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Trend analysis of climatic variables in the Indian subcontinent

N. R. CHITHRA, DILBER SHAHUL, SANKAR MURALIDHAR,

UPAS UNNIKRISHNAN and AKHIL RAJENDRAN K.

Department of Civil Engineering, National Institute of Technology Calicut, India

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e mail : chithranr@nitc.ac.in

सार - इस अध्ययन का उद्देश्य भारत में जलवायु परिवर्तनों के स्थानिक और कालिक परिवर्तनशीलता के महत्वपूर्ण रुझानों का पता लगाना और उनका आकलन करना है। जलवायु परिवर्तन के कारण सबसे संवेदनशील जगहों की भी पहचान की गई है। उस प्रयोजन के लिए, भारतीय उपमहाद्वीप के मासिक औसत तापमान, सतह का दबाव, सापेक्षिक आर्द्रता, जैसे विभिन्न जलवायु परिवर्तिताओं के रुझान का विश्लेषण किया गया। राष्ट्रीय पर्यावरण पूर्वानुमान केंद्र/राष्ट्रीय वायुमंडलीय अनुसंधान केंद्र (एनसीईपी/एनसीएआर) से प्राप्त 2.5° कोर रिजॉल्यूशन पर ग्रिडेड डेटा से पुनः विश्लेषित डेटा 1 के व्यापक रूप से अपनाने और सुगम उपलब्धता के कारण उपयोग किया जाता है। इसके अलावा, व्यापक रूप से इस्तेमाल किए जाने वाले रुझान विश्लेषण विधियों जैसे: मैन-केंडल टेस्ट, सेन के अनुमानक विधि और रैखिक प्रतिगमन का उपयोग महत्वपूर्ण रुझानों का पता लगाने और मापने के लिए किया गया। परिणामों से यह पता चला हैं कि तापमान में उल्लेखनीय वृद्धि और सापेक्ष आर्द्रता में महत्वपूर्ण कमी के चलते दक्षिणी भारत जलवायु परिवर्तन के प्रति अधिक संवेदनशील है। सतह का दबाव पूरे भारत में बढ़ रहा है और वृद्धि सांख्यिकीय रूप से महत्वपूर्ण है। उचित उपशमन योजना प्रदान करने के लिए नीति निर्माताओं के लिए ये परिणाम बहुत उपयोगी होंगे।

ABSTRACT. The objective of this study is to detect and assess the significant trend in the spatial and temporal variations in the climatic variables in India and to identify the most vulnerable locations to climate change in India. For that purpose, trend analysis of various climatic variables such as monthly mean temperature, surface pressure, relative humidity was conducted for the Indian subcontinent. Gridded data at 2.5° resolution obtained from National Centre for Environmental Prediction / National Centre for Atmospheric Research (NCEP/NCAR) reanalysis data 1 is used due to its wide acceptability and easy availability. Also, widely used trend analysis methods, *viz*., Mann-Kendall test, Sen's estimator method and linear regression were used to detect and quantify the significant trend. Results revealed that southern India is more vulnerable to climate change due to the significant increase in temperature and significant decrease in relative humidity. Surface pressure is increasing throughout India and the increase is statistically significant. The results will be very useful for policy makers for providing proper mitigation plans.

Key words – Climate change, Temperature, India, Trend analysis, Regression.

1. Introduction

It has been observed in many studies that the global climate has taken a significant turn in the recent decades. According to Intergovernmental Panel on Climate Change (IPCC), increase in greenhouse gas concentrations increased the annual mean global temperature by 0.6 ± 0.2 °C since the late 19th century (Houghton, 2001). According to the estimates by IPCC, earth's linearly averaged surface temperature has increased by 0.74 °C during the period 1901-2005 (Pachauri and Reisinger, 2007). Weather reports have shown that global mean surface temperature has warmed up approximately by 0.6 °C since 1850 and it is expected that by 2100, the increase in temperature could be 1.4-5.8 °C (Singh *et al.*, 2008). The impact of climatic change is projected to have different effects within and between countries. Information about such change is required at global, regional and basin scales for the policy makers to make mitigation plans.

The change in the trend of climatic variables may affect adversely various sectors, *viz*., water resources (Parry *et al.*, 2001; Gupta *et al.*, 2016), human health and agricultural yield. Climatic processes are likely to intensify, including the severity of hydrological events such as droughts, flood waves and heat waves. These projected effects of possible future climate change would significantly affect many hydrologic systems, which in turn affect the water availability and runoff and the flow in rivers. Such hydrologic changes have pronounced impact on many sectors of the society. The general impacts of climate change on water resources have been brought out by the Fifth Assessment Report of the IPCC emphasizing on increasing flood and extreme weather events leading to deteriorated drinking water quality and other health hazards with increase in epidemic diseases (Hartmann *et al.*, 2013). Observed warming over several decades has been linked to changes in the large-scale hydrological cycle such as, increasing atmospheric water vapour content; changing precipitation patterns, intensity of extremes reduced snow cover and widespread melting of ice as well as changes in soil moisture and runoff. Changes in precipitation show substantial spatial and temporal variability (Rajbhandari *et al.*, 2014). All these studies indicate that the change in climatic variables has been significant for the past decades and needs closer observations and studies in the present time also.

