainfall by different methods indicated similar annual trends in eastern India. North-eastern, south-eastern and western parts of eastern India indicated increasing trend, whereas the north-western, central and southern parts showed decreasing trend. A similar trend was observed by different methods in case of seasonal rainfall. During winter season, decreasing trend was observed in the central part, whereas similar results were obtained for pre-and post-monsoon in the western part. The trend during monsoon season was found similar to annual rainfall trend. Abrupt change in trend of rainfall with time was lacking in eastern India. Maximum temperature analysis indicated increasing trend in the western part for all the seasons (except in monsoon) and decreasing trend in the eastern part. On the contrary, increasing trend was observed in the eastern part and decreasing trend in the western half of the study area for all the seasons in case of minimum temperature. Significant changes were observed during monsoon season as compared to other seasons. A decreasing trend in mean temperature was observed in the central, southern and north western parts, whereas it was found to be increasing in the north-eastern, western and south-eastern parts. In majority of the eastern India region, any abrupt change of trend in temperatures with time was not clearly observed. Negative correlation between rainfall and maximum temperature was observed in the entire eastern India. Similar results were observed in case of minimum temperature (monsoon) and mean temperature (pre-monsoon and monsoon).

1. Introduction

Climate change is a global issue and threatens basic needs such as food, water, health and shelter. Precipitation and temperature are the most important variables for climate and hydro-meteorology which can be used for understanding the climate of a region and diagnosing climate change. Changes in its pattern may lead to flood, drought, loss of biodiversity and agricultural productivity (Sharma et al., 2011; Radinović and Ćurić, 2014; Sun et al., 2015; Zhang et al., 2015). Therefore, its spatial and temporal trends (Kundzewicz and Robson, 2000) are important for climate analyst and water resources planner.

Large spatio-temporal variations (magnitude and rate of change) in precipitation and temperature exist between climatically different regions (Yue and Hashino, 2003; Zhang et al., 2013). It has been recognized that the global or continental scale observations of historical or projections of the future climate are less than useful for the local or regional scale planning (Barsugli et al., 2009; Sharma et al., 2014). For example, convective precipitation leads to flash floods in small areas with both large spatial and temporal variability (Ćurić and Janc, 2011a). Knowledge of it is important for various predictions and analyses, for which numerical cloud model may be a useful tool (Ćurić and Janc, 2011b). Assessment of historical trends or future projections on a regional or local scale is essential. The IPCC has also demonstrated the need of same for climate change assessments. It has also found several gaps in the knowledge related to climate change and water (IPCC, 2007).

Detection of past trend, change, and variability in the time series of hydro-climatic variables is very important for understanding the õpotential impact of future changes in the region (Some'e et al., 2012). Statistical analysis could be extended to analyse these climatic parameters. Various parametric and non-parametric statistical tests in recent past have been widely used in India for the assessment of trends in hydro-meteorological time series, which includes rainfall

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http://dx.doi.org/10.1016/j.atmosres.2016.04.019
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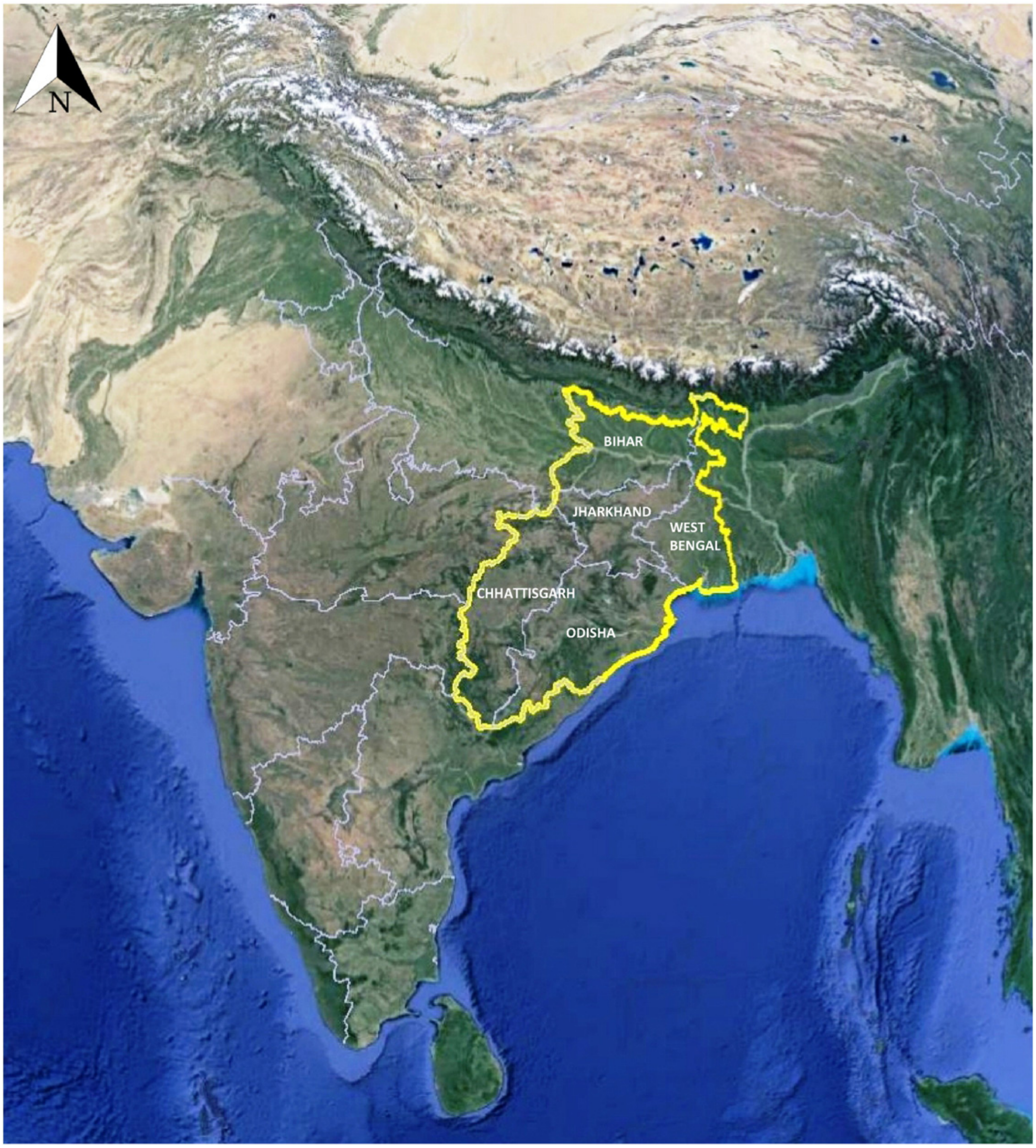

Fig. 1. Eastern India and its states.
(Source: Google Earth).

(Basistha et al., 2009; Ghosh et al., 2009; Kumar et al., 2010; Duhan and Pandey, 2013; Jain et al., 2013) and temperature (e.g., Kothawale and Rupa Kumar, 2005; Arora et al., 2005; Kothawale et al., 2010; Rao et al., 2014). Similarly, several researchers across the world have also studied the trends in temperature and precipitation (Ventura et al., 2002; Roy and Balling, 2004; del Rio et al., 2005; Liu et al., 2008; de la Casa and Nasello, 2010; Tabari and Talaee, 2011; Saboohi et al., 2012; Dash et al., 2013; Sayemuzzaman and Jha, 2014; Yürekli, 2015).

India is a land of diverse terrains and climates. One of the most vulnerable regions in India is its eastern part comprising states of West Bengal, Bihar, Jharkhand, Odisha, and Chhattisgarh having mostly warm-humid and composite climate. Rainfed agriculture in eastern India is entirely dependent on the behaviour of south-west monsoon. Despite of receiving high mean annual rainfall (1200–2000 mm), rainfed crops in the region suffer from either drought or flood situations in each alternate year. The reasons are attributed to the events of high intense rainfall in monsoon season that bring about 80% of the mean annual rainfall in few storms. Apart from the eccentric monsoon, the effect of climate change is also observed to exacerbate the crop production system further in the recent years. It is apprehended that the trend of climate change is likely to intensify in the coming years and appropriate strategy is needed to be prepared. Therefore, it is very important to examine the possible trend in the climatic parameters of eastern India.

Limited work has been done on hydrological impacts of climate change for Indian region/basins. Therefore, spatio-temporal assessment of climate change is required which considers the causative factors of climate change (i.e., anthropogenic, meteorological parameters, etc.). Majority of the studies in recent years is based on either rainfall or temperature. Combined study of both including their covariability is still limited. There is still a lack of information on trends and covariability of precipitation and temperature, especially for the eastern region of India. Studies on various region specific aspects and their inter-relation with the climatic parameters are also scarce. Inter-seasonal and annual variations in rainfall and temperature have not been investigated in detail yet for eastern India, which is primarily

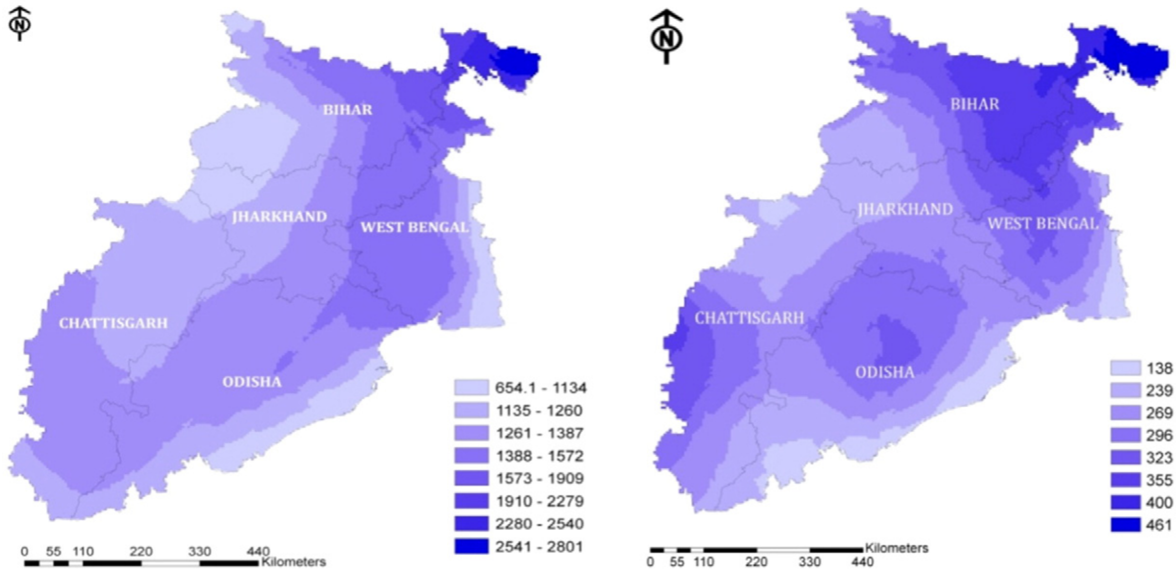

Fig. 2. Variation of average rainfall (a) and standard deviation of rainfall (b) in eastern India (mm).

