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Spatial and temporal analysis of rainfall and temperature trend of India

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Abstract Climate change is a serious issue resulting in global variation in the temperature and precipitation pattern. In this study, changes in rainfall trend in India for 141 years (1871–2011) and temperature trend for 107 years (1901–2007) were analysed. The annual, seasonal and monthly changes in different regions of India were investigated to see the climate change in different parts of the country, and the net excess or deficit of rainfall and temperature in India was obtained. Statistical non-parametric tests were performed to see the trend magnitude with the Mann-Kendall (MK) test and Sen's slope. Mann-Whitney-Pettitt (MWP) test was used for probable break point detection in the series, and change percentage was calculated over 30 sub-divisions and 7 broad regions. The results indicate decreasing annual and monsoon rainfall of India in most of the sub-divisions, and temperature fluctuations were observed in all the places. Temperatures (minimum, maximum and mean) were showing a significant increase, particularly in the winter and post-monsoon time. Wide variation was noticed all over India in the case of the minimum temperature. Variation was also observed at different spatial scales of sub-divisions and regions. This study gives the net impact of climate change in India which shows net excess of temperature and net deficit of rainfall.

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1 Introduction

Changes in the global temperature and rainfall pattern have raised concern regarding the present and possible future conditions. According to the IPCC (2007) reports, global climate change is probable in the 21st century if no mitigation measures are taken to control emission of greenhouse gases. It was observed that within 10° N to 30° N, precipitation has increased quite noticeably from 1900 to 1950, but it again declined after 1970. A decreasing trend was also found within the tropical areas of 10° N to 10° S. The eastern parts of North and South America, Northern and Central Asia and Northern Europe have become wetter, while the Mediterranean, the Sahel, Southern Africa and parts of Southern Asia have become drier. The seasonal and spatial change in the precipitation pattern is extremely variable in comparison to the change in temperature, and it is also consistent with the streamflow changes. The temperature increase is also evident since there is a reduction in the total number of frost days in the mid-latitudes and an increase in the number of extreme warm days. Droughts have increased in the tropical and sub-tropical regions since the 1970s. Decreasing precipitation over land with increasing temperatures and evapotranspiration have caused drying and contributed to droughts in many regions. The tropics are getting immensely affected from the droughts. Many studies on the rainfall trend were done including an indication of rising precipitation in Australia (Suppiah and Hennessy 1998), New York of USA (Burns et al. 2007) and Mexico from 1920 to 2004 (González et al. 2008). On the other hand, a decrease was observed in Italy (Buffoni et al. 1999), Kenya (Kipkorir 2002) and the north-eastern part of Brazil (Silva 2004). Rising precipitation in Australia during summertime was reported by Nicholls and Lavery (1992). Quite a significant variation in trend was found in Spain by Rodrigo et al. (2000). Different other studies in rainfall variation are found in the pieces of work of Akinremi et al. (2001), Modarres and Silva (2007), Ati et al. (2008), González et al. (2008) and Conway et al. (2009). Temperature is regarded as a good indicator for assessing the global climate (Jhajharia and Singh 2011). Evidence of increasing temperature is found in the studies of Reiter et al. (2012), who have observed a rise in temperature in the upper Danube basin and a rise of 0.8 °C/decade during the summertime. Several other studies on the temperature trend were done by Ventura et al. (2002), Feidas et al. (2004), Turkes and Sumer (2004) and Andrighetti et al. (2009). Changes in the long-term trend of mean annual temperature were observed by Ghahraman (2006) in Iran, and it was found that an increase in the heat of the Earth's surface is because of rising minimum temperature than the maximum temperature (Vose et al. 2005). In India, an increase in temperature over India and the subcontinent was observed by Arora et al. (2005) and Dash et al. (2007). Sen Roy and Balling (2005) worked with the seasonal trend of minimum and maximum temperature where minimum and maximum temperature rise was observed in the Deccan Plateau, but the diurnal temperature range was not significant except for Kashmir. Kothawale and Rupa Kumar (2005) and Pal and Al-Tabbaa (2010) also reported an increase in air temperature.

Different tests to analyse the climatic parameters of temperature and rainfall trend were performed by both parametric and non-parametric tests. Non-parametric tests can be applied on independent data sets and are also able to tolerate the outliers (Hamed and Rao 1998). Mann-Kendall test method is one of the most frequently used global methods for trend analysis (Yue et al. 2003; Burn et al. 2004; Ludwig et al. 2004; Singh et al. 2008; González et al. 2008; Batisani and Yarnal 2010) with rainfall, temperature and streamflow for ascertaining climate change. Some recent pieces of work on this were done by Tabari et al. (2012), Du and Shi (2012) and Wang et al. (2012). In India, there is wide climatic variation throughout the country with diverse culture and economic condition. Change in climate may adversely affect the people and the economy. Rising temperature has an influence on the rainfall of the region, which again affects the agricultural production. High temperature also affects the water availability of the area. Rainfall pattern is extremely varied, and agriculture is largely dependent on the rainfall distribution. One of the most unique characteristics of the Indian climate is monsoon rainfall, which largely determines the agriculture and water supply of most of India. The south-west monsoon or the summer rainfall contributes to the major water supply, while the winter monsoon or north-east monsoon is responsible for water supply in the southern parts of India. The country being huge, continuously growing population stress makes the condition even more unfavourable because of its dependence on rain for agriculture and food (Fisk 1997). Thus, monitoring and assessment of rainfall and temperature change is very important and provides insight for the present and possible future condition to the planners. Many pieces of work with the rainfall and temperature trend are found in the recent literature in India. Sonali and Nagesh (2013) gave a review of monthly, seasonal and annual maximum and minimum temperature of India in seven homogenous regions from 1901 to 2003 showing a significant trend. The temperature trend of the entire India from 1901 to 2003 was also reported by Pal and Al-Tabbaa (2010) to be increasing, and Kumar et al. (2010) analysed the rainfall trend of the entire India from 1871 to 2005. Dimri (2013) also analysed the rainfall pattern of monsoon and winter times in the Western Himalayan part of India. Temperature as well as rainfall trend and variability were carried out in the arid and semi-arid state of Rajasthan in India in 33 urban centres (Pingale et al. 2014).

All these studies, as mentioned, dealt with the trend analysis of rainfall and temperature in different parts of the world as well as in India. However, information and analysis of the trend of both rainfall and temperature together for the entire India are very few and limited with respect to the seasonal (pre-monsoon, monsoon, post-monsoon and winter) and annual variations over different spatial scales. Moreover, the account of rainfall and temperature 'excess' (increase) or 'deficit' (decrease), i.e. net change in the annual, seasonal and monthly scale in the entire India, is lacking. Hence, the major objective of the present study is to find the net change in the climate with respect to the temperature (mean) and rainfall in the entire India on different spatial scales. Annual and seasonal (pre-monsoon, monsoon, post-monsoon and winter) trend analysis was done with the temperature series (minimum, mean and maximum) from 1901 to 2007 (107 years) in seven regions and the entire India, and rainfall trend analysis was done from 1871 to 2011 (141 years) in five regions and 30 sub-divisions of India on annual, seasonal and monthly series. Various statistical techniques like Mann-Kendall (MK) test, Sen's slope, Mann-Whitney-Pettitt (MWP) tests and change percentage were applied to the analysis. The parametric linear regression test was also done with the seasonal and annual data to show the trend. Finally, net change in the climate was analysed.

2 Study area

India is a large country with very high spatially variable condition in climatic parameters. The precipitation amount varies immensely in different parts of the country, ranging from 160 to 1800 mm/year both spatially and temporally. On the basis of meteorological characteristics, the entire land of India has been divided into 36 (except for the hilly northern region and islands) sub-divisions for rainfall analysis. These 36 sub-divisions are again merged to form 30 sub-divisions. A total network of 306 rain gauge stations distributed over 30 sub-divisions was considered, such that one or more stations must represent each state. Precipitation data of certain sub-divisions are not available, which include the northern hilly region of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Arunachal Pradesh and the islands of Lakshadweep and Andaman and Nicobar Islands. The number of rain gauge stations varies from 2 in the Coastal Karnataka to 26 in the East Uttar Pradesh. Further, on the basis of homogeneity, five major regions (Northwest, Central Northeast, Northeast, West Central and Peninsular) were shown, which are available from the site of the Indian Institute of Tropical Meteorology (IITM) (http://www.tropmet.res.in/Data%20Archival-51-Page). Two separate regions of the Homogenous Monsoon Region (Haryana, Punjab, East Rajasthan, West Rajasthan, West Madhya Pradesh, East Madhya Pradesh, Gujarat, Saurashtra and Kutch, Konkan and Goa, Madhya Maharashtra, Marathwada, Vidarbha, Chattisgarh, Telangana and North Interior Karnataka) and Core Monsoon Region (East Rajasthan, West Madhya Pradesh, East Madhya Pradesh, Gujarat, Konkan and Goa, Madhya Maharashtra, Marathwada and Vidarbha) include few sub-divisions with specific monsoon characteristics. With respect to temperature, seven regions are formed on the basis of meteorological characteristics, which are east coast of India, interior peninsular of India, North Central India, North-east India, North-west India, west coast of India and Western Himalaya of India (Fig. 1). The entire study area of India is about 2,880,000 km^2 in area, excluding only the islands.