India is the second populous and a very large country in Asia. India exhibits varying temperature such as very low temperature at the Himalayas to very high temperature at the Thar Desert. The study by Srivastava *et al.* (1992) on decadal trends in climate over India gave the first indication that temperature trends in India are quite different from that observed over various parts of the globe. They observed that the maximum temperatures show much larger increasing trends than minimum temperature, over a major part of the country and an overall slightly increasing trend of the order of 0.35 °C over the last 100 years. Kumar *et al.* (1994) have shown that the countrywide mean maximum temperature has risen by 0.6 °C. Lal *et al.* (1995) suggested that the increase in the annual mean minimum and maximum surface air temperatures would be of the order of 0.7-1.0 °C in the 2040s, in comparison with 1980s. Another study by Ray and Srivastava (2000) has shown that the frequency of heavy rains during the south west monsoon showed an increasing trend over certain parts of the country. Parthasarathy and Dhar (1974) found that the annual rainfall for the period 1901-1960 had a positive trend over central India and the adjoining parts of the peninsula and a decreasing trend over some parts of Eastern India.

Das *et al.* (2014) analysed temporal trends of rainfall and rainy days during summer monsoon using gridded precipitation data (0.5° × 0.5°) provided by IMD. They found that statistically significant increasing trend exists for eastern coast and Deccan plateau whereas a statistically significant decreasing trend exists for western and north eastern regions. Another study by Kishore *et al.* (2016) on gridded precipitation data and reanalysis data revealed that north east and west coast of Indian region shows significant positive trends whereas western Himalayas and north central Indian region shows a significant negative trend in precipitation. Studies on gridded temperature data by IMD reported a mean temperature anomaly over 4 °C over central India and over northwest India minimum temperatures were below normal by 4 °C (Srivastava *et al.*, 2009).

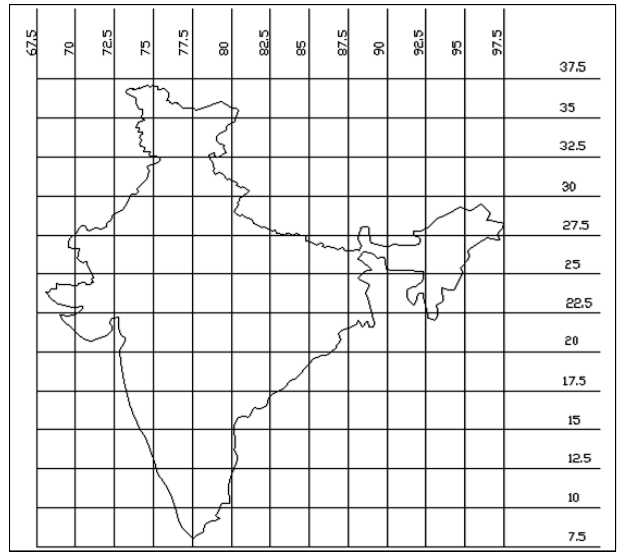

Fig. 1. Map of India showing grid points

In this study, change in trend is detected in various climatic variables such as, temperature and relative humidity at different pressure levels and surface pressure at various grid points of the Indian subcontinent and examined whether the change is significant. Brief methodology and results are discussed in the following sections.

2. Methodology

The methodology adopted is a trend analysis of various climatic variables on monthly basis and seasonal trend analysis of the temperature, over a time period of 1948 to 2014. The climatic variables namely monthly air temperature and relative humidity at the levels, surface, 500 hPa pressure level, 850 hPa pressure level and 1000 hPa pressure level and surface pressure were used in this study.

2.1. *Study area*

The study area chosen consists of the Indian subcontinent, between 8°4' and 37°6' north latitude and 68°7' and 97°25' east longitude. The study area contains a variety of geographical features. The Indian subcontinent is surrounded by Arabian Sea in the West, Bay of Bengal in East and Indian Ocean in the South. South India is a peninsula with two coastal lines at the boundaries and a plateau in the centre. North India occurs in the valley of Himalayas and North Eastern India is mainly foothills and peaks of Himalayas. There exists a wide variation of geographical features which might result in highly varying climatic conditions. The study area is illustrated in Fig. 1.

2.2. *Data used*

The study uses monthly climatic data simulated by National Center for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR) for the period of 1948-2014. As the data points are available in grids of 2.5°, the Indian subcontinent was divided into grids of the same measure and 47 data points were identified which are presented in Fig. 1. The NCEP/ NCAR data is a reliable basis for analysis of the natural variability over the last several decades especially in the Northern Hemisphere (Rudeva and Gulev, 2011). Also, due to the lack of availability of observational meteorological data in extremes terrains like the North Eastern parts of India, the reanalysis data is considered most complete and physically consistent data set (Dell' Aquila *et al.*, 2005; Simmonds and Keay, 2000). The data assimilation system uses a 3D-variational analysis scheme, with 28 sigma levels in the vertical and a triangular truncation of 62 waves which corresponds to a horizontal resolution of approximately 200 km (Kalnay *et al.*, 1996). This data have been used for Indian conditions in several studies (Anandhi *et al.*, 2009; Ghosh and Mujumdar, 2007; Chithra *et al.*, 2015). Also in this study, NCEP/NCAR data is validated by comparing with observations for the Chaliyar river basin in Kerala, India using correlation coefficient analysis. Correlation coefficient values of surface temperature obtained from NCEP/NCAR and observations at this river basin is in the range of 0.7 to 0.8 for most of the seasons, showing temperature data well simulated by NCEP/NCAR.

2.3. *Trend analysis*

Trend analysis of a time series consists of estimation of the magnitude of trend and assessing its statistical significance. Different researchers have used different methodologies for trend detection. As the data obtained can be classified as ordinal and interval data, both non parametric and parametric tests could be used to evaluate the same. Parametric test cannot be employed alone as the data is not necessarily normal, but it will lead to better conclusions. Therefore parametric regression analysis is done along with non-parametric Sen's estimator method as a check. Both these methods assume a linear trend in the time series. Mann Kendall (MK) test is also employed to check the possibility of a trend in a specific time series.

2.3.1. *Regression analysis*

Regression analysis is a statistical process for estimating the relationships among variables, especially deriving a relationship between a dependent variable and one or more independent variables. Regression analysis is widely used for prediction and forecasting. Methods such as linear regression and least squares regression are parametric methods, in that the regression function is defined in terms of a finite number of unknown parameters that are estimated from the data.