rainfed. In India, trend detection studies are primarily concentrated to rainfall as compared to temperature with commonly used techniques such as Least square regression, Mann–Kendall test and Sen's slope estimator. More than one method should be used for the identification of temporal change/trend (Kundzewicz and Robson, 2004; Khaliq et al., 2009; Önöz and Bayazit, 2011; Sonali and Nagesh Kumar, 2013), which is almost lacking in all the studies over Indian region and past research. Moreover, previous studies mainly concentrated to trend analysis of rainfall or temperature homogenous regions in India. Detailed and robust analysis for identifying trends and effect of changing climate within homogenous regions is almost missing in previous works. Considering rainfall and temperature (maximum, minimum, and mean) within homogeneous regions at seasonal and annual level is rarely studied. In India, no studies have yet focused on starting time of trend with a formal trend detection technique like Sequential Mann Kendall test in detail.

Thus, the present study was aimed for studying climate change in eastern India by trend analysis of rainfall and temperature (minimum, mean and maximum) at the spatial and temporal scales (annual and seasonal). Statistical trend analysis techniques, namely the Least square linear regression (LSLR), Mann–Kendall test (MK), Sen's slope estimator (SS), Spearman Rank Correlation test (SR) and Sequential Mann-Kendall test (SQMK) were used. It also evaluates the possible spatio-temporal relationship between temperature and precipitation regimes. It is expected that the findings of this study will bring more insights into the linkage between climate change and hydrological cycle alongwith understanding of regional hydrologic behaviour. It will be helpful to formulate a regional strategy for water resources management. It will also act as a reference for climate impact studies, including those for assessment, adaptation and mitigation, disaster management plans for the eastern India region.

2. Study area

The eastern region of India mainly spreads over five states, namely West Bengal, Bihar, Jharkhand, Odisha and Chhattisgarh covering an area of approximately 553,643 km^2 (Fig. 1). Most part of the

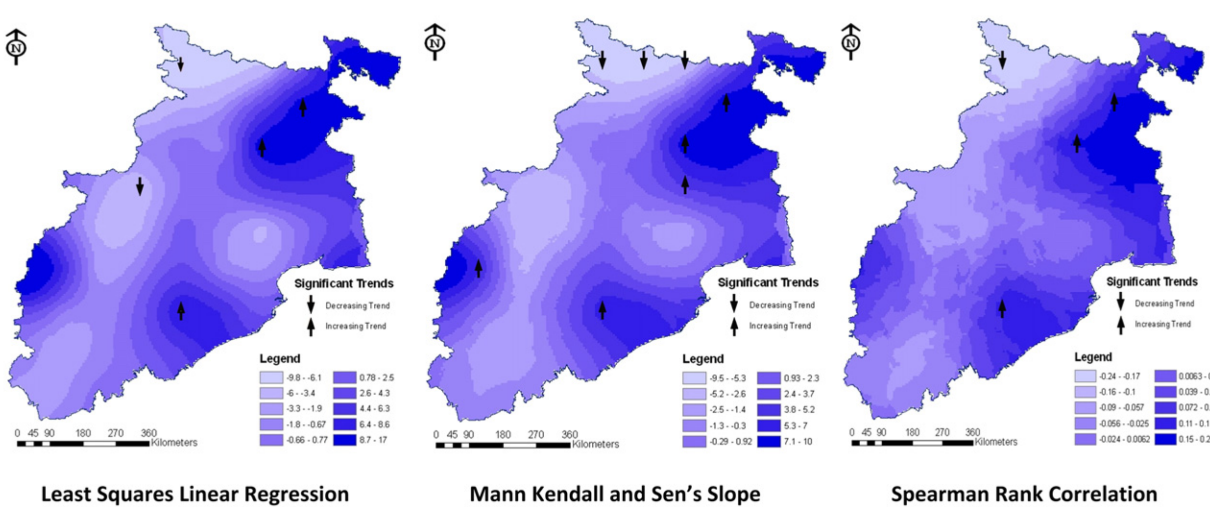

Fig. 3. Trend analysis of annual rainfall.

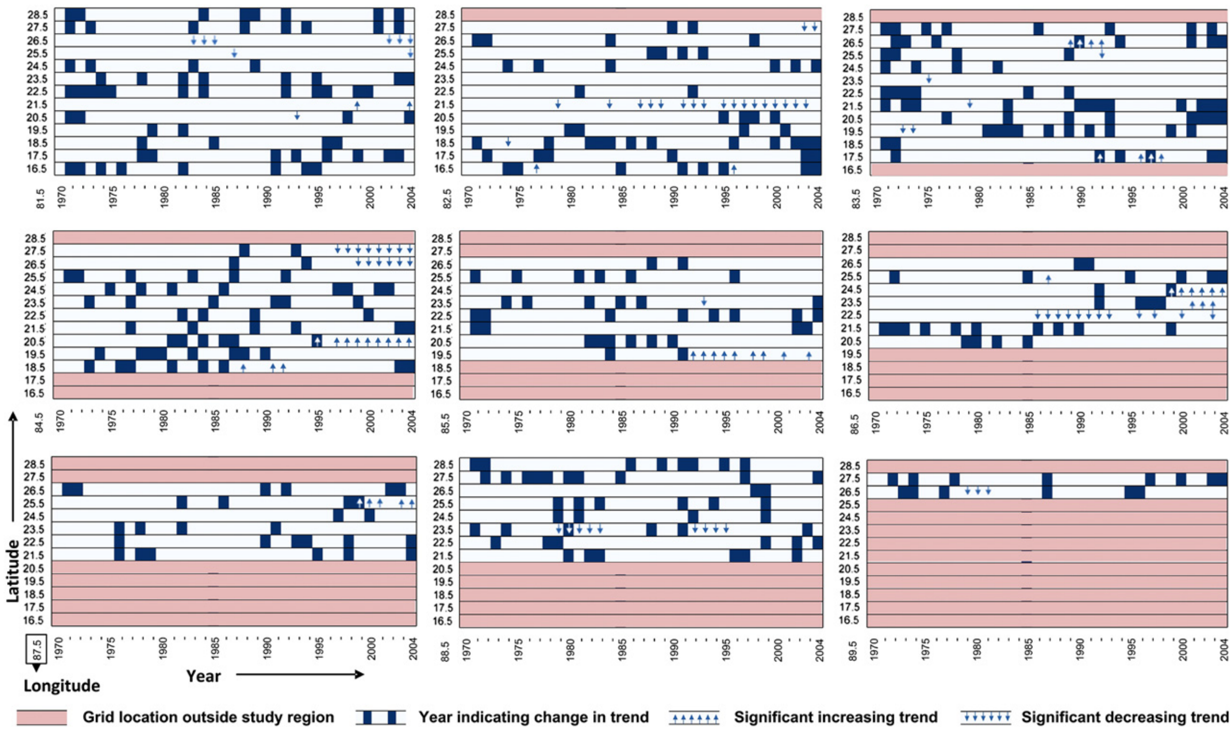

Fig. 4. Sequential Mann–Kendall test for annual rainfall.

region lies on the east coast of India between the Bay of Bengal and Indo-Gangetic plain. The region is bounded by the Nepal and Sikkim portion of the Himalayas in the north, the states of Uttar Pradesh, Madhya Pradesh and Maharashtra on the west, the state of Andhra Pradesh in the south and the Bay of Bengal in the east.

In eastern India, mainly warm-humid and composite climate exists with cold climate in extreme north of West Bengal. The interior states have a drier and slightly more extreme climate, especially during the winters and summers, but the whole region receives heavy, sustained rainfall throughout the months of monsoon. West Bengal and majority of Odisha falls under warm-humid climate. Here temperature is moderately high during day and night. This region has very high humidity and rainfall. Similarly, majority of Chhattisgarh except extreme southern part, extreme eastern and southern part of Jharkhand, alongwith eastern and northern Bihar falls under warm humid climate. Composite climate exist in Chhattisgarh, Jharkhand and Bihar having high temperature in summer and cold in winter. Humidity is low in summer whereas it is high in monsoon season.

3. Data and methods

Spatio-temporal variability of annual and seasonal (winter, pre-monsoon, monsoon, and post-monsoon) rainfall alongwith temperature (maximum, minimum and mean) was studied by multiple trend analysis techniques (Mann–Kendall test, Sen's slope estimate, Least square linear regression, Spearman rank correlation, and Sequential Mann–Kendall test) at 95% confidence level (significance level of 0.05) using IMD (Indian Meteorological Department) gridded (1° x 1°) rainfall and temperature data of eastern India for a period of 35 years (1970–2004). Study was also carried out to investigate the spatio-temporal correlation between rainfall and temperature.

3.1. Data

Gridded data sets of rainfall and temperature have been used in many hydrological and climatological studies worldwide, including India, for hydro-climatic forecasting, climate attribution studies and climate model performance assessments.