3 Data and methodology

The monthly rainfall data of 141 years (1871–2011) and temperature data for 107 years (1901–2007) were used in the study obtained from the IITM (http://www.tropmet.res.in/Data%20Archival-51-Page). Long-term trend was assessed for monthly, pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November), winter season (December–February) and annually for all the sub-divisions and major regions of India. Homogeneity of the data series was assessed by a standard normal homogeneity test (SNHT) at the 5 % significance level (Alexandersson 1986; Alexandersson and Moberg 1997). The rainfall data series was considered as homogeneous as the critical value of the test T_0 for 141 samples at the 95 % level was less than 9.468, and the temperature data series for 107 years at 95 % level was less than 9.23 (Khaliq and Ouarda 2007). Tables 1 and 2 show the break point and homogeneity of rainfall and temperature series, respectively.

The serial-correlation test was applied to the data series (Hamed and Rao 1998; Yue et al. 2003) to observe the presence of any trend in the series, and thereafter, a pre-whitening method was used for eliminating the impact of correlation on the results of the MK test (Storch 1993; Yue et al. 2002; Cunderlik and Burn 2002, 2004). To test the long-term rainfall and temperature trend, MK was applied for monotonic trend analysis, which is considered as better than the parametric tests (Xu et al. 2003). Application of the MK test (Mann 1945; Kendall 1975) checks whether there is any trend in the series against the null hypothesis of no trend. The parametric regression method was also applied to see the trend of the annual data series. Trend magnitude was determined by the Theil-Sen's estimator (Theil 1950; Sen 1968). These methods are widely used and are proven to be better for hydrological and meteorological trend detection (Yue and Hashino 2003a; Tabari et al. 2010, 2011). MWP test was used for detecting break point in the series (Pettitt 1979). Then, change percentage was computed for 141 years of rainfall and 107 years for temperature (Yue and Hashino 2003b). Finally, the net change in the rainfall amount and temperature was estimated by using sub-division-wise data for rainfall and region-wise data for temperature. The areal average method (Sen 1998) was used to calculate the net change with the positive significant, positive non-significant, negative significant and negative non-significant magnitude of rainfall and temperature with respect to the area. The net change in the climate of the entire study area was found from the difference of the total positive and total negative of the monthly, seasonal and annual data.

4 Results and discussion

Analysis of annual and seasonal trend of temperature (1971–2007) and annual, seasonal and monthly rainfall (1971–2011) was done with the 7 regions and 30 sub-divisions of India. The MK test was applied to get the significance in the trend results, and Sen's slope was used to see the magnitude of the trend. Similarly, the percentage of change was used to show the change in the trend. The increasing and decreasing trend with the level of significance and change in percentage was shown in the figures for rainfall and temperature in different colours and symbols.

4.1 Break point detection and serial correlation

The break point of each of the sub-divisions and regions is given in Tables 1 and 2 indicating the point of change or break in the trend of 141 years of rainfall and 107 years of temperature. Although the break points are quite variable, 1961 was found to be the most probable one for rainfall as observed in three sub-divisions, one region and for the entire country. For temperature, no such specific time was observed. There was a lack of any dominant break point here. The measure of lag-1 serial correlation was applied on the data before performing the MK test to observe the presence of any significant correlation. Pre-whitening was applied to remove the existing correlation in the data series.

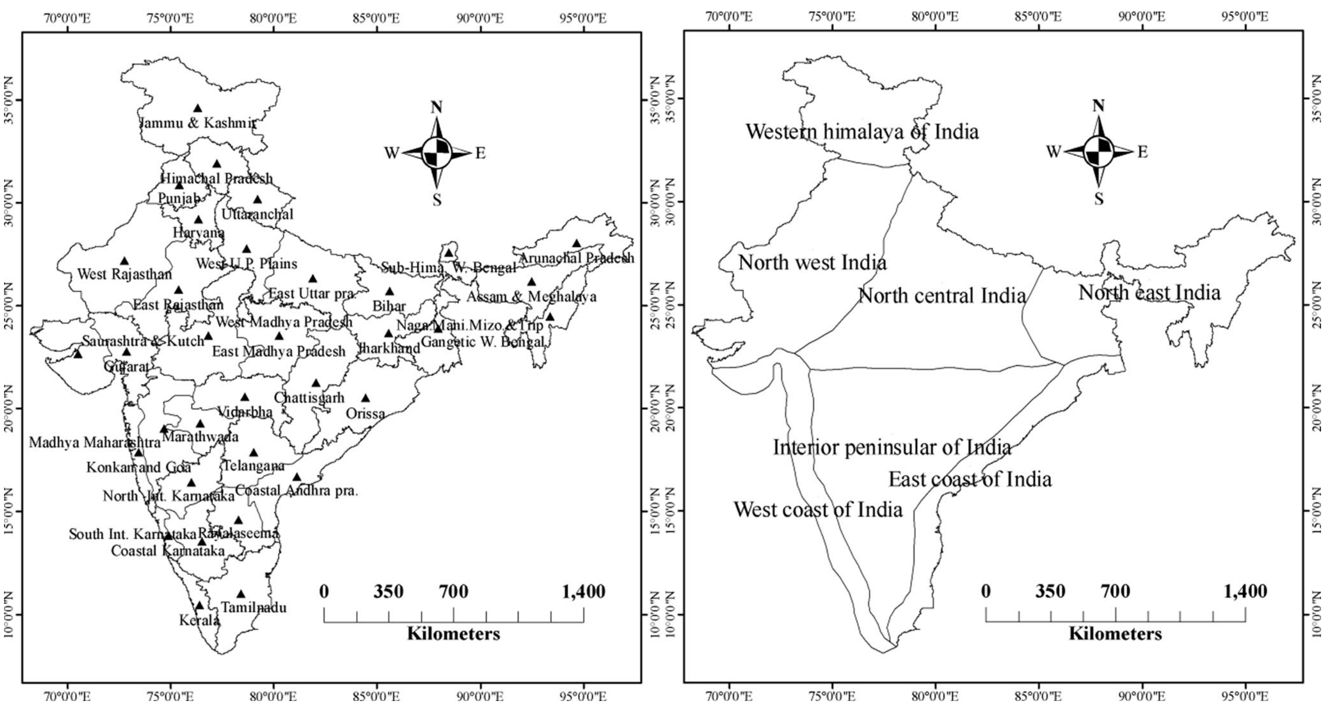

Fig. 1 Rainfall and temperature zones of India (30 sub-divisions and 7 regions)

4.2 Rainfall trend analysis (monthly, seasonal and annual)

Figure 2 (A–E and a–e) indicates the spatial distribution of seasonal (pre-monsoon, monsoon, post-monsoon and winter) and the annual rainfall trend showing significant or non-significant, positive or negative and no trend with different symbols, and percentage of change was shown in different colours in 30 sub-divisions and 5 regions of India,

Table 1 Homogeneity test and Mann-Whitney-Pettitt test (rainfall)

Station Sub-divisions	Pettitt's test t	SNHT test t	Station Sub-divisions	Pettitt's test t	SNHT test t
Assam and Meghalaya	1956	2005	Vidarbha	1961	1877
Nagaland, Manipur, Mizoram and Tripura	1956	2007	Chattisgarh	1961	1961
Sub-Himalayan West Bengal and Sikkim	1956	1873	Coastal Andhra Pradesh	1914	1989
Gangetic West Bengal	1966	1992	Telangana	1930	1877
Orissa	1963	1963	Rayalaseema	1954	1987
Jharkhand	1953	2008	Tamil Nadu and Pondicherry	2003	2003
Bihar	1922	1871	Coastal Karnataka	1927	1927
East Uttar Pradesh	1985	1871	North Interior Karnataka	1945	1942
West Uttar Pradesh	1895	1895	South Interior Karnataka	1952	2004
Haryana	1952	1952	Kerala	1962	1900
Punjab	1943	1946	Regions		
West Rajasthan	1972	2009	Entire India	1961	1964
East Rajasthan	1978	1997	Homogeneous Indian Monsoon	1964	1894
West Madhya Pradesh	1978	1999	Core Monsoon India	1894	1894
East Madhya Pradesh	1961	1961	North-west India	1941	1941
Gujarat	1894	1894	West Central India	1964	1964
Saurashtra, Kutch and Diu	1942	2005	Central North-east India	1961	2008
Konkan and Goa	1930	1930	North-east India	1956	2007
Madhya Maharashtra	1929	2004	Peninsular India	1914	2004
Marathwada	1895	1871			