The regression analysis can be carried out directly on the time series. A linear equation,

$$y = mt + c \tag{1}$$

defined by c (the intercept) and trend m (the slope), can be fitted by regression. The linear trend value represented by the slope of the simple least-square regression line provided the rate of rise or fall in the variable.

2.3.2. *Sen's estimator method*

Sen's estimator method is a robust linear non-parametric method that chooses the median slope among all lines through pairs of two-dimensional sample points (Theil, 1950; Sen, 1968). It is insensitive to outliers and its accuracy is high especially for skewed and heteroskedastic data. Sen's estimator has been widely used for determining the magnitude of trend in hydro-meteorological time series. In this method, the slopes (T_i) of all data pairs are first calculated by:

$$T_i = \frac{x_j - x_k}{j - k} \tag{2}$$

for $i = 1, 2, \ldots, N$

where, x_j and x_k are data values at time j and k ($j > k$) respectively.

The median of these N values of T_i is Sen's estimator of slope which is calculated as

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \tag{3}$$

A positive value indicates an upward or rising trend and a negative value indicates downward or decreasing trend.

2.3.3. *Mann-Kendall (MK) test*

Mann Kendall test is a statistical test used for the analysis of trend in climatologic and in hydrologic time series. It is used to ascertain the presence of statistically significant trend in hydrologic climatic variables (Mann, 1945; Kendall, 1975). The null hypothesis (H_0) of the test is that there is no trend (the data is independent and

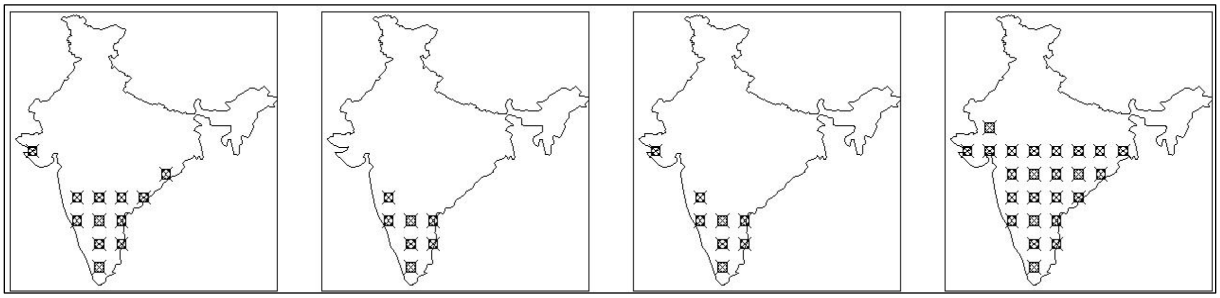

Fig. 2. Results of Mann-Kendall test for air temperature. Points shown are points with statistically significant trends at 95% confidence interval. (From left: Level surface, Level 1000, Level 850 and Level 500)

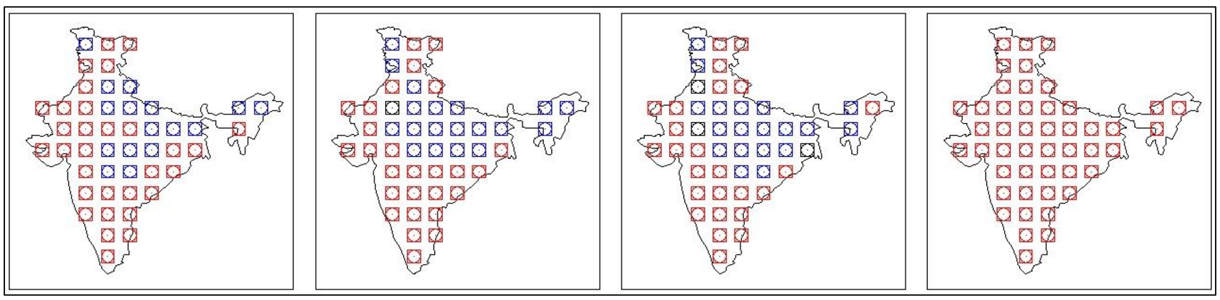

Fig. 3. Results of Sen's test for air temperature. Red points shows a positive trend, Blue points a negative trend and Black points no trend. (From left: Level surface, Level 1000, Level 850 and Level 500)

randomly ordered) versus the alternative hypothesis (H_1), which assumes that there is an increasing or decreasing trend.

The MK test considers the time series of n data points. This data set is divided into two subset datasets x_i and x_j where i = 1,2,3,…, n-1 and j = i+1, i+2, i+3, …, n. These data sets are evaluated as ordered time series.

The statistics (S) is defined as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\,(x_j - x_i) \tag{4}$$

where, N is the number of data points. Assuming $(x_j - x_i) = \theta$, the value of $sign\,(\theta)$ is computed as follows:

$$sign\,(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \tag{5}$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples ($N > 10$), the test is conducted using a normal distribution, with the mean and the variance as follows:

$$E[S] = 0 \tag{6}$$

$$var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k(t_k-1)(2t_k+5)}{18} \tag{7}$$

where, N is the number of tied (zero difference between compared values) groups and t_k is the number of data points in the k^{th} tied group.

The standard normal deviate (Z-statistics) is then computed as

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{var(S)}} & if\ S < 0 \end{cases} \tag{8}$$

If the computed value of $|Z| > Z_{\alpha/2,}$ the null hypothesis (H_0) is rejected at α level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level.

2.3.4. *Seasonal analysis*

The data obtained was divided into three seasons namely wet (June to November), dry (December to May) and south west monsoon (June to September).