In the present study 1° × 1°gridded datasets of daily rainfall and temperature from the period 1970 to 2004 were used which was developed by the Indian Meteorological Department (IMD), Pune. Daily rainfall gridded dataset was developed considering 1384 stations in India which had a minimum 70% data availability during the analysis period in order to minimize the risk of generating temporal inhomogeneities in the gridded data due to varying station densities (Rajeevan et al., 2008). Multi-stage quality control of observed rainfall data was carried out before interpolating station rainfall data into regular grids. Basic data quality checks (such as rejecting values, greater than exceeding known extreme values, minimum temperature, greater than maximum temperature, same temperature values for many consecutive days, unusual high values, homogeneity, location of the station, typing error, missing data) were performed for each station, and then stations were selected based on data quality for the development of the gridded data sets of temperature and rainfall. The developed datasets were checked against the observed station data before releasing the data to users. Further, homogeneity, persistence and periodicity in the data were also analysed by autocorrelation. The Shepard interpolation method was used for interpolating station rainfall data into regular grids. The quality of the data set has been validated and can be used for examining long term rainfall trends (Rajeevan et al., 2008).

Similarly, temperature gridded data was developed using 395 stations data of daily temperature (minimum, maximum and mean) for the Indian region. The modified Shepard's angular distance weighting algorithm was used for interpolating the stations of temperature data into grids. These datasets were evaluated using the cross validation technique to estimate the interpolation error (root mean square error), which was found to be less than 0.5 °C. This data set was subjected to a comprehensive set of quality assurance procedures and found highly correlated with other global gridded data sets (Srivastava et al., 2009). The data set is

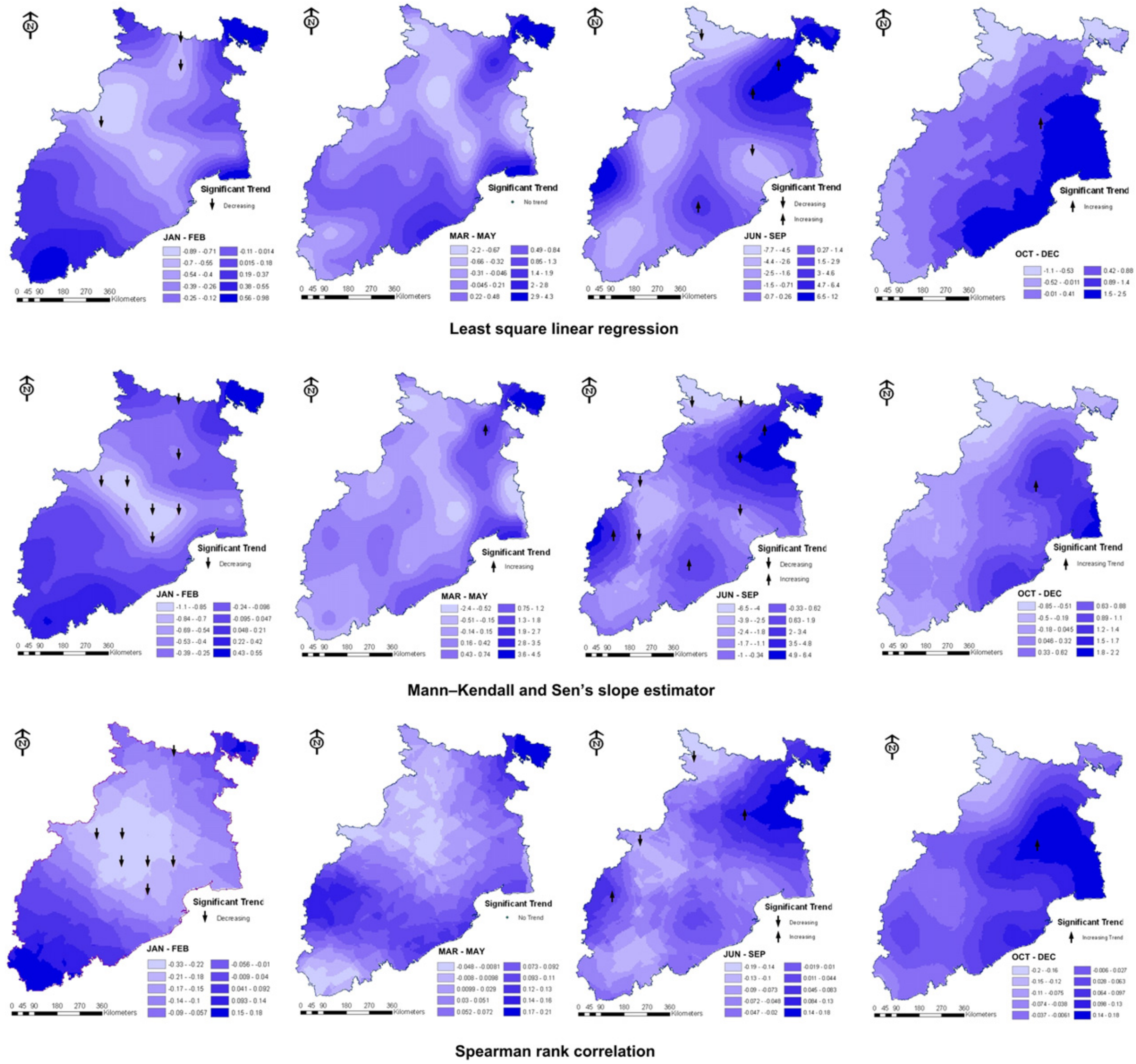

Fig. 5. Seasonal rainfall trend analysis.

homogeneous in space and time, which has been used for the validation of climate model simulation and trend analysis in the past.

3.2. Trend analysis

3.2.1. Mann–Kendall test (MK)

The Mann–Kendall test is a non-parametric rank based test (Kendall, 1975; Mann, 1945), which does not require the data to be distributed normally. The test statistic *S*, which has mean zero and a variance computed by Eq. (3), is calculated using Eqs. (1) and (2):

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} \text{sign}(x_i - x_j) \tag{1}$$

$$sign(x_i - x_j) = \begin{Bmatrix} +1 & for & (x_i - x_j) > 0 \\ 0 & for & (x_i - x_j) = 0 \\ -1 & for & (x_i - x_j) < 0 \end{Bmatrix} \tag{2}$$

$$Var(S) = \frac{\left[n(n-1)(2n+5) - \sum_{p-1}^{q} t_p(t_p - 1)(2t_p + 5)\right]}{18} \tag{3}$$

where, x_i and x_j are the annual values in years *i* and *j*. t_p is the number of ties for the *p*th value and *q* is the number of tied values. Standardized test statistic Z is computed by Eq. (4).

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

To test for monotonic trend at a significance level, the null hypothesis of no trend is rejected if the absolute value of standardized test statistic *Z* is greater than $Z_{1-\alpha/2}$.

3.2.2. Sen's slope estimate (SS)

If a linear trend is present in a time series, the true slope (change per unit time) can be estimated using a simple non-parametric procedure developed by Sen (1968). The slope estimates of *N* pairs of data are first computed by,

$$Q_i = \frac{x_j - x_k}{j - k} \quad for\ i = 1, \ldots\ldots\ldots, N \tag{5}$$

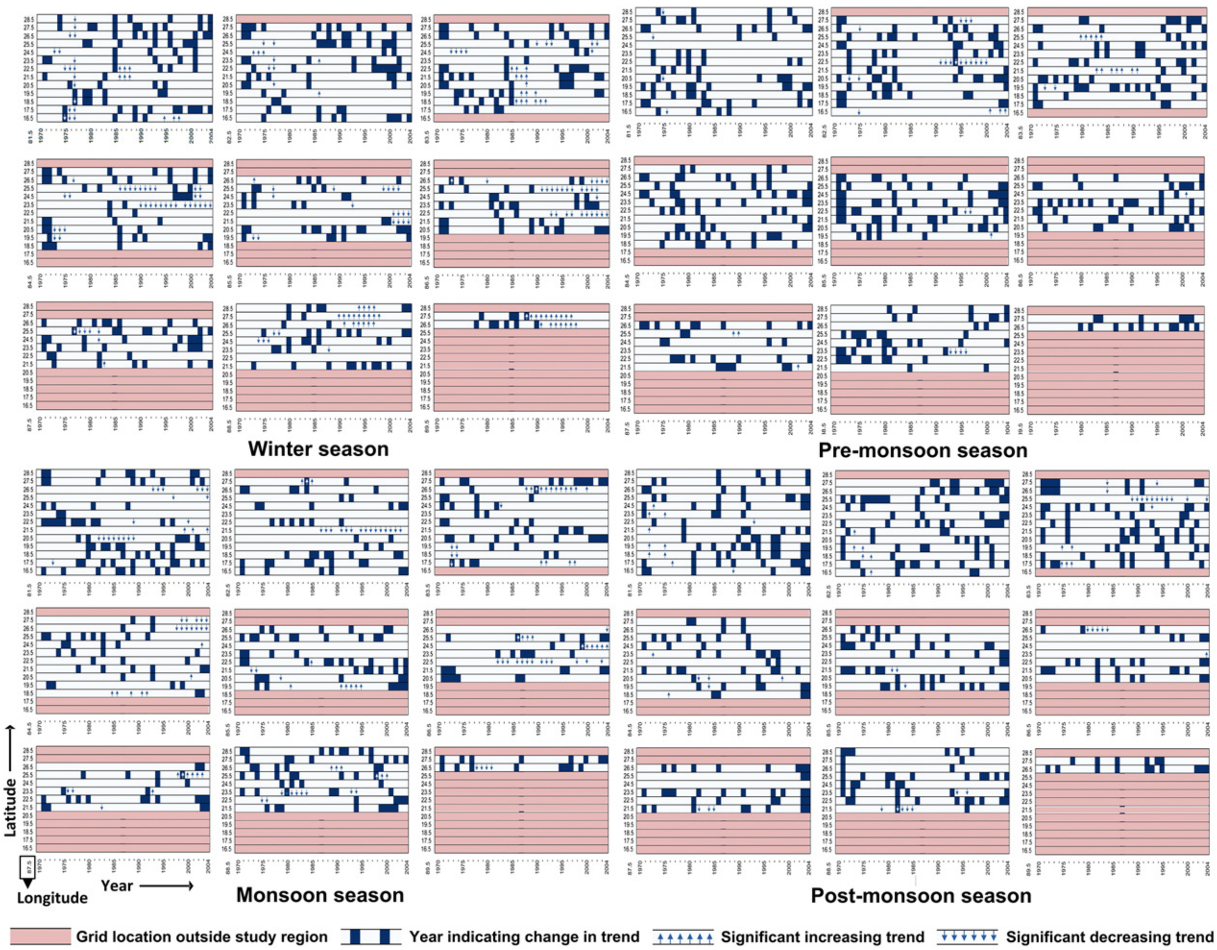

Fig. 6. Sequential Mann–Kendall test for seasonal rainfall.

where, x_j and x_k are data values at times j and k ($j > k$), respectively. The median of these N values of Q_i is Sen's estimator of slope. If N is odd, Sen's estimator is computed by,

$$Q_{med} = Q_{[(N+1)/2]}. \quad (6)$$

If N is even, Sen's estimator is computed by,

$$Q_{med} = \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right). \quad (7)$$

Positive and negative signs of test statistics indicate increasing and decreasing trends.