Table 2 Homogeneity test and Mann-Whitney-Pettitt test (temperature)

Minimum temperature			Mean temperature			Maximum temperature		
Stations	Pettitt's test t	SNHT test t	Stations	Pettitt's test t	SNHT test t	Stations	Pettitt's test t	SNHT test t
All India	1993	1997	All India	1945	1997	All India	1962	1963
East coast of India	1977	1977	East coast of India	1976	1977	East coast of India	1963	1971
Interior peninsular of India	1935	1918	Interior peninsular of India	1963	1971	Interior peninsular of India	1963	1963
North Central India	1940	1994	North Central India	1945	1940	North Central India	1950	1950
North-east India	1993	1997	North-east India	1937	1937	North-east India	1950	1950
North-west India	1924	2005	North-west India	1986	1997	North-west India	1945	1997
West coast of India	1976	1992	West coast of India	1957	1984	West coast of India	1957	1958
Western Himalaya of India	1978	1993	Western Himalaya of India	1983	1997	Western Himalaya of India	1927	1997

respectively. Figure 2 (A–E) shows seasonal and annual change in 30 sub-divisions, and Fig. 2 (a–e) shows seasonal and annual change in five broad climatic regions of India. All the sub-divisions and regions have indicated many significant variations in the rainfall trend. The trend and change rate vary widely in different places. The eastern part of the country like Assam and Meghalaya has a significant decrease at 5 % significance level in January (−0.04 mm/year) and August (−0.53 mm/year) with the change percentage of −33.31 and −20.83 %, respectively. Nagaland, Manipur, Mizoram and Tripura were also observed to have a negative trend and decreasing rate of change in most of the months with particular significance in August (−0.48 mm/year and −20.00 %). Significant negative trends and change percentage were also observed in the month of May in Gujarat (−0.006 mm/year and −11.84 %), in June in Sub-Himalayan West Bengal and Sikkim (−0.65 mm/year and −18.59 %) and East Madhya Pradesh (−0.38 mm/year and −32.76 %), in July in Chhattisgarh (−0.59 mm/year and −21.37 %) and East Madhya Pradesh (−0.73 mm/year and −26.39 %), in September in Marathwada (−0.42 mm/year and −30.07 %) and East Rajasthan (−0.01 mm/year and −40.24 %) in December. Region-wise, the month of July has the highest rate of significant decreasing rainfall followed by August indicating rainfall decline in the monsoon months. The entire India was depicting a significant decreasing trend and change percentage (−0.14 mm/year and −7.13 %) in July along with the Homogeneous Indian Monsoon region (−0.24 mm/year and −12.93 %), Core Monsoon India (−0.29 mm/year and −13.25 %) and West Central India (−0.31 mm/year and −14.58 %). Northeast India (−0.33 mm/year and −13.29 %) had shown rainfall decrease in August. However, some significant positive trend in rainfall was also observed in Konkan and Goa in the months of January, February, March, August and December; in Coastal Karnataka during the months of January, February, March and August; in the North Interior Karnataka during January and August; in Saurashtra, Kutch and Diu during March, April and November and also in Sub-Himalayan West Bengal and Sikkim during July, November and December. Notably, while considering the regions, no such significant positive changes in rainfall were observed in any of the months. Thus, the overall dominance of negative trend and percentage of change was noticed despite of some mixed trends which were observed in different months.

The rainfall trend and rate of change on a regional scale indicate negative trends in the north-west and north-east, and positive trend is noticed in the south in January. The month of February has a positive trend in most of the regions except for North-east India. North-east India in March shows a very high negative rate of change (−24 %), although non-significant, while other regions indicate a non-significant positive change. Central North-east India has a very high positive rate of change in April (>32 %), and none of the regions have a negative trend. North-east India and North-west India have low or decreasing trend in May, and in June, most of the regions have a negative trend except for the North-west. A significant decrease was observed in West Central in July and in North-east in August. Again, November and December show a negative rate of change, and North-west India shows a significant decrease in December.

The spatial distribution of seasonal and annual rainfall trend and percentage of change is shown in Fig. 2 with different symbols for positive, negative, significant, non-significant and no trend and in different colours. The A–E maps show the seasonal (pre-monsoon, monsoon, post-monsoon and winter) and annual trend and change percentage of 30 sub-divisions of India, while a–e maps represent the seasonal and annual trend and change percentage of the entire India divided into five climatic regions.

The monsoon and winter months were showing a decreasing trend in rainfall at the 5 % significance level. During the monsoon period, a significant negative trend was noticed in many places with a decreasing change rate such as in Chhattisgarh (−1.38 mm/year and −16.38 %),

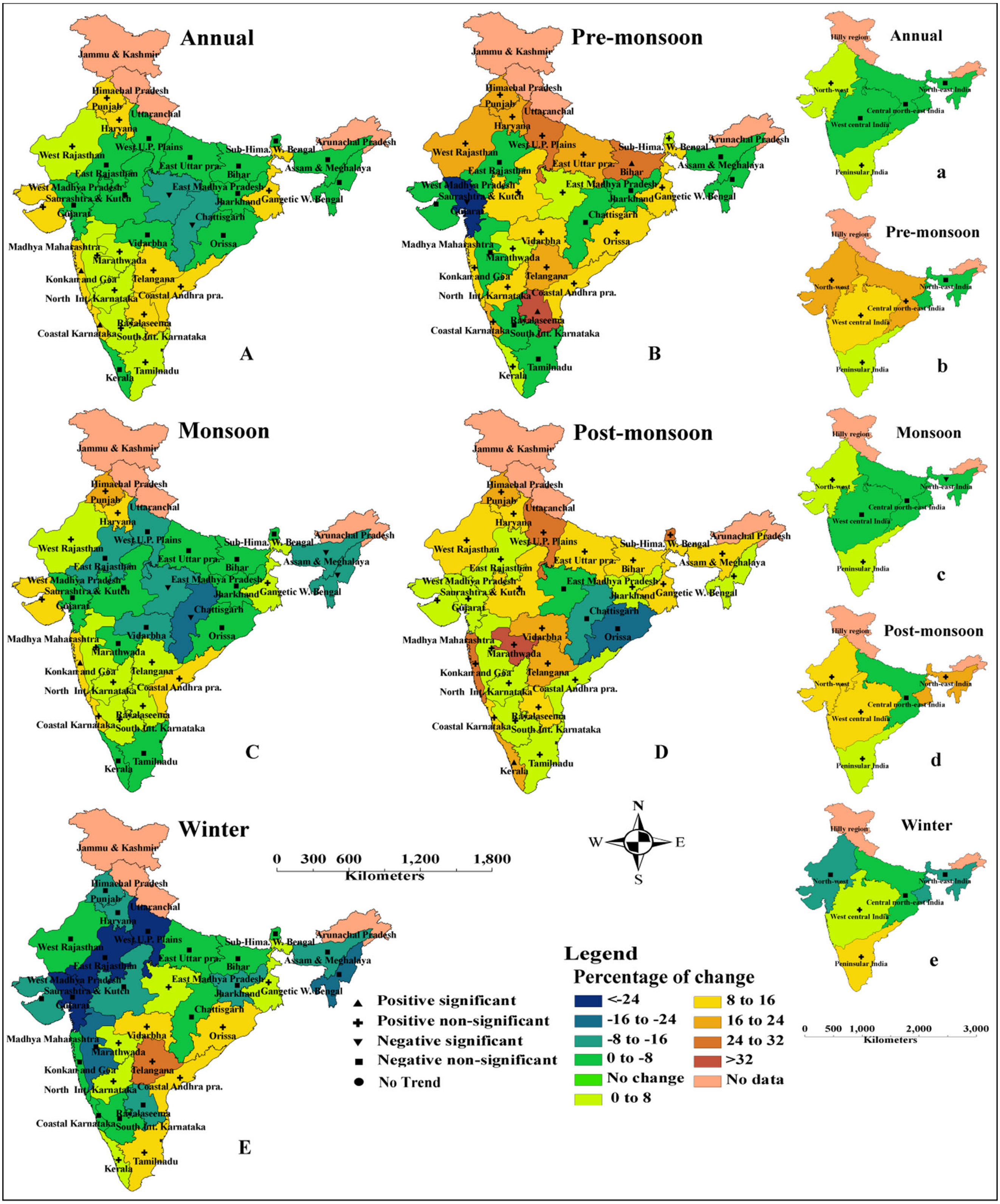

Fig. 2 Seasonal and annual rainfall trend and percentage of change A–E: over 30 sub-divisions of India; a–e: over 5 different regions of India