3. Results and discussion

3.1. *Air temperature*

The mean monthly temperature for the duration 1948 to 2014 at the 48 identified grid points at all the four

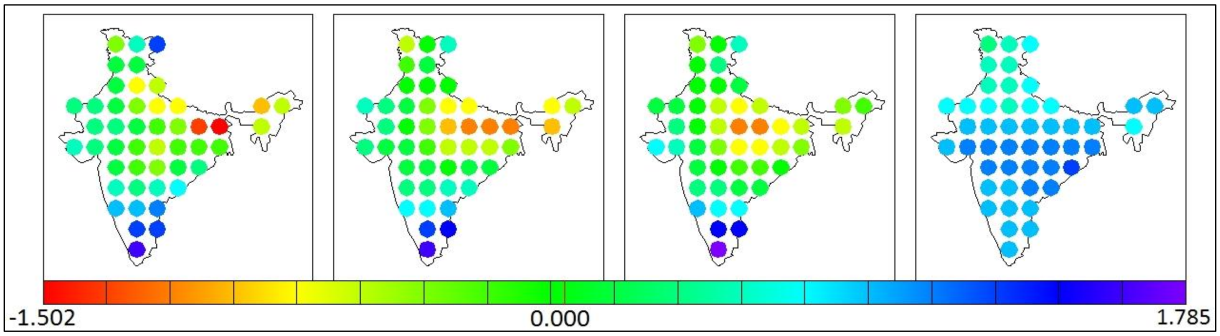

Fig. 4. Change in air temperature (in °C) for 66.5 years (January 1948 - June 2014), estimated using linear regression analysis. (From left: Level surface, Level 1000, Level 850 and Level 500)

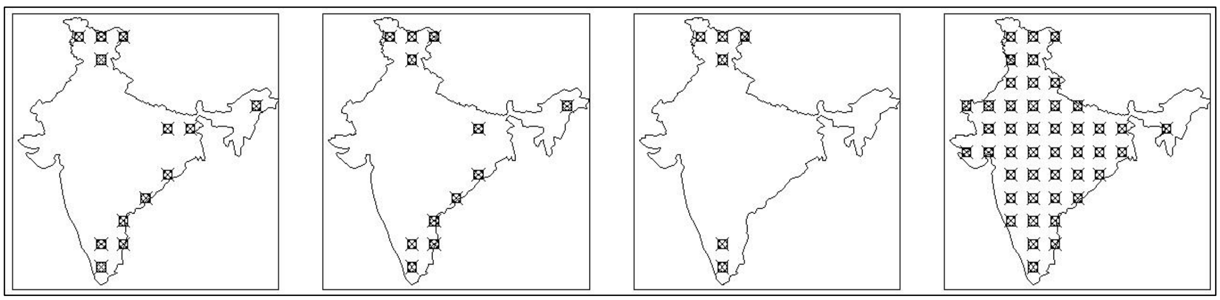

Fig. 5. Results of Mann-Kendall test for relative humidity. Points shown are points with statistically significant trends at 95% confidence interval. (From left: Level surface, Level 1000, Level 850 and Level 500)

pressure levels were subjected to the three tests explained above. The result of the MK test is presented in Fig. 2. It can be seen that in all the four pressure levels considered, statistically significant trend exists in South India. Existence of a trend was confirmed on surface level, at 500 hPa and at 850 hPa for 22.5° N 70° E. All grid points showed the possibility of a trend at 500 hPa except Northern and North Eastern regions. It can be concluded that a statistically significant trend of mean monthly air temperature is present in Southern India.

The results of Sen's estimator method is presented in Fig. 3, which shows an increasing trend for all grid points at 500 hPa pressure level. At 850 hPa pressure level, the constant and significant increase of monthly mean temperature in the Southern India is alarming. It was observed that Central and North Eastern parts of India showed a negative trend indicating fall of mean air temperature. At 1000 hPa pressure level, the grid points at North Eastern/Central Eastern regions showed a fall in temperature and the south and western parts of India showed increase in temperature. At surface level, all the points from Central Eastern/North Eastern Region showed a fall but is more scattered. Sen's method is also showing an increasing trend for all the pressure levels considered in southern India.

Using Regression Analysis, the temperature rise during the considered period (1948-2014) was found for each grid point and at every pressure level (Fig. 4). At the 500 hPa pressure level, all the points showed a rise in temperature of the order 0.82 °C. At the 850 hPa pressure level, the average obtained showed a fall in temperature of 0.01 °C. Northern, Central and Eastern parts of India showed a fall in temperature over 66 years. At 1000 hPa pressure level, the average obtained showed a fall of temperature of 0.03 °C. For this case also Northern, Central and Eastern parts of India showed a decrease in temperature. At surface level, the average obtained showed a rise of temperature of 0.07 °C. For surface level also Northern, Central and Eastern regions showed a decrease in temperature. Southern India is showing an increasing trend at all the pressure levels according to regression analysis also.

It can be concluded that Southern India is showing statistically significant increasing trend for mean air temperature at all pressure levels based on the three methods. The temperature has decreased slightly over Central, Eastern and North Eastern parts of India while the rest shows rise in temperature.