3.2.3. Least square linear regression method (LSLR)

Least square linear regression method is a parametric test. This test is used to describe the presence of linear trend in time series (Haan, 1977). The test statistic T is defined as,

$$T = \frac{\hat{b}}{se\left(\hat{b}\right)} \quad (8)$$

where, $\hat{b}$ is the estimated slope of regression line between observed values and time, whereas $se(\hat{b})$ stands for the standard error of estimated slope. Test statistic (T) follows a student's t-distribution with n-2 degree of freedom, where n is the sample size. The null hypothesis of slope zero will be rejected when the test statistic T value is greater than the critical value $t_{\alpha/2}$ with α as significance level.

3.2.4. Spearman rank correlation test (SR)

This is similar to the Mann–Kendall test method and is a non-parametric test. The Spearman rank correlation (SR) test is a simple method with uniform power for linear and non-linear trends and is commonly used to verify the absence of trends (Lettenmaier, 1976). In this test, the null hypothesis (H_0) is that all the data in the time series are independent and identically distributed; while the alternative hypothesis (H_1) is that increasing or decreasing trends exist. The SR test statistic D and the standardized test statistic Z_{SR} are expressed as follows:

$$D = 1 - \frac{6\sum_{i=1}^{n}(R_i - i)^2}{n(n^2 - 1)} \quad (9)$$

$$Z_{SR} = D\sqrt{\frac{n-2}{1-D^2}} \quad (10)$$

where, R_i is the rank of *ith* observation (X_i) in the time series and n is the length of the time series. Positive values of Z_{SR} indicate upward trends; while negative Z_{SR} indicate downward trends in the time series. When $|Z_{SR}| > t_{(n-2,1-\alpha/2)}$ the null hypothesis is rejected and a significant trend exists in the time series.

3.2.5. Sequential Mann–Kendall test (SQMK)

Sequential Mann–Kendall test is a progressive and retrograde analysis of the Mann–Kendall test (Sneyers, 1990). It gives sequential values u(t) and u′(t), respectively. These are standardized variables with zero mean

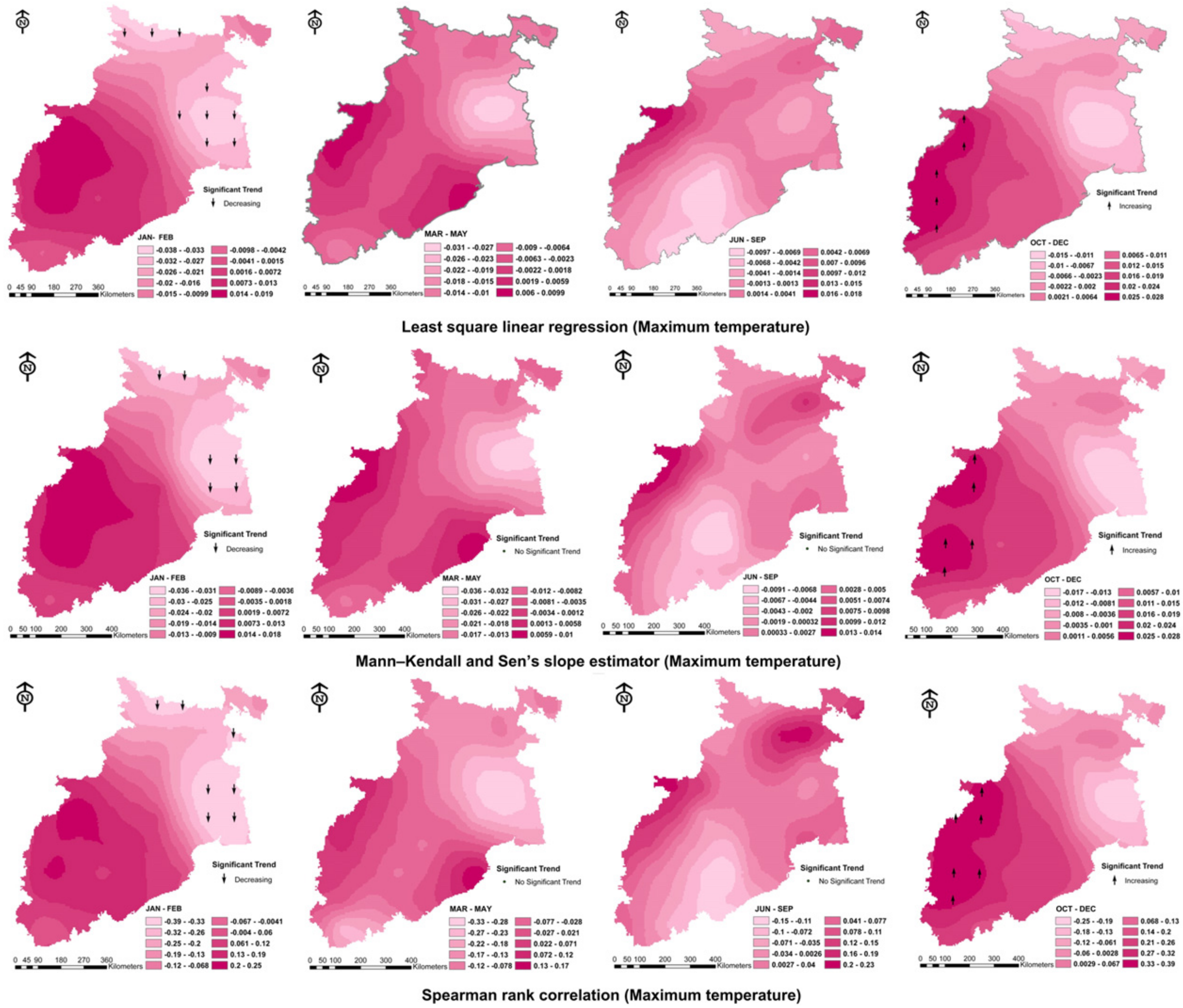

Fig. 7. Seasonal maximum temperature trend analysis.

and unit standard deviation. So its sequential behaviour fluctuates around the zero level. It provides the beginning as well as the changes over time.

The first step in this method is to find out n_j, number of time $x_j > x_i$ where x_i and x_j are the sequential values in a series. x_j ($j = 1,\ldots, n$) are compared with x_i ($i = 1,\ldots, j$). The test statistic t_j is calculated as,

$$t_j = \sum_{i}^{j} n_j. \tag{11}$$

The mean and variance of the test statistic t_j are:

$$E(t) = \frac{n(n-1)}{4} \tag{12}$$

$$Var(t_j) = \frac{\{j(j-1)(2j+5)\}}{72}. \tag{13}$$

After that $U(t_j)$ is calculated using,

$$U(t_j) = \frac{t_j - E(t)}{\sqrt{Var(t_j)}}. \tag{14}$$

In the same way $U'(t_j)$ is calculated starting from end of the series.

3.3. Pearson product-moment correlation

The Pearson product–moment correlation coefficient, one which is most widely used, measures the strength of the linear relationship between two variables. For response variables x_i and y_i of two time series, it is denoted as r and computed as,

$$r = \frac{\sum_{i=1}^{N}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{N}(y_i - \overline{y})^2}} \tag{15}$$

where $\overline{x}$ and $\overline{y}$ are the averages of the time series x_i and y_i. The correlation coefficient r describes the degree of closeness to a linear relationship between two variables x and y. The value of r varies from -1 to 1 and the coefficient of zero indicates that no linear relationship exists. Strong correlation is indicated by the value of r closer to maximum (positive) or minimum (negative), whereas the value of coefficient (r) is nearer to zero for weak correlation.

3.4. Spatial interpolation method

The ordinary Kriging estimate at any unsampled location is obtained by a linear combination of the available sample data and