East Madhya Pradesh (−1.16 mm/year and −14.62 %), Assam and Meghalaya (−1.02 mm/year and −9.59 %) and in Nagaland, Manipur Mizoram and Tripura (−1.09 mm/year and −11.57 %). Significant positive trend and percentage of change were observed in Konkan and Goa (1.81 mm/year and 10.73 %) and Coastal Karnataka (1.79 mm/year and 8.86 %), which are part of West Central and Peninsular India, while Punjab has a high rate of change percentage (0.66 mm/year and 18.82 %) in the north-west. Thus, north-west and south have a positive trend in monsoon unlike the rest of India. Non-significant negative changes were also noticed in many states like Vidarbha, Marathwada, West Madhya Pradesh, East Rajasthan, Gujarat and in the extreme south like Kerala and Tamil Nadu (with the rate of change varying up to −16 %). The region-wise monsoon trend (Fig. 2 (c)) of India also indicates a non-significant positive trend in the Northwest (0.07 mm/year and 2.11 %) and Peninsular India (0.09 mm/year and 1.99 %), while other parts have negative trends with significance in the north-east part (−0.72 mm/year and −7.24 %). Winter season illustrates a great variation with decreasing rainfall in major parts, while an increase was observed only on the east coast and south central, and the change rate was highest in Telengana (28.53 %) although the trend was non-significant (0.04 mm/year). The highest negative change percentage was observed in West U.P. Plain (−25.96 %) with the negative trend magnitude (−0.09 mm/year); East Rajasthan (− 0.04 mm/year and −34.82 %); Gujarat (−0.01 mm/year and −24.58 %); Nagaland, Manipur, Mizoram and Tripura (−0.09 mm/year and −22.24 %) and West Madhya Pradesh (−0.02 mm/year and −13.84 %). Region-wise, winter season (Fig. 2 (e)) illustrates a non-significant positive trend in the West Central and Peninsular India, and other parts show a non-significant negative trend. In the pre-monsoon period, a negative trend and decreasing rate of change were observed in the north-eastern part, southern part and western part, particularly in the Gujarat (−0.02 mm/year and −25.44 %) with a significant trend, and in some areas of Eastern Rajasthan, Chhattisgarh and Jharkhand. Significant positive trend was also observed in the south central part of Rayalseema (0.17 mm/year and 32.35 %). Figure 2 (b) or the major Indian regions in the pre-monsoon period show that only Northeast India has a negative change (−0.07 mm/year and −2.38 %), and the rest of India has a positive or increasing rainfall. Interestingly, the post-monsoon period shows increasing rainfall throughout the country except for three states of Orissa (−0.19 mm/year and −17.14 %), Chhattisgarh (−0.05 mm/year and −9.46 %) and the East Madhya Pradesh (−0.02 mm/year and −5.28 %). Except for Kerala (0.72 mm/year and 22.55 %), none of the values was significant in this season. In regions (Fig. 2 (d)), only Central Northeast India has a negative trend and change rate (−0.03 mm/year and −5.59 %), which was also evident from the subdivision-wise observation. The trend magnitude of annual rainfall gives a significant decrease in the East Madhya Pradesh (−1.12 mm/year and −12.66 %); Chhattisgarh (−1.43 mm/year and −14.93 %); Nagaland, Manipur, Mizoram and Tripura (−0.98 mm/year and −6.99 %) and Assam and Meghalaya (−0.96 mm/year and −5.79 %). Significant rise was found in the Konkan and Goa (2.06 mm/year and 11.44 %) and Coastal Karnataka (2.53 mm/year and 10.89 %), and non-significant increasing rainfall was observed in most of the southern states and in some of the north-western states. The region-wise analysis (Fig. 2(a)) was also showing a non-significant positive trend magnitude and percentage of change in the Peninsular India (0.37 mm/year and 4.59 %) and North-west India (0.19 mm/year and 5.14 %) (Fig. 2 (A–E and a–e)).

Therefore, the overall picture indicates a decrease in annual rainfall, although non-significant for the entire India (−0.04 mm/year and −0.56 %), which is similar to the rainfall of monsoon season of the entire India (−0.23 mm/year and −3.92 %). The rainfall variation in all over India is quite prominent as observed from the figures such as North-east India is facing mostly negative rainfall trend along with the Central North-east India in some seasons like annual, monsoon and winter and West Central India in annual and monsoon times. The climatic fluctuations and seasonal differences were clearly observed in the results, which have an impact on the rainfall of the region. Although monsoon is the main season, which gives the abundant rainfall, other seasons also contribute in some specific areas. Peninsular India is having an increasing rainfall trend as it receives rainfall from both the south-west and north-east monsoon. Winter monsoon or the retreating monsoon is dominant over the Peninsular India, which receives more than 50 % of the annual rainfall in the winter months that overcomes the effect of low rainfall in the monsoon months. In the north-western part of India, there develops extreme low pressure in the summertime and high pressure during the winter. The western disturbances or Nor'westers and convective activities produce rainfall in the winter and pre-monsoon time over north-western parts of India resulting in more rainfall in this region (Pal and Al-Tabbaa 2011). Similar results are found in the pieces of work of Dash et al. (2007) (working with the period from 1871 to 2003). And, Kumar et al. (2010) (working with the period from 1871–2005) found the highest increase in the monsoonal rainfall in Konkan and Goa, Coastal Karnataka and Punjab, while for decreasing trend, Dash et al. (2007) reported the highest decline in Nagaland, Manipur, Mizoram and Tripura; East Madhya Pradesh and Orissa. Kumar et al. (2010) showed a maximum decrease in Chattisgarh, Kerala and Nagaland, Manipur, Mizoram and Tripura. Wide variability was also observed in the annual series. Similarity in the monsoonal trend and annual trend was also observed recently in the work of Pingale et al. (2014) in the Rajasthan state of India.

The phenomena of ENSO or El Niño Southern Oscillation and the Himalayan snow are considered as major reasons associated with the monsoon character. The La Niña phase strengthens the Indian monsoon, while the El Niño is responsible for the weaker one. For snow cover also, it is said that less snow in the winter gives favourable monsoon condition and vice versa (Kripalani et al. 2003). As the monsoon rainfall is associated with the active and break phases, any longer or persistent break phase may lead to a decrease in the monsoon rainfall (Ramesh Kumar et al. 2009). India is the monsoon-rainfall-dependent country; hence, declined precipitation at monsoon time may cause problems in the water resources as well as agriculture sectors. Excessive decrease in the areas of Chattisgarh (−14.93 %) and East Madhya Pradesh (−12.66 %) may result in severe conditions. Decrease in monsoon rainfall in North-east India (−7.24 %) is also a major concern. Only the North-west India (2.12 %) and Peninsular India (2 %) are showing an increase. These two regions have separate effects of monsoon as mentioned previously.