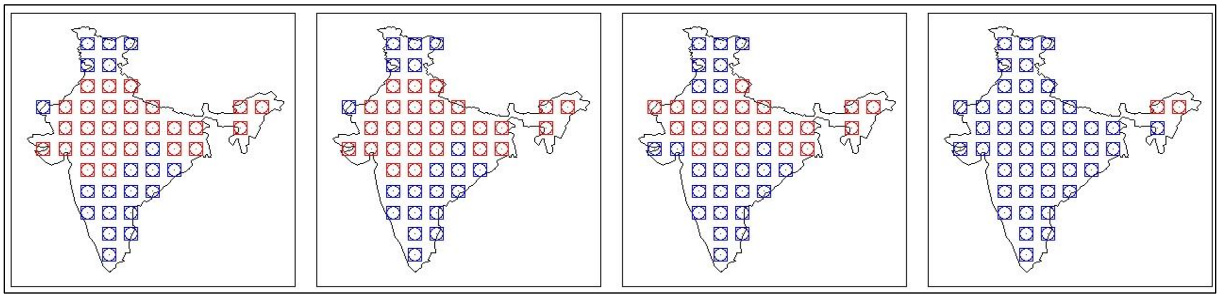

Fig. 6. Results of Sen's test for relative humidity. Red points show a positive trend, Blue points a negative trend and Black points no trend. (From left: Level surface, Level 1000, Level 850 and Level 500)

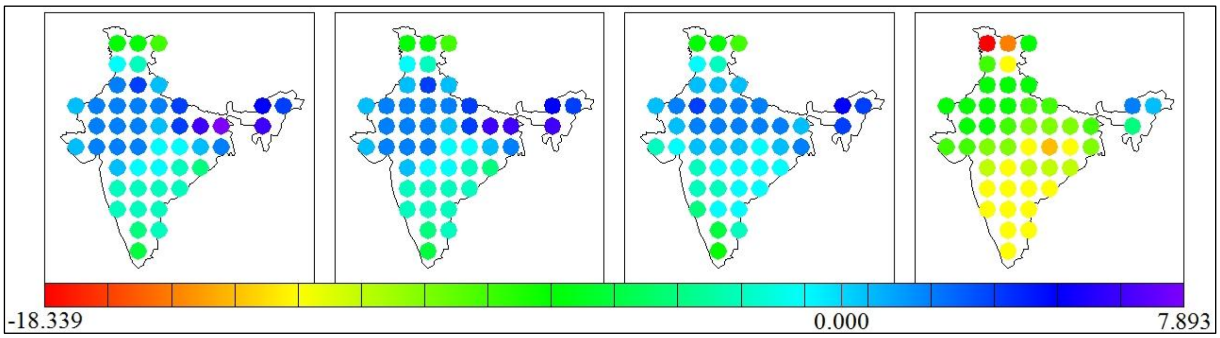

Fig. 7. Change in relative humidity (in %) for 66.5 years (January 1948 - June 2014) estimated using linear regression analysis. (From left: Level surface, Level 1000, Level 850 and Level 500)

3.2. *Relative humidity*

Relative humidity is a very important climatic variable which affects precipitation pattern and hence studies on its change with time is required in hydrology. The linear regression analysis, Sen's estimator method and Mann-Kendall test were performed for the 47 grid points for all the three pressure levels and surface.

The MK Test was conducted at 95% confidence level & the results are presented in Fig. 5. For the 500 hPa pressure level, except two grid points (27.5° N 92.5° E and 27.5° N 95° E), all other points indicated statistically significant trends. The 850 hPa, 1000 hPa & surface levels have very few points showing statistically significant trend. These three levels have statistically significant results in Jammu & Kashmir and southern India. The levels 1000 hPa and surface had statistically significant results along the south eastern coastal region of India.

The results of Sen's estimator test (Fig. 6) for the level 500 hPa gave a decreasing trend for all regions except north east. The patterns of trends for the relative humidity were identical for the surface level, 1000 hPa pressure level and the 850 hPa pressure level in India. The southern peninsular region of India showed a decreasing trend for all the four pressure levels. The western, central eastern and eastern parts of India showed an increasing trend for the surface, 1000 hPa and 850 hPa pressure levels. Jammu and Kashmir showed a negative trend for all the four pressure levels.

The regression analysis gave the change in the relative humidity for a period of 66 years for all the grid points (Fig. 7). The pressure levels 500 hPa, 850 hPa and 1000 hPa showed an overall decrease in the relative humidity in India whereas the surface level showed a slight increase in relative humidity. At the 500 hPa pressure level, there was an average decrease of 9.64%. The average decrease in the relative humidity throughout India for the 850 hPa and 1000 hPa pressure level was found to be 0.43% and 0.04% respectively. The surface level showed a slight increase of 0.02% for the average relative humidity in India.

3.3. *Surface pressure*

The surface pressure was analysed by performing the linear regression analysis, Sen's estimator test and Mann-Kendall test to determine the statistical significance.

The results of MK test gave positive trend for all the grid points in India indicating the presence of a statistically significant trend in the mean surface pressure.

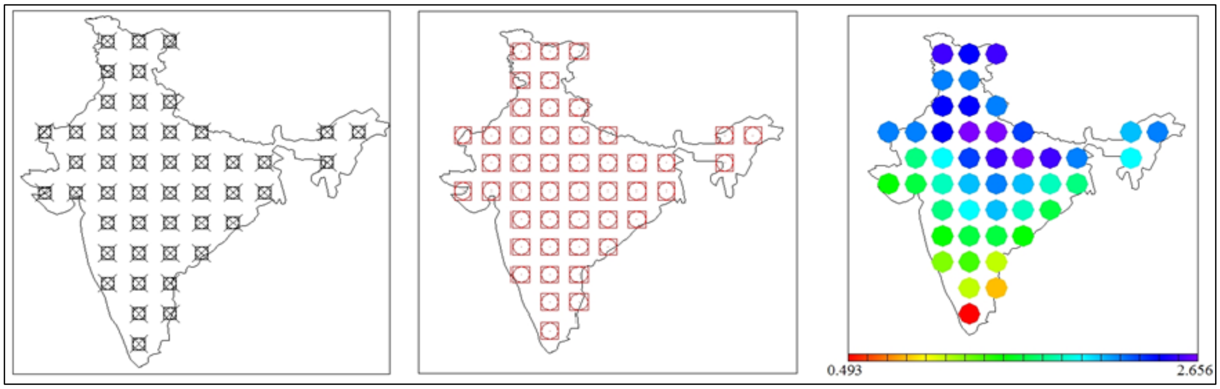

Fig. 8. Results of Mann-Kendall test (left), Sen's test (center) and linear regression analysis (right) for surface pressure. Points shown are points with statistically significant trends at 95% confidence interval (left). Circle with positive sign shows a positive trend (center). Change in 66.5 years estimated using regression analysis (right)