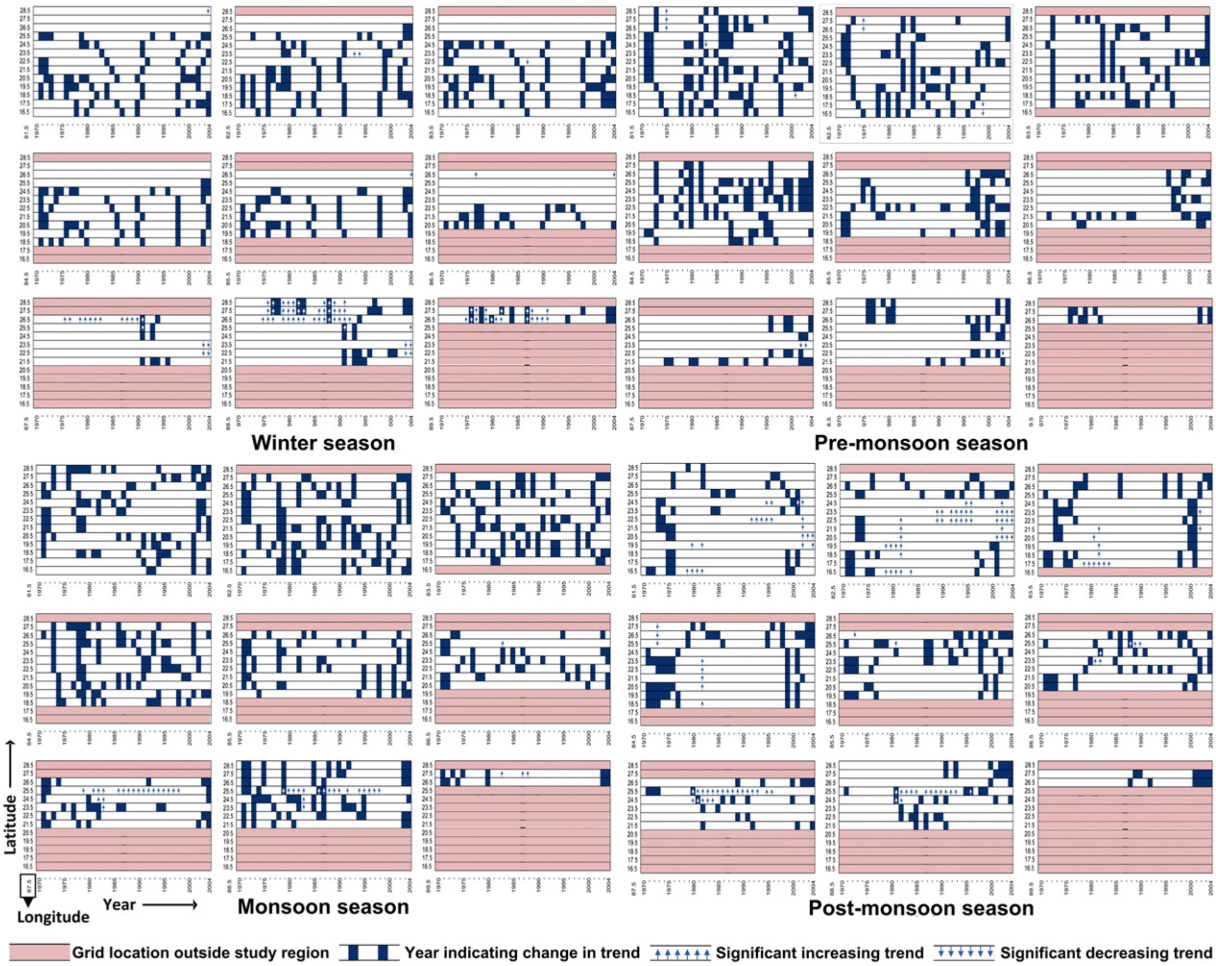

Fig. 8. Sequential Mann–Kendall test for seasonal maximum temperature.

is given by,

$$Z^*(u) = \sum_{\alpha=1}^{n(u)} \lambda_\alpha(u) Z(u_\alpha) + \left[1 - \sum_{\alpha=1}^{n(u)} \lambda_\alpha(u)\right] m \quad (16)$$

where, $Z^*(u)$ is the ordinary Kriging estimate at spatial location u, $n(u)$ is the number of data used at the known locations given a neighbourhood, $Z(u_\alpha)$ are the n measured data at locations u_α located close to u. m is mean of distribution, $\lambda_\alpha(u)$ = weights for location u_α computed from the spatial covariance matrix based on the spatial continuity (variogram) model. The weights are assigned based on the distances between the data and the location being estimated as well as the spatial structure of the variable. A semivariogram is commonly used to characterize the spatial structure of a variable under study. It quantifies the dissimilarity between sampled points as the distance between the samples increases. The variogram model is given by,

$$\lambda(h) = \frac{1}{2n} \sum_{i=1}^{n} (z(u_i) - z(u_i + h))^2 \quad (17)$$

where, n is the number of data pairs separated by distance h for a specific direction, $z(u_i)$ and $z(u_i + h)$ are the data values at locations separated by distance h. Ordinary Kriging assumes a constant but unknown mean and estimates the mean value as a constant in the searching neighbourhood. Since Kriging needs the semivariogram values for any given lag, a theoretical model may be fitted to the experimental values and the characteristics of this model can be used. The adjusted semivariogram used in the present study is a spherical model,

$$\lambda(h) = \begin{cases} C\left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right] & \text{for } h \le a \\ C & \text{otherwise} \end{cases} \quad (18)$$

where C is the partial sill and a is the range. The spatial interpolation of rainfall and temperature trends was carried out in ArcGIS software.

4. Results and discussion

4.1. Rainfall trend analysis

Annual rainfall as well as the rainfall variability was observed to be the highest in the north-eastern parts of Bihar and West Bengal (Fig. 2a and b). In eastern India, areas receiving high rainfall showed higher spatial variability than low rainfall receiving areas.

Trend analysis of annual rainfall (Figs. 3 and 4) by different methods indicated similar annual trend in eastern India. North-eastern, south-eastern and south-western parts of eastern India indicated increasing trend, whereas north-western, central and southern parts showed decreasing trend. Almost similar spatial trends was observed by LSLR (−9.8 to 17 mm/year), MKSS (−9.5 to 10 mm/year), and SR (−0.24 to 0.20) tests. The region experiencing decrease in trend of annual rainfall indicates that droughts may become more recurrent. Conversely, in the region of increasing rainfall trend, floods may become more intense.

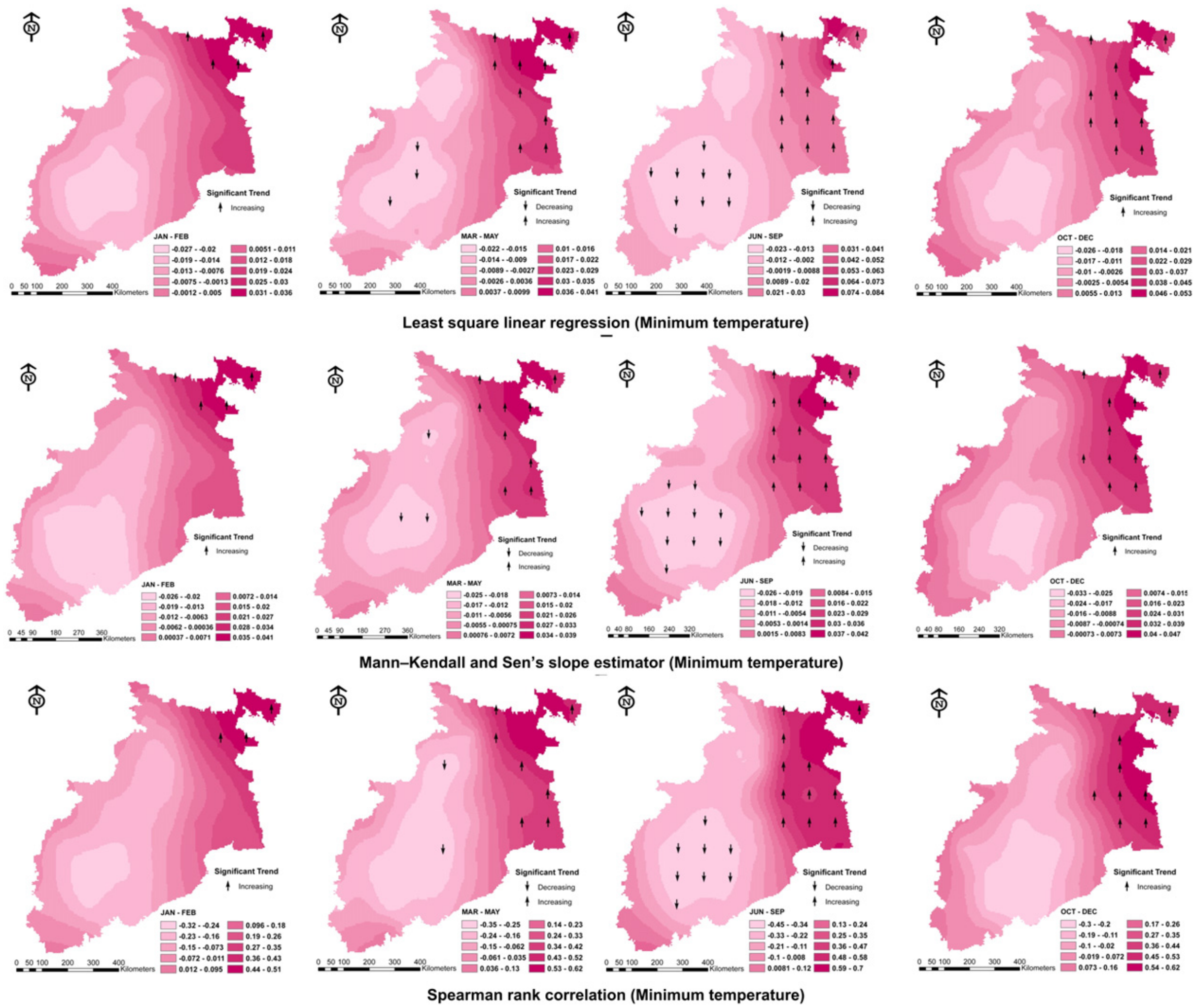

Fig. 9. Seasonal minimum temperature trend analysis.

Eastern India falls within a rectangular grid of latitude 16.5°–28.5° N and longitude 81.5°–89.5° E. Each block of SQMK test represent a particular longitude for which latitude varies from 16.5°–28.5° N. For each analysis (annual or seasonal) there are nine blocks (81.5°, 82.5° … 89.5°). In a block, each row corresponds to SQMK test result of a particular grid point. Rows in red colour symbolize grid points falling outside study region. Blue bar in a row represents point of intersection of progressive and retrograde plots of SQMK test. It indicates the year of change in trend. Upward or downward arrows show significantly increasing or decreasing trend. Few change points in trend with time were detected by SQMK test for annual rainfall, indicating lack of clear existence of abrupt change in trend for most of the area in eastern region. At some locations, it was observed around 1975, 1990, and 2004. In central region, significantly decreasing or increasing trend was observed at few locations after the year 1990.