4.3 Temperature trend analysis (seasonal and annual)

4.3.1 Trend of minimum temperature

The change percentage and trend values with significance are presented in the Fig. 3 in symbols for annual and seasonal temperature analysis (minimum, mean and maximum). In all the months, east coast of India, west coast of India and interior peninsular of India have shown increases in the minimum temperature, while North-east India has shown high minimum temperature in all the seasons except for the monsoon. As observed in Fig. 3, significant changes are observed in all the regions in the minimum temperature. Annual temperature illustrates the increase in temperature everywhere except for North-west India (−0.001 °C/year and −0.63 %). In the Western Himalayas, 4.5 to 6 % rise of minimum temperature was noticed. Significant increase in minimum temperature of Western Himalayas was observed in the post-monsoon period (0.008 mm/year and 30.14 %). The significant trend of increasing minimum temperature was also found in the interior peninsular and west coast of India in all the seasons with highest values in post-monsoon (0.006 °C/year and 0.004 °C/year) and winter (0.005 °C/year and 0.001 °C/year) seasons, respectively. The corresponding change percentages are 3.53 and 3.19 % of post-monsoon and winter of interior peninsular and 2.23 and 0.94 % of post-monsoon and winter of the west coast of India, respectively. There was an increase in temperature throughout India in the pre-monsoon period with the maximum increase in the Western Himalayas (9.1 %), although non-significant (0.005 °C/year). Monsoon season shows a significant increase in the south India, and non-significant positive change was also observed in the Western Himalayas. A significant decrease was noticed in the North-west India (−0.002 °C/year and −1.00 %), while North-east and Central India have non-significant decreasing minimum temperature trend. A significant increase was noticed in the interior peninsular of India (0.002 °C/year and 1.03 %). Notably, an extreme rise in temperature was found to have occurred in the post-monsoon and winter seasons. Significant increase in trend magnitude and positive change percentage were observed in most of the regions. Western Himalayas have a significant increase and change (0.008 °C/year and 30.14 %) in the post-monsoon period, but in the winter, they show a significant decrease (−0.006 °C/year and −19.18 %). All the regions show a significant rising trend in the winter varying from 1.5 to 6 %, except for West Himalayas and North-west India (Fig. 3 (a)). However, the rate of increase in Western Himalayas is of great concern which indicates a gradual warming of the snow-covered areas.

4.3.2 Trend of mean temperature

Dominant increase in the mean temperature was observed all over India annually for 107 years with the highest rise in the Western Himalayas (0.004 °C/year and 3.16 %). For Western Himalayas, all the four seasons show quite high rise in the temperature with a significant increase in the pre-monsoon (0.008 °C/year and 7.05 %), post-monsoon (0.006 °C/year and 5.89 %) and winter (0.009 °C/year and 41.08 %) seasons. Hence, it indicates the possible cause of retreating glacier or rise in snow lines. The most notable thing as observed from Fig. 3 (b) is all the regions in all the seasons have rising temperature and are most significant with a higher percentage of change values. This increase is again more prominent in the post-monsoon and winter season that may have resulted in the warming of even very cold areas. There was a significant positive rise in mean temperature in all the regions in the post-monsoon and winter season with only the North-west India with non-significant rise. Annual mean temperature shows a significant increase in all the regions with Western Himalayas having the highest percentage of mean temperature. In the pre-monsoon period, a non-significant increase was observed in most of the regions, and a significant increase was observed in the west coast (0.005 °C/year and 1.97 %) and Western Himalayas. The monsoon temperature has only shown a non-significant negative mean temperature in North-west India (−0.18 %) with the rest of the region having significant or non-significant rise. Both post-monsoon and winter have a significant rising mean temperature, particularly with the highest percentage change in the Western Himalayas while North-west India has a non-significant rise. Thus, the overall results show a significant rise in Western Himalayas, west coast and east coast, while North-west India has a non-significant rise or even decrease in monsoon season (Fig. 3 (b)).

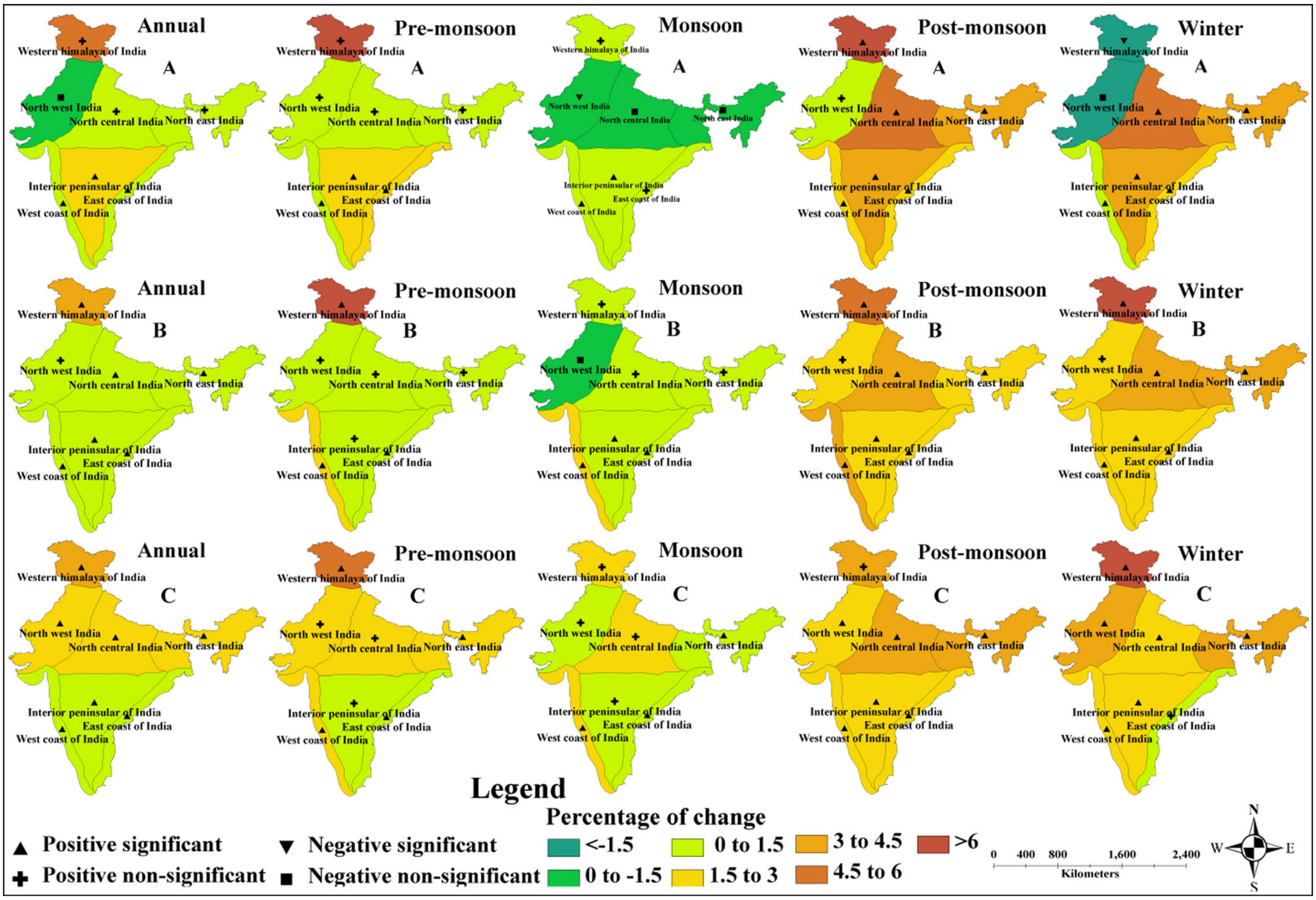

Fig. 3 Seasonal and annual temperature trend and percentage of change over 141 years. A minimum temperature, B mean temperature; and C maximum temperature

4.3.3 Trend of maximum temperature

An increase in the maximum temperature is extremely noteworthy as illustrated in Fig. 3 (c). Significant increase in all the regions is observed with the highest increase in the Western Himalayas annually (0.006 °C/year and 3.55 %) as well as in all the seasons. The pre-monsoon season has a significant increase in the Western Himalayas (0.01 °C/year and 5.86 %), the east coast (0.004 °C/year and 1.27 %) and the west coast (0.007 °C/year and 2.09 %). Monsoon season indicates a significant rise in North-east India (0.004 °C/year and 1.47 %) and the west coast of India (0.006 °C/year and 2.25 %), while other regions show a non-significant increasing maximum temperature. Both the post-monsoon and winter seasons imply the highest and significant temperature rise in the Western Himalayas in the winter (0.013 °C/year and 17.98 %). Regions such as the west coast, interior peninsular, North-west, North Central and North-eastern part of the country were also experiencing a high temperature rise (Fig. 3 (c)). Only the east coast in the winter has a non-significant temperature increase, which may be due to its location and other atmospheric factors. High rise of maximum temperature in the Western Himalayas is indicating warming of the cold region. A similar type of result is observed in the pieces of work of Pal and Al-Tabbaa (2010), where a rise in the temperature of Western Himalayas is observed along with the north-eastern part of the country.