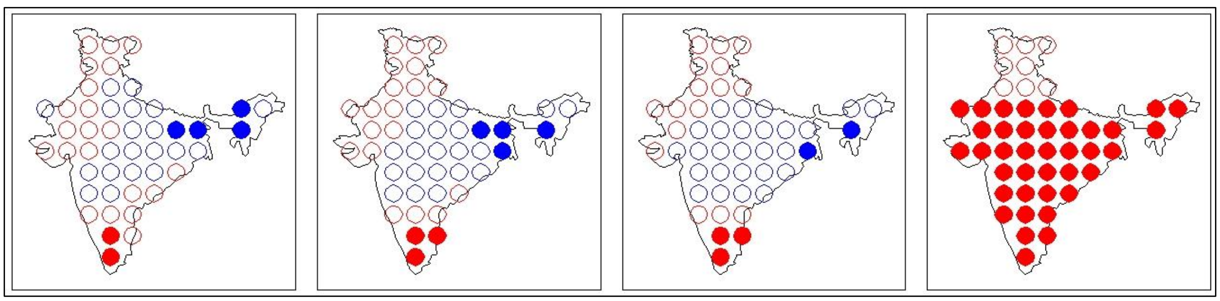

Fig. 9. Results of Mann-Kendall test and Sen's estimator method for air temperature during the dry season months. Red circles shows increasing points, Blue circles shows decreasing points, Red filled circles shows significant increasing points and Blue filled circles shows significant decreasing points. (From Left: Level surface, Level 1000, Level 850, Level 500)

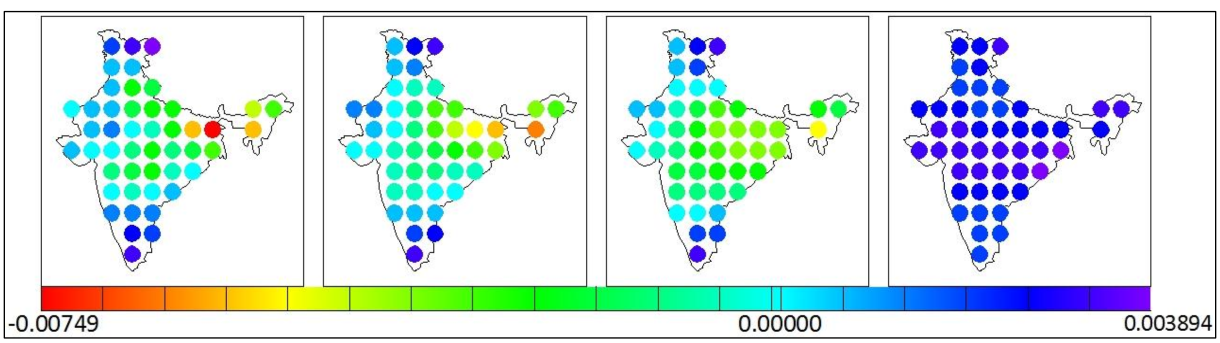

Fig. 10. Air temperature change per month during dry season months, estimated using regression analysis. (From Left: Level surface, Level 1000, Level 850, Level 500)

The Sen's Estimator Method also gave increasing trend for all the grid points in India indicating an increase in the surface pressure in India. The Linear regression analysis gave the change in the mean monthly pressure in India for the 66 years (Fig. 8). The average value of the surface pressure in India was found to be increasing by 1.94 hPa. Summary of trend analysis performed is presented in Table 1.

3.4. *Seasonal trend analysis*

Analysis on seasonal basis is required to study the actual situation of temperature rise in a season. All the three tests, namely MK test, Sen's Estimator method and linear regression analysis were performed for air temperature during the three seasons (dry, wet and south west monsoon).

TABLE 1

Trend analysis results summarised (1948-2014)

Significant trend	Variable	Surface level		1000 hPa pressure level		850 hPa pressure level		500 hPa pressure level	
		Region	Average change	Region	Average change	Region	Average change	Region	Average change
Positive	Temperature (°C)	South, West, Eastern & western coast (31 points)	0.43	Southern peninsula, north western region (28 points)	0.39	South, west, north west (25 points)	0.46	All over India (47 points)	0.84
	Relative humidity (%)	Central, North eastern regions (27 points)	2.65	Central, North eastern regions (27 points)	2.54	Central, North eastern regions (21 points)	2.01	North eastern regions (2 points)	1.35
	Surface pressure (hPa)	All over India (47 points)	1.94	NA	-	NA	-	NA	-
Negative	Temperature (°C)	North eastern regions (16 points)	-0.61	Central, North eastern regions (19 points)	-0.66	Central, North eastern regions (22 points)	-0.56	No points	-
	Relative humidity (%)	South, Eastern coast (20 points)	-3.30	South, Eastern coast (20 points)	-3.30	Southern peninsula (26 points)	-2.77	All over India except north eastern region (45 points)	-10.25
	Surface pressure (hPa)	No points	-	NA	-	NA	-	NA	-

MK test was performed on the temperature data during dry season and the results indicated a statistically significant trend for a few grid points. However, almost all regions except north India showed a positive trend in the pressure level 500 hPa. Sen's estimator method indicated the presence of a rising trend in southern and north western India in all the pressure levels (Fig. 9). Southern parts of India showed a significant increasing trend while the north east parts of India showed a significant decreasing trend. Linear regression analysis results (Fig. 10) were also in line with the Sen's estimator method. At the 500 hPa pressure level, all the points showed a rise in temperature of the order 1.10 °C in the 66 years considered. At the pressure levels 850 hPa and 1000 hPa the average obtained showed a fall in temperature of 0.41 °C and 0.30 °C respectively. At surface level, the average obtained showed a fall in temperature of 0.24 °C in the period 1948 to 2014.