In case of seasonal rainfall, winter season (January–February) trend obtained from different methods were comparable and showed similar trends with LSLR and MKSS varying from −0.89 to 0.98 and −1.10 to 0.55 mm/year. Increasing trend was observed in northern and southern parts, whereas decreasing trend was observed in central part of eastern India (Fig. 5). During pre-monsoon season (March–May), an increasing trend was observed in the eastern and decreasing trend in the western parts. LSLR and MKSS varied from −2.20 to 4.30 and −2.40 to 4.50 mm/year. Furthermore, it was observed that the trends from LSLR (−7.7 to 12.00 mm/year), MKSS (−6.5 to 6.40 mm/year) and SR (−0.19 to 0.18) in the monsoon season (June–September) was almost similar to that of annual rainfall trend. However, LSLR (−1.10 to 2.50 mm/year), MKSS (−0.85 to 2.20 mm/year) and SR (−0.21 to 0.18) indicated minor deviation in the results of spatial trend during post-monsoon season (October–December).

The result of SQMK test with significant trend in eastern India is shown in Fig. 6. U(t) and U′(t) intersect each other at many intermediate points in most parts of the region indicating lack of clear starting point of abrupt change in trend for all the seasons. During winter season, increasing trend was observed in the eastern and western parts, while decreasing trend in the central region. At few locations, change points were detected by the year 1970, significant increasing or decreasing trend was observed at few locations in the western part during pre-monsoon season. Combination of decreasing and increasing trend varied spatially over the study region in the monsoon season. While in the post-monsoon season, increasing trend was observed in western part and decreasing trend in rest of the eastern region.

4.2. Temperature trend analysis

Temporal variation of temperature in different seasons of a year were analysed in the present study. Trend results of the seasonal

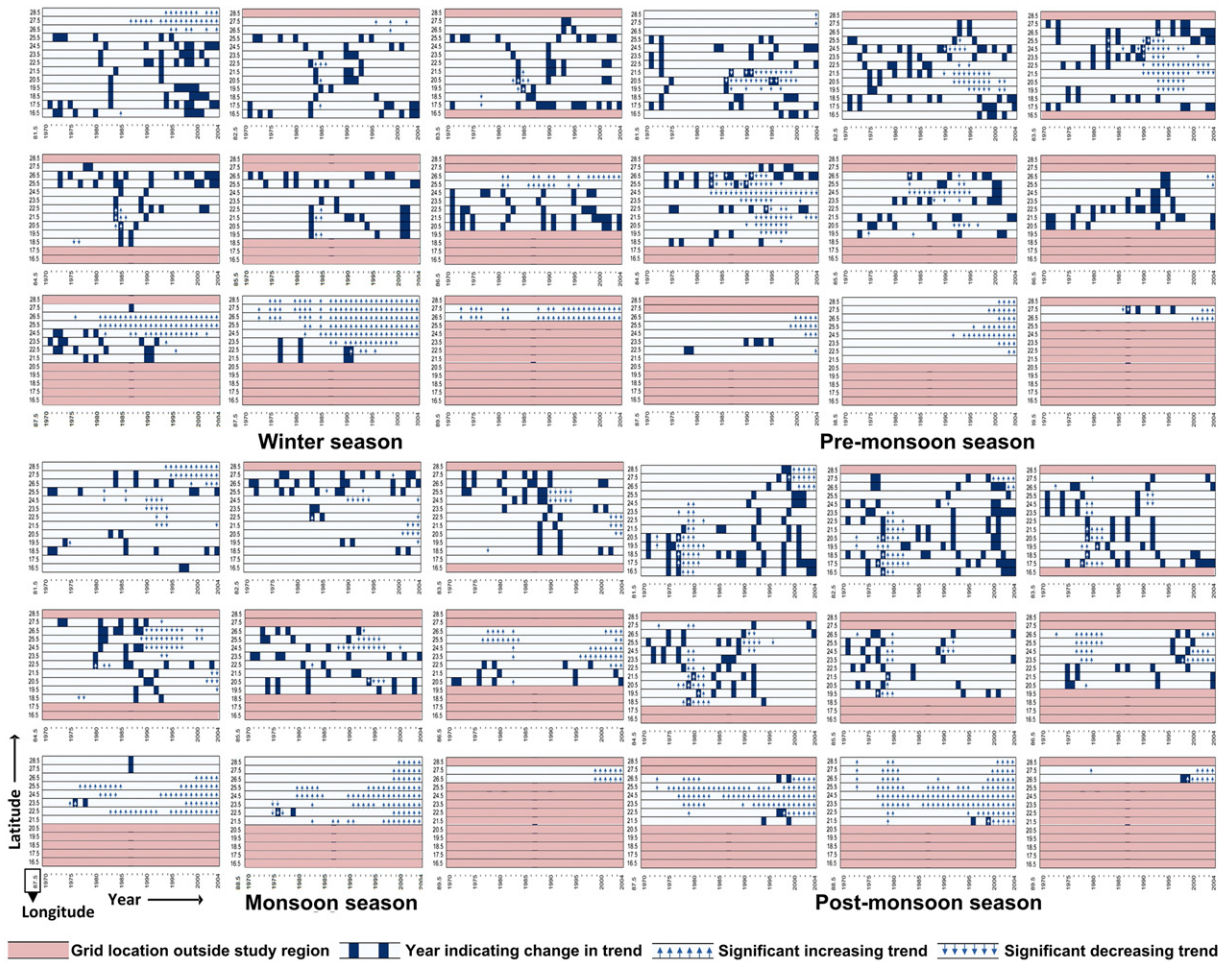

Fig. 10. Sequential Mann–Kendall test for seasonal minimum temperature.

maximum, minimum and mean temperature using multiple trend analysis methods are discussed below in detail.

4.2.1. Maximum temperature

Overall, the results obtained through various methods are consistent with each other on seasonal time scale (Fig. 7). Decreasing trend was observed in the eastern and northern parts and was significant in winter season. On the contrary, increasing trends in the lower half (western and southern) of eastern India was detected. LSLR, MKSS, and SR varied from −0.38 to 0.19 °C/decade, −0.36 to 0.18 °C/decade and −0.39 to 0.25, respectively. Pre-monsoon and monsoon seasons did not indicate any significant increasing or decreasing trend. During pre-monsoon season, decreasing trend similar to the winter season was observed in the eastern part, whereas an increasing trend was observed in southern and western parts. LSLR (−0.31 to 0.10 °C/decade) and MKSS (−0.36 to 0.10 °C/decade) yielded almost similar results. On the contrary to pre-monsoon, decreasing trend was observed in southern part during the monsoon season. Increasing trends (western part) similar to pre-monsoon was also observed in monsoon season. Maximum temperature trend obtained from LSLR and MKSS test varied from −0.09 to 0.18 °C/decade and −0.09 to 0.14 °C/decade. Post-monsoon trend was found to be decreasing in eastern part, which was similar to winter and pre-monsoon season. On the other hand, significant increasing trend was observed in western part of eastern India. Variation in trend from −0.15 to 0.28 °C/decade and −0.17 to 0.28 °C/decade was observed for LSLR and MKSS test.

The SQMK test results with significant trend for different season are shown in Fig. 8. During winter season, multiple intersection points between U(t) and U′(t) was observed in most part of the study area, except eastern part. The results showed non-existence of clear starting point for change in trend. In eastern part, change in trend after 1990 was observed (increasing or decreasing). Change in trend was also observed in eastern part between 1975 and 2004 in pre-monsoon season. Similarly, change of significant increase in trend was detected in monsoon season between 1970 and 2004. In western part, change in trend was observed after 1975 (upto 2000) and was significantly increasing in most of the locations during post-monsoon season. Change in trend was also observed in eastern part around the year 1985.

4.2.2. Minimum temperature

Minimum temperature trend analysis of winter season indicated decreasing trend in western, central and southern parts, whereas increasing trend was observed in eastern part with significant trend in north-eastern part (Fig. 9). Trend of −0.27 to 0.36 °C/decade and −0.26 to 0.41 °C/decade was observed for LSLR and MKSS, whereas SR varied from −0.32 to 0.51. Similar results and spatial variation of trend were obtained for the pre-monsoon season with more significant trend locations as compared to winter season. Trend varied between −0.22 to 0.41 °C/decade (LSLR) and −0.25 to 0.39 °C/decade (MKSS), whereas SR ranged from −0.35 to 0.62. During monsoon season, locations with significant trend increased in comparison with the winter and pre-monsoon seasons, having almost identical