The increasing trend is observed in case of both minimum and maximum temperatures. However, the rate of increase of maximum temperature is higher than the minimum temperature. A significant rise (95 %) of minimum annual temperature is found in the east coast, west coast and interior peninsular, while post-monsoon and winter seasons indicate significantly higher temperature in almost all the regions (except North-west India and the west coast). The highest magnitude of trend of minimum temperature is 0.008 °C in post-monsoon time in North Central and Western Himalaya. The rate of significant increase of annual maximum temperature is observed in all the regions, and the rate is higher than the minimum temperature. The highest rate of increase is 0.013 °C in the winter season in the Western Himalaya. The higher rate of rise in the daytime temperature will lead to water scarcity in the area. The rise in the magnitude of maximum temperature also conforms to the study of Subash and Sikka (2014).

The total annual and seasonal rainfall and minimum, mean and maximum temperatures of the entire India and seven regions are illustrated in Fig. 4 (a, b, c and d respectively). The linear regression method was applied along with the MK test to see how closely the results are related. The rainfall and temperature trends are obtained showing a high rate of rainfall decrease after 1961 mostly in the North-east, Central North-east and West Central India, but an increase in rainfall was observed in the peninsular India. These major regions of decreasing rainfall also have an extreme rise of temperature throughout the year along with all other regions. The graph shows a rise in the minimum temperature in the post-monsoon and winter seasons, and a rise in mean and maximum was dominant for all the seasons and throughout the year, which was again affected by little decreasing rainfall trends.

4.3.4 Rainfall and temperature account of the entire India

The rainfall trend as examined by different methods is showing a general trend whether positive or negative, significant or non-significant. However, the amount of rainfall in 'excess' or 'deficit' for the entire study area or the net amount of change with respect to the area was not recognised. Figure 5a illustrates the net change in the magnitude of rainfall in different months and also shows the categories of significant positive, significant negative or non-significant positive and non significant negative. The areal average method was used for calculation, and the difference of total positive (significant + non-significant) and total negative (significant + non-significant) gives the monthly, annual and seasonal net change using rainfall data of different sub-divisions. Figure 6 shows that significant negative rainfall is quite prominent in the annual and monsoon season with the net change being negative. The months of June, July and September also indicate net negative changes. So, the summer month of June and major monsoon months (except August) are experiencing decreasing net change. Figure 5b shows the total area covered by the type of rainfall pattern. The annual graph shows that 48 % of the area was experiencing non-significant negative rainfall and 7 % with significant negative rainfall. Similar higher values are observed in the monsoon (50 %) and winter (63 %) with significant negative rainfall of 11 % in monsoon. Two monsoon months of July (55 and 7 %) and September (53 and 3 %) also indicate that major areas are dominated by the non-significant and significant negative rainfall, respectively.

The net change of mean temperature is given in Figure 6a that indicates an overall positive change with only January, May, June, July and the monsoon season experiencing a

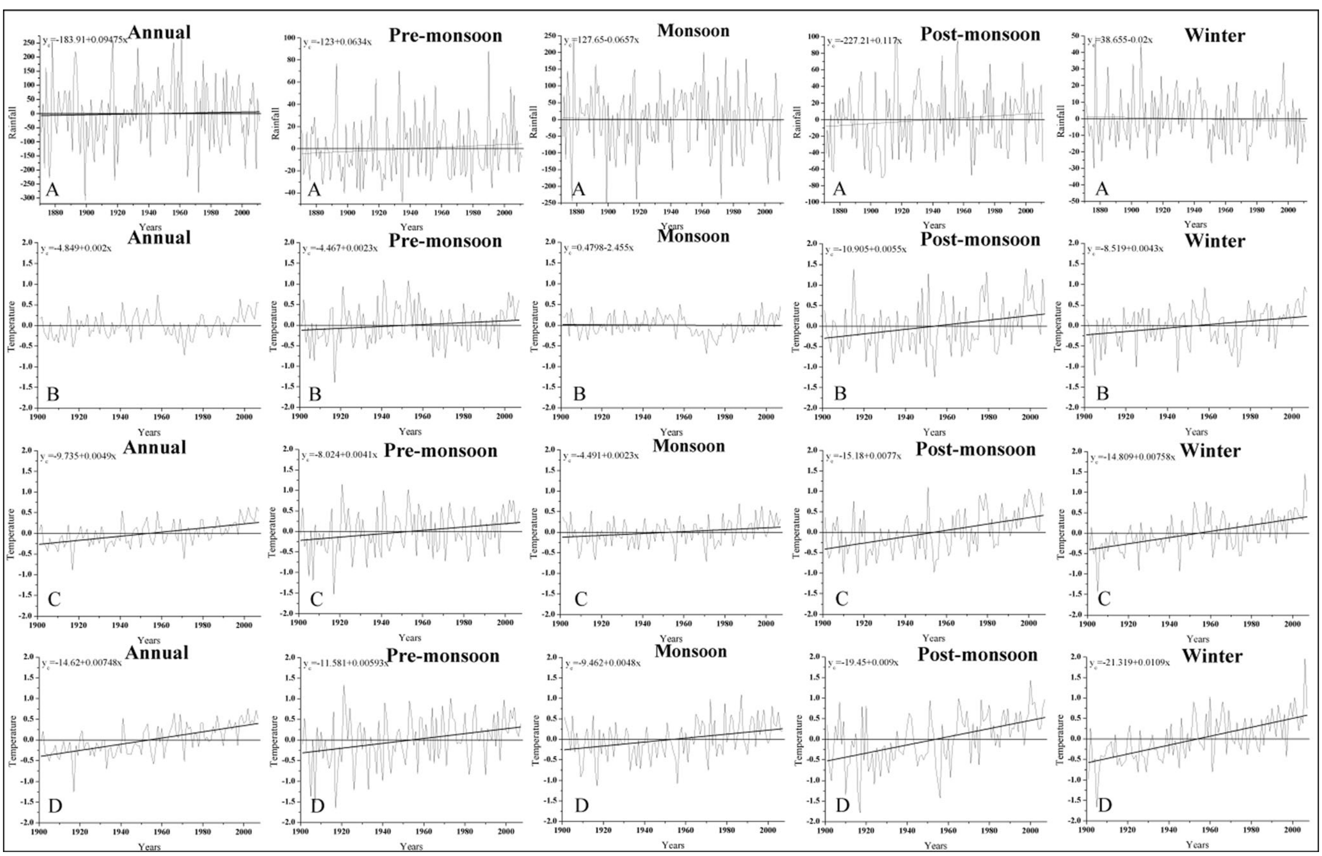

Fig. 4 Annual and seasonal trend of rainfall (1871–2011) and temperatures (1901–2007) by linear regression method (A rainfall, B minimum temperature, C mean temperature, D maximum temperature)

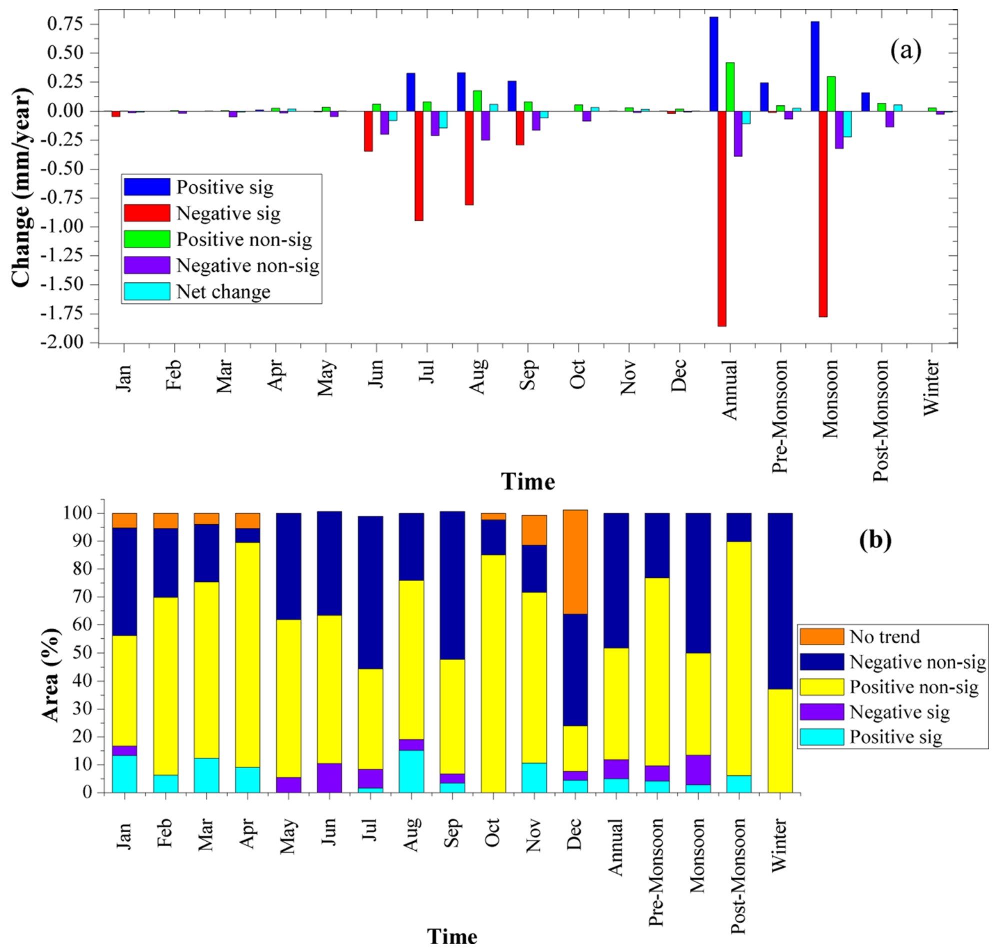

Fig. 5 **a** Net change in the rainfall and **b** total area coverage of rainfall pattern