For wet season data, all points except those in North India showed a significant increasing trend as per MK test and Sen's estimator method (Fig. 11). The number of points which showed a significant increasing trend is more during wet season than the dry season. This is in line with the result obtained using linear regression analysis. Using regression analysis, the change in the temperature during the last 66 years (1948-2014) was obtained for each grid point (Fig. 12). At the 500 hPa pressure level, there was an average increase of 0.53 °C. The average increase in the temperature throughout India for the 850 hPa and 1000 hPa pressure level was found to be 0.43 °C and 0.29 °C respectively. The surface level showed an increase of 0.44 °C for the average temperature in India.

In the case of south west monsoon season, all points except those in North India showed a significant increasing trend as per MK test and Sen's estimator method (Fig. 13). This result is also in line with the result obtained using linear regression analysis (Fig. 14). The average change in temperature based on the regression analysis was found to be increasing for all the four pressure levels. The average increase in the temperature throughout India was found to be 0.57 °C, 0.53 °C, 0.32 °C and 0.48 °C for the 500 hPa, 850 hPa, 1000 hPa and surface pressure levels respectively. Results of seasonal trend analysis are summarized in Table 2.

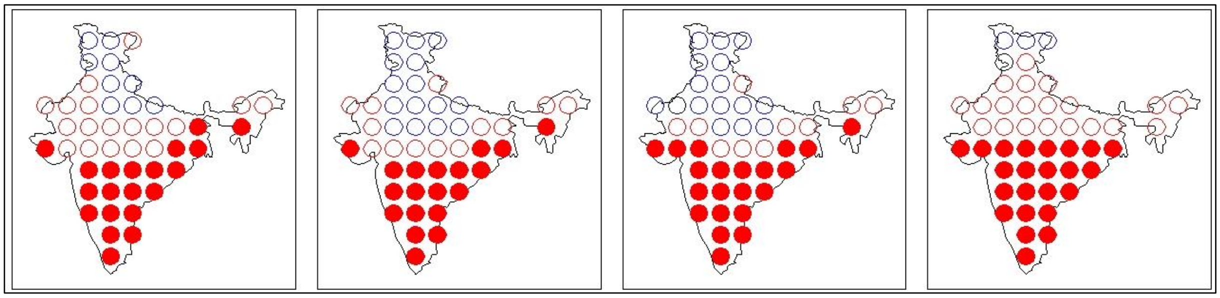

Fig. 11. Results of Mann-Kendall Test and Sen's estimator method for Air Temperature during the wet season months. Red circles shows increasing points, Blue circles shows decreasing points, Red filled circles shows significant increasing points and Blue filled circles shows significant decreasing points. (From Left: Level Surface, Level 1000, Level 850, Level 500)

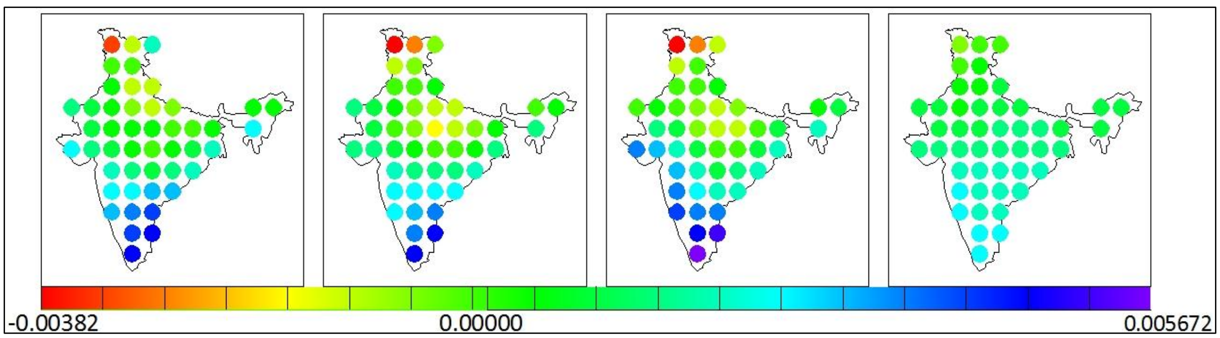

Fig. 12. Air Temperature change per month during wet season months, estimated using regression analysis. (From Left: Level Surface, Level 1000, Level 850, Level 500)

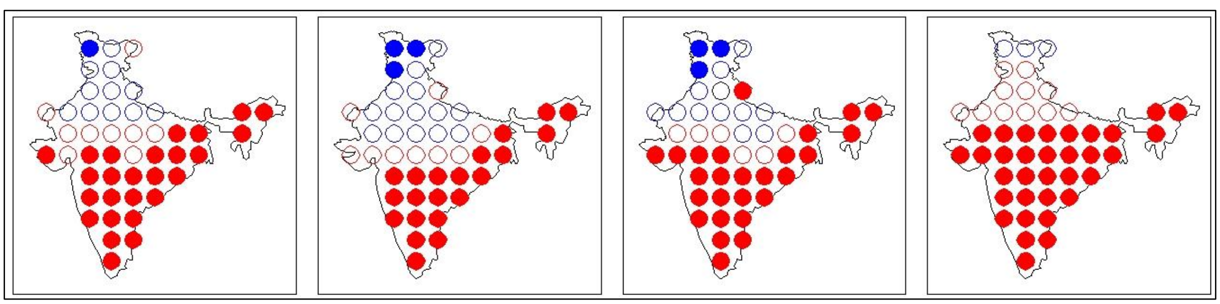

Fig. 13. Results of Mann-Kendall Test and Sen's estimator method for air temperature during the south-west monsoon season months. Red circles shows increasing points, Blue circles shows decreasing points, Red filled circles shows significant increasing points and Blue filled circles shows significant decreasing points. (From Left: Level Surface, Level 1000, Level 850, Level 500)