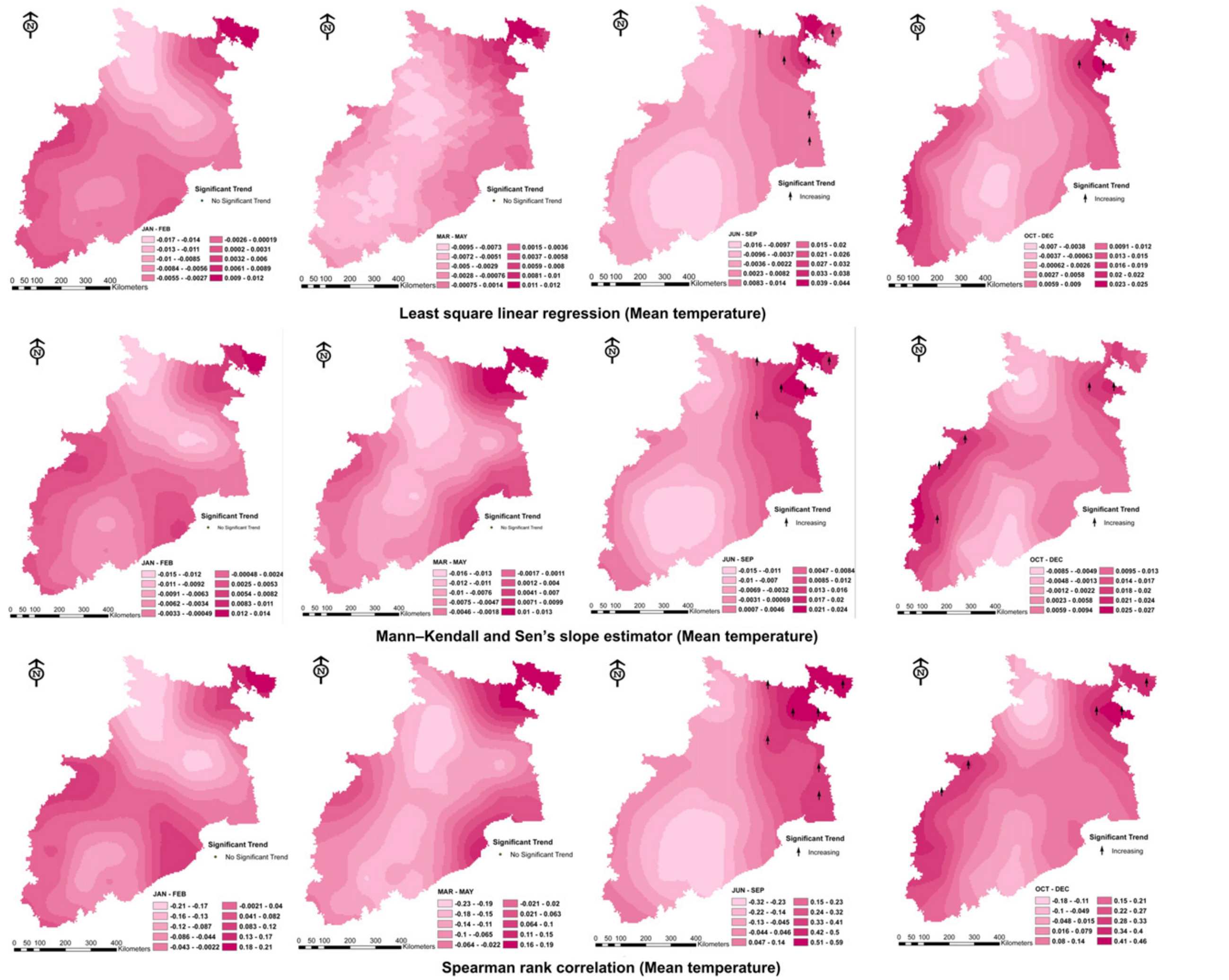

Fig. 11. Seasonal mean temperature trend analysis.

trend. Spatial variation of trend was observed between −0.23 to 0.84 °C/decade for LSLR and −0.26 to 0.42 °C/decade for MKSS, whereas SR varied from −0.45 to 0.70. Trend in post-monsoon season was similar to previous seasons having trend values ranged from −0.26 to 0.53 °C/decade (LSLR), 0.33 to 0.47 °C/decade (MKSS), and −0.30 to 0.62 (SR). Significantly increasing trend was observed in eastern part of the study area.

The SQMK test of seasonal minimum temperature is shown in Fig. 10. In winter season, change in trend at few locations in the central part was observed around the year 1985 with significant increasing trend in the north eastern part. In the western part, change of trend at few locations was observed by the year 2000 in pre-monsoon season. However, during monsoon season, the change of trend in the western part occurred in different years. At few locations in central part, it was observed between the year 1975 and 2004. Similar results were observed in the eastern part for change in trend. Post-monsoon season results revealed change of trend in different years (1975, 1995, 2000 etc.) in the western part, whereas for the central part it was observed by the year 1975, 1990 and 2000. In the eastern part, change of trend occurred between 1995 and 2000 at few locations.

4.2.3. Mean temperature

Trend analysis at seasonal scale indicated increasing trends in mean temperature for most of the eastern India region (Fig. 11). Significant trend during winter and pre-monsoon seasons were not observed in the study area. Decreasing trend was found in north-western, central and southern parts, whereas increasing trend was observed in north-eastern, western and south-eastern parts during winter season. LSLR (−0.17 to 0.12 °C/decade) and MKSS (−0.15 to 0.14 °C/decade) yielded approximately same results, while SR varied from −0.21 to 0.21. Similar spatial trend to that of winter was also observed in pre-monsoon season with LSLR (−0.09 to 0.12 °C/decade) and MKSS (−0.16 to 0.13 °C/decade). In monsoon season, significantly increasing trend in eastern part was observed at some points. On the contrary, decreasing trend was observed in western and southern parts with overall trend varying from −0.16 to 0.44 °C/decade (LSLR) and −0.15 to 0.24 °C/decade (MKSS). Result obtained from SR ranged from −0.32 to 0.59 in the study area. During post-monsoon season, north-western, central, and southern parts showed decreasing trend, while eastern and western parts indicated increasing trend with some locations showing significant trend. Trend analysis results for LSLR and MKSS varied from −0.07 to 0.25 °C/decade and −0.08 to 0.27 °C/decade, whereas SR ranged from −0.18 to 0.46.

Change in trend (SQMK test) during winter season was observed at few locations in central region by the year 2004 (Fig. 12). North-eastern part indicated significantly increasing trend alongwith change of trend in the year 1987 at some locations. In pre-monsoon season, change in trend was observed during the year 1970–75 and 1985 in the western part. Significantly increasing trend in eastern part was observed at some points in monsoon

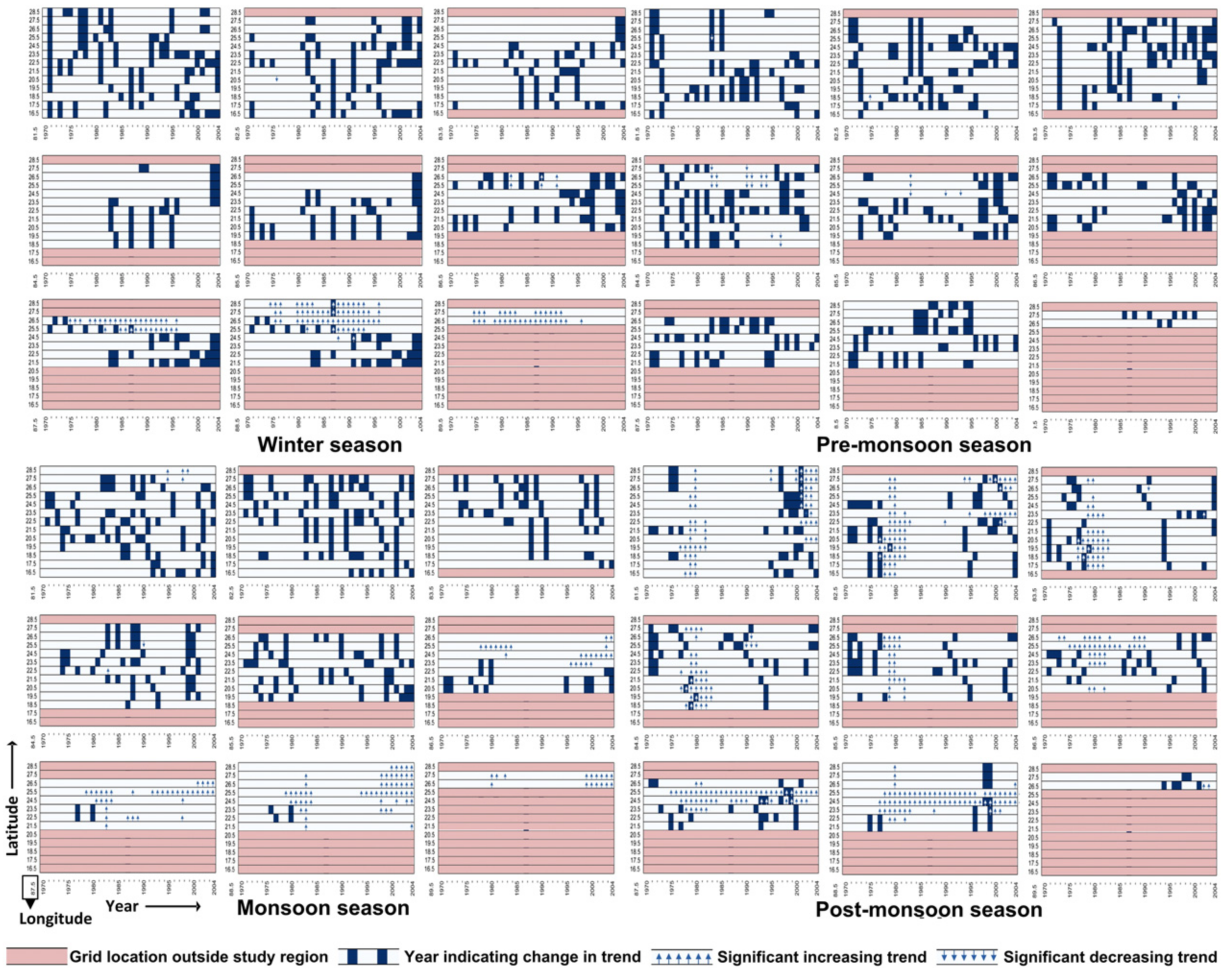

Fig. 12. Sequential Mann–Kendall test for seasonal mean temperature.

season with change of trend occurring between the years 1975–80. Change of trend in post-monsoon season in western half was observed between the years 1975–80 and 1995–2004. Similar pattern of change in trend was observed for northern, central, and southern parts during post-monsoon season. In eastern half of the study area, change in trend was observed between the years 1975–80 and 1995–2000.

4.3. Rainfall-temperature correlation analysis

Hitherto, trends of rainfall and temperature have been analysed and discussed. To evaluate the possible relationship between rainfall and temperature, correlations between them were determined and analysed. Correlations between the seasonal rainfall and temperature (maximum, minimum and mean) are shown in Fig. 13. Negative correlation between rainfall and maximum temperature was observed in all the seasons. It ranged from −0.66 to −0.10 (winter), −0.72 to −0.29 (pre-monsoon), −0.57 to −0.27 (monsoon), and −0.63 to −0.24 (post-monsoon), respectively. Strong negative correlation exists in the western (winter); eastern, southern and north-western (pre-monsoon); and central (monsoon and post-monsoon) parts. Conversely, weak negative correlation existed in the northern, eastern, and southern (winter); western and north-eastern (pre-monsoon); and northern and southern (monsoon and post-monsoon) parts of eastern India.

Negative as well as positive correlations were observed between the rainfall and minimum temperature. During winter, it ranged from −0.32 to 0.50 with negative correlation in the northern and southern parts. Correlation was also negative in the entire region except north-eastern part in pre-monsoon season; it varied between −0.55 and 0.16. During the monsoon season, negative correlation was observed in almost entire study area (−0.44 to 0.03). On the contrary, only positive correlation was observed in post-monsoon season (0.05 to 0.43).