significant negative temperature. Interestingly, the net change in all these months and the monsoon season indicate a positive or increasing temperature trend. February has the highest positive net change followed by December. This is reflected in the seasons showing the highest positive net change in the post-monsoon and winter periods. Figure 6b shows the area covered by the different temperature patterns. The graph indicates a similar pattern of 83 % of areas with significant positive temperature and 17 % with non-significant positive temperature in the months of February, October and November and annual, post-monsoon and winter seasons. December shows the entire 100 % of the area under the influence of a significant rising temperature. Except for a few months and monsoon season, decreasing temperature is not observed in the entire area.

4.4 Discussion

The results indicate that a significant decrease (at 95 % significance level) of rainfall in the Assam and Meghalaya and Nagaland, Manipur, Mizoram and Tripura comprises the North-east India zone, and also in the East Madhya Pradesh and Chhattisgarh in the West Central India zone. Significant rising minimum and maximum temperatures are observed in almost all the regions during most of the season, particularly in North-east India, North Central India, east coast, west coast, and interior peninsular India. The boundary zones of rainfall and temperature are different and do not coincide. Therefore, the extreme impact of climate change in a particular area is assessed on the basis of the estimated maximum boundary areas of rainfall zones falling within the temperature zones. North-east India has significant temperature rise and rainfall decrease particularly in the monsoon season. Monsoon is the main season, contributing to the highest rainfall in the country; therefore, decreasing rainfall and increasing maximum temperatures here may lead to severe disasters like droughts in the future. However, a non-significant decrease in rainfall (i.e. less than 95 %) is observed in all the seasons. East Madhya Pradesh and Chhattisgarh also indicate a significant decrease of rainfall that is included within the West Central India zone, and increase in minimum and maximum temperature is observed in North Central India and in some parts of the interior peninsular of India. Therefore, North-east India and West Central

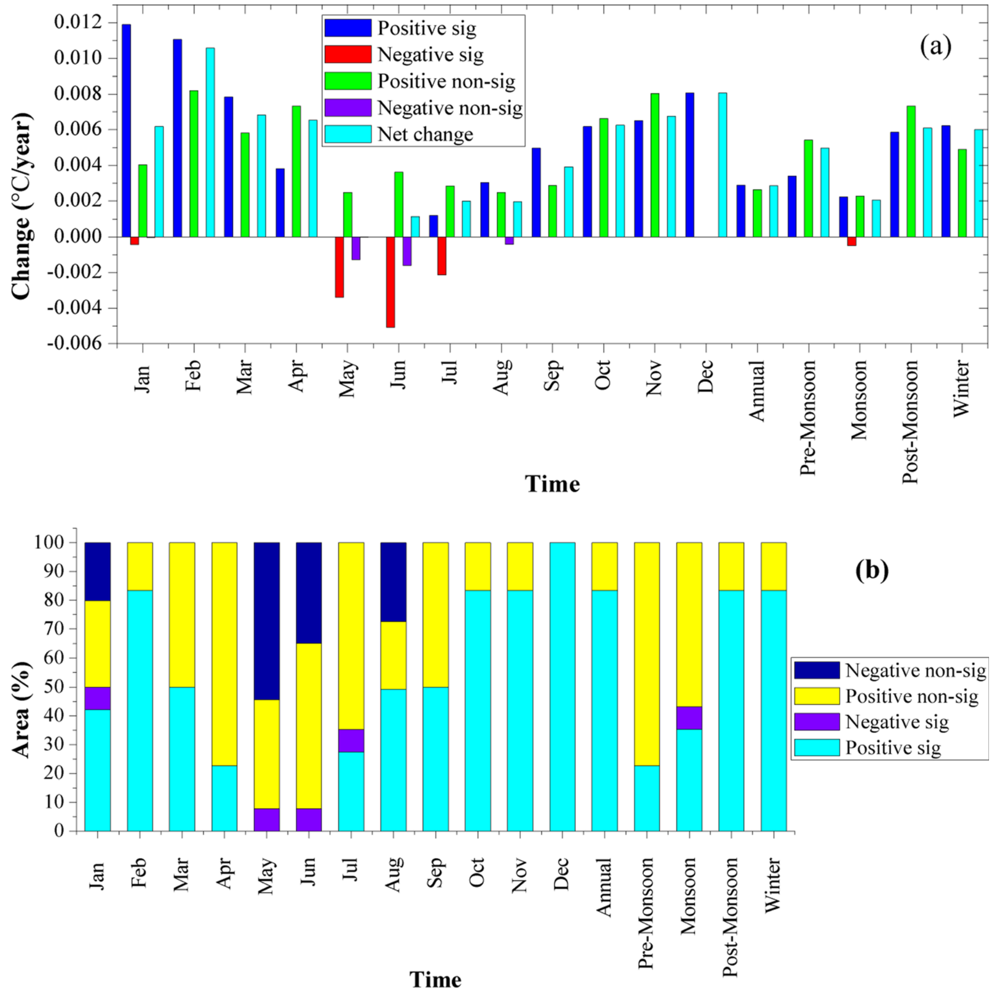

Fig. 6 **a** Net change in the mean temperature and **b** total area coverage of mean temperature pattern

India are the areas which will be affected by the major adversities of climate change, i.e. increasing temperature and decreasing rainfall.

5 Conclusion

The monthly, seasonal, annual temperature (1901–2007) and rainfall (1873 to 2011) variability for the entire India was analysed in this study over two different spatial scales of 30 sub-divisions and 7 regions of India. The Mann-Kendall test and Sen's slope was used for the trend analysis. Mann-Whitney-Pettitt test and change percentage were applied to get the break point and percentage of change in 107 and 141 years for temperature and rainfall, respectively. The parametric test with a linear trend was also used to show the trend. The spatial distribution of the seasonal and annual rainfall and temperature trend was shown to analyse the climatic difference in various parts of India. Further, the overall net change in the rainfall and temperature of India as well as its area of influence was given. The net change in the rainfall and mean temperature indicates decreasing rainfall and increasing temperature in most of the months and seasons. The impact of climate change was quite noticeable on the overall rainfall and temperature of the entire India. The rainfall trend of 141 years in 30 sub-divisions shows a variation in the annual trend. There are 15 sub-divisions with a decreasing trend and 15 with the increased rainfall trend. But, on a larger level, the overall trend is negative for the entire India. The annual rainfall trend varies from 2.53 mm/year in Coastal Karnataka to −1.43 mm/year in Chhattisgarh. A significant decrease in annual rainfall was found in the states of East Madhya Pradesh and Chhattisgarh (−1.43 mm/year and −14.93 %), while in monsoon, a significant decrease was observed in East Madhya Pradesh and Chhattisgarh; Nagaland, Manipur Mizoram and Tripura and Assam and Meghalaya. The significant increasing trend was mainly noticed in the south (Konkan and Goa being the highest with 1.81 mm/year and 10.73 %, Coastal Karnataka) and non-significant in the west and south (Rajasthan, Telangana, Coastal Andhra Pradesh, Tamil Nadu, Rayalseema, etc.) in annual rainfall. A similar observation for monsoon rainfall was made where increasing rainfall was noticed in the south-west like Konkan and Goa (2.06 mm/year and 11.44 %) and other states in the south and west. In the case of non-monsoonal rainfall, a significant rise was noticed in Rayalseema (0.017 mm/year and 32.35 %) and Bihar (0.19 mm/year and 31.17 %), while a non-significant decrease was observed in the north-eastern states, west and extreme south in the pre-monsoon time. A non-significant decrease in non-monsoonal rainfall (winter) was found in many parts of the north-east, west and central. In region-wise analysis, only two regions of North-west India and peninsular India are showing an increasing trend. According to the trend of the entire India, there was a decrease in the rainfall pattern. The range of rainfall in regions varies from −0.46 mm/year in Northeast India to 0.38 mm/year in peninsular India. A decrease was very high during monsoon in the North-east, West Central and Core Monsoon India regions. Thus, a falling trend was noticed in annual, monsoon and winter seasons, which have maximum impact on the entire country despite having a mixed trend in other seasons. The annual and monsoonal trend indicated a decrease for all divisions except areas belonging to the regions of West Central India and peninsular India, which is due to different atmospheric circulation.