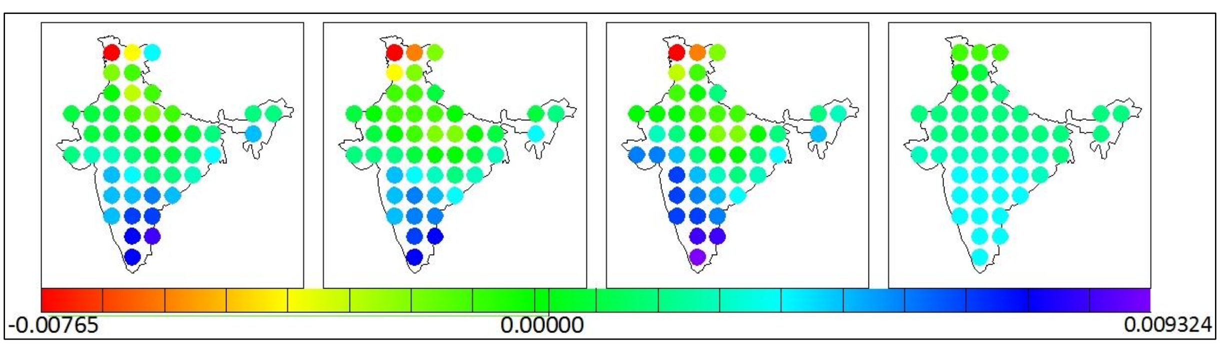

Fig. 14. Air temperature change per month during south-west monsoon season months, estimated using regression analysis. (From Left: Level Surface, Level 1000, Level 850, Level 500)

TABLE 2

Trend analysis results summarised (1948-2014) - Seasonal analysis of air temperature

Significant trend	Season	Surface level		1000 hPa pressure level		850 hPa pressure level		500 hPa pressure level	
		Region	Average change	Region	Average change	Region	Average change	Region	Average change
Positive	Dry (Dec-May)	South India (2 points)	1.15 (°C)	South India (3 points)	1.07 (°C)	South India (3 points)	1.00 (°C)	All over India except northern most tip (39 points)	1.13 (°C)
	Wet (Jun-Nov)	Southern peninsula, North eastern regions (20 points)	1.00 (°C)	Southern peninsula, North eastern regions (19 points)	0.93 (°C)	Southern peninsula, North eastern regions (21 points)	1.13 (°C)	Southern peninsula (23 points)	0.78 (°C)
	South west monsoon (Jun-Sep)	Southern peninsula, North eastern regions (26 points)	1.00 (°C)	Southern peninsula, North eastern regions (21 points)	1.02 (°C)	Southern peninsula, North eastern regions (22 points)	1.20 (°C)	Southern peninsula, Central, north eastern regions (33 points)	0.74 (°C)
Negative	Dry (Dec-May)	North eastern regions (4 points)	-2.32 (°C)	North eastern regions (4 points)	-2.00 (°C)	North eastern regions (2 points)	-1.70 (°C)	No points	-
	Wet (Jun-Nov)	No points	-	No points	-	No points	-	No points	-
	South west monsoon (Jun-Sep)	Northern most tip (1 point)	-1.92 (°C)	Northern most tip (3 points)	-1.49 (°C)	Northern most tip (3 points)	-1.42 (°C)	No points	-

4. Conclusions

The Indian mainland was identified as a collection of 47 grid points in the resolution 2.5° Lat. × 2.5° Long. The data was obtained from NCEP/NCAR Reanalysis data and is in the form of monthly mean values for surface and the pressure levels 1000 hPa, 850 hPa and 500 hPa. The climatic variables under consideration are air temperature (°C), surface pressure (hPa) and relative humidity (%).

All the variables were subjected to three tests namely, Mann Kendall test which gave the grid points which might have a significant trend, Sen's estimator method which indicated if the trend present was increasing or decreasing and Linear regression method which indicated by how much the variable has increased or decreased in the period. Further, the same analysis was performed on seasonal subsets of the temperature data for the three seasons, namely, dry season (December - May), wet season (June - November) and south west monsoon season (June - September).

Based on the trend analysis, a statistically significant increasing trend was identified in surface temperature in South India and based on regression analysis, this was found to be of the order of 0.23 °C over the period. Surface pressure has increased all over India in the order of 1.94 hPa. Relative humidity showed a significant decrease in South India, Eastern Coastal Region and in the northern most tip. The average increase was of the order 2.53%. Analysis on seasonal subsets revealed that for dry season, South India showed an increase and North Eastern India showed a decrease in temperature. For wet season, Indian Peninsular region showed a significant increase of the order 0.06 °C. For south west monsoon, peninsular and North Eastern India showed a significant increase while the northern most tip showed a significant decrease. The results may be concluded as the southern India is most vulnerable to climate change. The results by Jaswal *et al.*, 2015 that the increase in number of high temperature days is maximum in southern India substantiate the results of the present study.

These results obtained will be useful to get an overall idea about the change in climatic variables in India and its trend. Also, the variables used in this study are probable predictors of precipitation in statistical downscaling and hence trends in these variables may be used to predict the change in precipitation pattern. The results obtained may further be verified using station based observations in different regions.

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