Correlations between the rainfall and mean temperature were negative as well as positive in all the seasons with values of −0.43 to 0.25, −0.63 to −0.13, −0.61 to −0.13, and −0.35 to 0.31 during winter, pre-monsoon, monsoon, and post-monsoon, respectively. Positive correlation was observed in south-eastern (winter) and the entire region except the north-western (post-monsoon) parts of eastern India. Only negative correlation was observed during pre-monsoon and monsoon seasons. In the pre-monsoon season, strong negative correlation was observed in the central, eastern and southern parts. Similarly, strong negative correlation was observed during the monsoon season in central part of eastern India.

Agriculture will be more adversely affected in the areas having strong negative correlation. Water requirement for crop growth, to satisfy evapotranspiration demand, will vary significantly with increased frequency of droughts and floods. Apart from this, soil water storage, groundwater level will also be affected.

4.4. Discussion

The findings of the results indicated that there may be considerable direct or indirect effects of the observed rainfall and temperature trends (maximum, minimum, and mean) in eastern India. Moreover, the

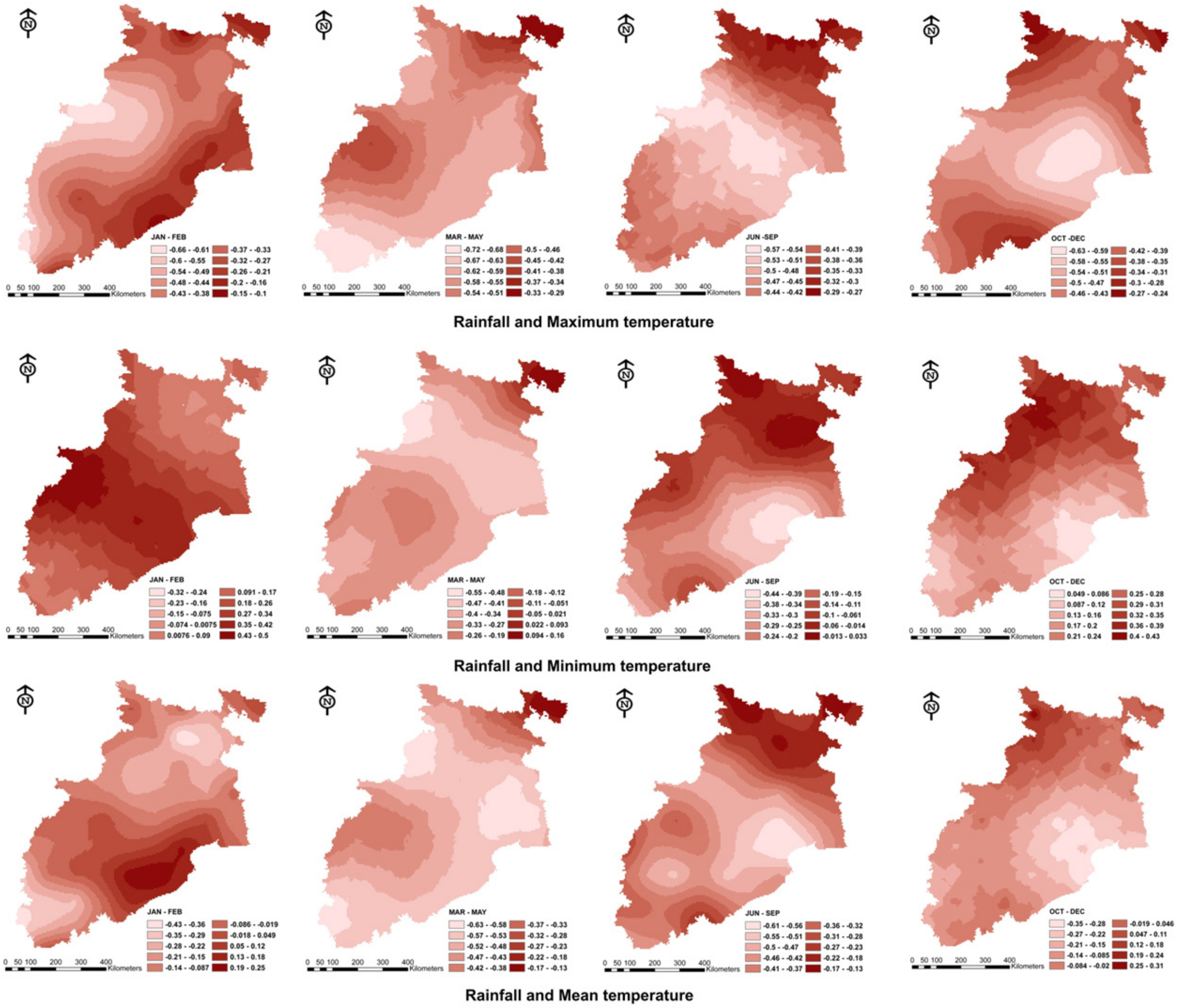

Fig. 13. Correlation between rainfall and temperature.

variation of rainfall is more complicated as compared to temperatures. The effect is likely to be on land use due to spatial and temporal rainfall variability, availability of irrigation, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, change in pest profiles, decline in arable areas due to submergence of coastal lands. All these points discussed above will have tremendous impact on agricultural production and hence, food security of the eastern India.

In eastern India, Kharif is the main crop growing season. Crops grown in both monsoon (Kharif) and post-monsoon (Rabi) seasons respond significantly to the monsoon rainfall. Decreasing/increasing rainfall in the study area will be associated with similar anomalies of Kharif and Rabi foodgrain yield. It will change the water and soil moisture availability within a season to impact crop yield. Moreover, drought as well as flood condition will lead to low foodgrain yields.

Apart from rainfall, increased temperature has greater impact at the end of growing season. For the parts indicating increasing trend in temperature, its rise during the entire cropping season is likely to influence crop production through factors such as increased respiration, evaporation losses, higher basal metabolism, and altering plant responses to biotic stresses. Rise in metabolic rate can shorten the crop duration and/or increase the crop water demand. Such a case may be for paddy crop, which is the main crop of eastern India. Water and nitrogen use efficiencies in paddy decreases linearly with increase in temperature. Rise in atmospheric temperature will have a negative impact resulting in reduced biomass and yield of paddy crop.

Rabi crop production may also become comparatively more vulnerable due to larger increase in temperature, asymmetry of minimum and maximum temperature, along with higher uncertainties in rainfall. The impacts on agricultural production in near future may be seriously affected depending upon season, level of management, and magnitude of climate change.

Crop diversification can not only reduce the climatic risks but also improves the farm income. Rice cultivars of short duration, suitable for water logging conditions, and late transplanting can be recommended for the areas indicating increase in temperature trend. In-situ soil moisture conservation, zero tillage with mulching, crop residue management will reduce the risk of crop failure especially during dry season.

In the areas with increasing rainfall trend, it is suggested to promote long duration high yielding paddy varieties for lowlands. On the other hand, in areas with decreasing rainfall trend, rainwater harvesting structure like farm pond or open well can be promoted to provide supplemental irrigation to paddy for mitigation of crop stress during critical crop growth stage and also provide irrigation to non-monsoon crops.

5. Conclusion

Climate change is likely to affect all facets of life. Knowledge on spatio-temporal distribution and variability in rainfall and temperature is a basic and important requirement for the planning and management of water resources. The present study examined trends in rainfall and temperature with multiple techniques and their correlation for eastern India. Rainfall trend analysis indicated increasing trend in annual rainfall distribution in north-eastern, south-eastern, and western parts. North-western, central, and southern parts of eastern India showed decreasing trend in annual rainfall distribution. Monsoon season trend was found to be representative of annual rainfall trend. Furthermore, abrupt change in trend with time was not clearly observed for majority of the parts in eastern India. Maximum temperature analysis indicated decreasing trend in eastern part and increasing in western part for all the seasons (except in monsoon season). Conversely, increasing trend in eastern half and decreasing trend in western half was observed for all the seasons in minimum temperature analysis. Most significant change was observed during monsoon season as compared to other seasons. Moreover, mean temperature trend was found to be decreasing in central, southern and north western parts, whereas it was increasing in north-eastern, western and south-eastern parts. Change in trend of temperatures with time was not clearly observed in majority of the study area. Negative correlation between rainfall and maximum temperature was observed in the entire eastern India. Similar results with minimum temperature (monsoon) and mean temperature (pre-monsoon and monsoon) was observed.

According to the aforementioned discussed results, drought/flood situation may arise in the areas indicating increase in temperature/rainfall trends. Therefore, there is a need for efficient land and water resources management to mitigate the impact of changing climate in eastern India. As the growing period of crop will change, planting date will also have to be changed accordingly for higher yield. In the study area, parts showing decrease in rainfall, amount of irrigation water required will increase for optimal crop growth which may lead to decrease of crop water productivity. The major challenge in the eastern India, which is primarily rainfed, will be to maintain the water use efficiency as it is expected to decrease in future. Promotion of long duration paddy varieties for lowlands can be recommended in areas with increase in rainfall trend. Paddy cultivars of short duration, suitable for water logging conditions, and late transplanting can be recommended in the areas having increasing trend in temperature. Conversely, rainwater harvesting structures can be promoted in areas with decrease in rainfall trend. Crop diversification will reduce the climatic risks alongwith improvement in farm income. In-situ soil moisture conservation, zero tillage with mulching, crop residue management reduces the risk of crop failure especially during dry season.

It is suggested that the policy-makers or water resource managers should focus on adaptation measures and better policy making in future. Proper care must be taken for water conservation and management of rainfed eastern India. It is strongly recommended that the balance between water surplus and deficit area should be met. Attention is also required in allocation of water resources for improvement of water use efficiency.

Acknowledgement

Financial support extended by the Central Research Institute for Dryland Agriculture (Indian Council of Agricultural Research, New Delhi), Hyderabad in the National Initiative on Climate Resilient Agriculture project entitled, "Integration of rainwater harvesting and climate resilient agriculture in sustaining productivity and profitability of rainfed agro-climatic zones of eastern India", Sanctioned No. NICRA/CG/95/2011 is highly acknowledged.

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