The highest variation in the temperature was found in the minimum temperatures where both significant increase and decrease were observed in different regions. Significant and non-significant increase was found in major places at seasonal and annual scale, mostly in the post-monsoon (maximum 0.008 °C/year and 30.14 %) and winter (0.005 °C/year and 5.22 %) periods. Mean temperature also significantly increased in the majority of the regions and in most seasons, particularly in the post-monsoon (0.007 °C/year and 5.89 %), winter (0.009 °C/year and 41.08 %) and annual (0.004 °C/year and 3.16 %) timescale. The highest increase in mean temperature was found in the Western Himalayas. Only north-west of monsoon season had a decreasing temperature. Significant increase in all the regions with maximum annual (0.006 °C/year and 3.55 %) and winter (0.013 °C/year and 17.98 %) temperature was observed. Almost similar trends in the post-monsoon period were noticed. The entire northern and central India was experiencing significant rising maximum temperature. Noticeably, monsoon months, in the case of all minimum, mean and maximum temperatures, have shown comparatively lesser rates of increase and sometimes even a decrease like in the north-west. The Western Himalaya of India, North-east India and west coast of India have a significant increase, particularly in maximum and mean temperature. Thus, the climate impact is fairly observable here, which may lead to more snow melting in the mountains. The climatic picture shows that pre-monsoon and monsoon seasons have comparatively less temperature fluctuation than the post-monsoon and winter seasons. The highest warming trend was noticed in winter and post-monsoon seasons.

The analysis of net change in these two climatic parameters of India illustrates a decrease in rainfall, particularly in the annual and monsoon timescale, while a net change towards a significant warming trend was found in the case of temperature. Though the net change in the climate during monsoon time shows a decline of both rainfall and temperature, the rate of decrease of temperature was not much dominant. The monsoon season results in cloudiness and continuous rainfall because of monsoon circulation, which consequently gives lower temperature (Pal and Al-Tabbaa 2010). Thus, a net deficit of rainfall was observed over India, which was further aggravated by an excess of temperature. It was also evident from the annual trend magnitude for India as a whole that shows the downward rainfall trend and change percentage (−0.04 mm/year and −0.56 %) as well as an increase in the mean temperature (0.003 °C/year and 1.2 %), respectively.

Thus, annual and monsoonal decrease in rainfall and rising temperatures are indicating global warming with water scarcity and possibilities of droughts. These will have an adverse effect on the rain-fed agriculture and economic development of the country. Though the cause of this change in climate is whether due to natural or man-made factors is debatable, but assessment of the recent trend of temperature and rainfall along with the net climatic change for the entire India on a sub-divisional as well as on a broad regional basis is very important. The results from the study should be useful for planning and managing the water resources, for agriculture of the country and also for the development of any strategy for future adaptation.

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Appendix

Method

Serial correlation and pre-whitening

Detection of trend in a series is affected by the presence of a positive or negative autocorrelation (Hamed and Rao 1998; Yue et al. 2003). The autocorrelation coefficient of ρk for a discrete time series for lag-k is given as

$$\rho_k = \frac{\sum_{k=1}^{n-k}\left(x_t - \overline{x}_t\right)\left(x_{t+k} - \overline{x}_{t+k}\right)}{\left[\sum_{k=1}^{n-k}\left(x_t - \overline{x}_t\right)^2\left(x_{t+k} - \overline{x}_{t+k}\right)^2\right]^{1/2}} \quad (1)$$

where $\bar{x}_t$ and $Var\ (x_t)$ are represented as the sample mean and sample variance of the first $(n-k)$ terms, respectively; $\bar{x}_{t+k}$ and $Var\ (x_t+k)$ stand for the sample mean and sample variance of the last $(n-k)$ terms correspondingly. Again, the hypothesis of no correlation is examined by the lag-1 autocorrelation coefficient as H_0: $\rho_1=0$ against H_1: $|\rho_1|>0$:

$$t = |\rho_1|\sqrt{\frac{n-2}{1-\rho_1^2}} \tag{2}$$

Here, the t test is the Student's t distribution with $(n-2)$ degrees of freedom (Cunderlik and Burn 2002, 2004). If $|t|\geq t_{\alpha/2}$, the null hypothesis about no serial correlation is rejected at the significance level α.

Pre-whitening method is used to remove the serial correlation effect on the MK test (Storch 1993). Pre-whitening method with no trend was applied by Yue et al. (2002) with modification in the technique.

$$Y_i = x_i-(\beta \times i) \tag{3}$$

Here, β is Theil-Sen's estimator. The r_1 (lag-1 serial correlation coefficient) has been computed for new series. If r_1 does not vary significantly from zero, then the data will be used without serial correlation, and the MK test will be applicable to the sample data directly. But, if it is opposite, then method of pre-whitening will be applied before the testing of trend.

$$Y_i^{'} = Y_i-r_1 \times Y_{i-1} \tag{4}$$

The $\beta\times i$ value is added to the residual data set of Eq. 4

$$Y_i^{''} = Y_i^{'} + (\beta \times i) \tag{5}$$

This $Y_i^{''}$ is the final pre-whitened series.

Mann-Kendall test and Theil-Sen's estimator

The statistic of the MK test is given as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} if, S > 0 \\ 0 if, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} if, S < 0 \end{cases} \tag{6}$$

where

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j-x_i) \tag{7}$$

Here, x_j and x_i are data values that are in sequence with n data; sgn (θ) is equivalent to 1, 0 and −1 if θ is more than, equal to or less than 0 respectively. If Z_c appears to be greater than $Z_{\alpha/2}$, then the trend is considered as significant, where α represents the level of significance (Xu et al. 2003).

The rainfall trend magnitude is calculated by Theil-Sen's estimator (Theil 1950; Sen 1968).

$$\beta = median(X_i-X_j/i-j), \quad \forall j < i \tag{8}$$

where $1<j<i<n$ and β estimator stands for the median of the entire data set of all combination of pairs and is resistant to the effect of extreme values (Xu et al. 2003).

Percentage of mean

The change percentage is calculated by its approximation with linear trend. So, change percentage is equal to the median slope multiplied with the length of the period and the whole divided by the corresponding mean value which is given in percentage (Yue and Hashino 2003b).

$$\text{Percentage change } (\%) = \frac{\beta \times \text{data length}}{\text{mean}} \times 100 \tag{9}$$

Mann-Whitney-Pettitt method (MWP)

A time series $\{X_1, X_2 \ldots, X_n\}$ with length n is considered. Let t be taken as the time of the most expected change point. Two samples of $\{X_1, X_2, \ldots, X_t\}$ and $\{Xt_{+1}, X_{t+2}, \ldots, X_n\}$ can be then obtained by dividing the time series at t time. The U_t index is derived in the following way:

$$U_t = \sum_{i=1}^{t} \sum_{i=1}^{n} \mathrm{sgn}(X_i-X_j) \tag{10}$$

where

$$\mathrm{sgn}(x_j-x_i) = \begin{Bmatrix} 1.......if\,(x_j-x_i) > 0 \\ 0.......if\,(x_j-x_i) = 0 \\ -1.......if\,(x_j-x_i) < 0 \end{Bmatrix} \tag{11}$$

Plotting the U_t value against t in a time series with no change point will result in a continuously increasing value of $|U_t|$. Nevertheless, if there is a presence of change point (even a local change point), then $|U_t|$ will increase up to the level of the change point, and then, it will begin to decrease. The main significant change point t is considered as the point where the value of $|U_t|$ remains highest:

$$K_T = \max_{1 \le t \le T} |U_\tau| \quad (12)$$

The estimated significant probability $p(t)$ for a change point (Pettitt 1979) is given as:

$$p = 1 - \exp\left[\frac{-6K_T^2}{n^3 + n^2}\right] \quad (13)$$

The change point becomes statistically significant at t time with the significance level of α when probability $p(t)$ surpasses $(1-\alpha)$.

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