TRENDS OF STABILITY INDICES OVER DIFFERENT METEOROLOGICAL STATIONS OF INDIA BY USING IGRA RADIOSONDE DATA

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Abstract: —This paper describes long term trends of stability indices such as Lifted index (LI), K index (KI), Showalter index (SI) and Total total index (TTI) over 31 meteorological stations of India. All 31 stations are divided into six regions such as East coast, West coast, North west, Central and internal peninsula. In each region the above four indices are discussed and plotted graphs. Indices of each station are analyzed and discussed using Mann Kendall test statistics and linear regression. Duration of data is 37 years (1980-2016). The range of LI, KI, SI and TTI are -10 to 20, 25 to 45, -2 to 17 and 35 to 50 respectively. LI, SI show increasing trend, KI, TTI show decreasing trend. But few stations in south show negative trend.

Key words: Lifted index, radiosonde, Mann Kendall etc

1. Introduction

Study of atmospheric conditions is important for survival of life process. Because of convective activity, Water vapor in atmosphere modifies the air temperature which relates to convective indices also changes. Many researchers presented long term variability of convective indices over different parts of India using rainfall data. When there is a convective system over south peninsular India, the value of LI over the region is less than −4. On the other hand, the region where LI is more than 2 is comparatively stable without any convection. When KI values are in the range 35 to 40, there is a possibility for convection. The threshold value for TTI is found to be between 50 and 55. [1]. Over Gadanki, India, strong diurnal variation in all the stability indices are noticed and the more negative value of LI represents the more unstable atmosphere leading to higher convective activity. LI values are more negative ranging between −4 and −8 revealing that the convective activity is more and there is a probability of occurrence of thunderstorms [2]. Significant positive and negative trends are noticed during the monsoon season over India and the variability is more over northeast (82.4 mm) than the west coast (68.1 mm) region. Annual rainfall was extremely low in 1951 (984 mm), 1965 (974 mm), 1972 (910 mm) and 2002 (918 mm) [3]. Rajeevan et al. (2008) studied the variability and long-term trends using extreme IMD rainfall events. It was found that the frequency of extreme rainfall events shows significant inter-decadal variations in addition to a statistically significant long-term trend of 6 % per decade. Previous studies reported the trends of the Indian monsoon and rainfall with different aspects and different regions (Guhatakurtha and Rajeevan 2008; Dash et al 2009; Ranade et al. 2008; Lacombe and McCartney 2014). All these studies have concentrated with regional average rainfall and other studies from short-term rainfall datasets. The monsoon season shows an increasing trend over certain parts of the country, whereas a decreasing trend has been observed during winter and premonsoon seasons [4]. Previous studies showed that the trends analysis with respect to region.

In this paper we described the trend analysis of various atmospheric stability indices such as LI, KI, SI and TTI over 31 meteorological stations of India based on Mann Kendall test statistics (Z_{MK}) and Linear Regression.. All 31 stations are divided into six regions such as East coast, West coast, North east, North west, Central and internal peninsula.

2. Data description

The Integrated Global Radiosonde Archive (IGRA) consists of radiosonde and pilot balloon observations at over 2,700 globally distributed stations. The earliest data date back to 1905, and recent data become available in near real time. Observations are available at standard and variable pressure levels, fixed- and variable-height wind levels, and the surface and tropopause. Variables include pressure, temperature, geopotential height, relative humidity, dew point depression, wind direction and speed, and elapsed time since launch. Sounding-derived parameters are available for a subset of the soundings in IGRA. This subset includes soundings at fixed observing stations on land that contain temperature observations and a surface pressure level. The parameters include precipitable water between the surface and 500 hPa, the refractive index, vertical gradients of several variables, and various measures of boundary-layer characteristics and stability.

3. Methodology

For the present study the data is taken from 1980 to 2016. Every day there were two sounding at 00z and 12z GMT. Monthly mean is calculated for each year for which we get 12 data points for one year. Thus from 1980 to 2016 there were 444 data points were calculated for all the indices. Two statistical approaches were used to analyze the indices trends. Linear regression is useful to estimate tendency of the parameters, and Mann-Kendall test to estimate significance of the tendency. Mann Kendall test statistics is applied to analyse trends and linear regression statistics to calculate slope for the trend. Both statistics are described below.

Description of indices:

The Showalter index (Showalter 1953) is calculated by adiabatically lifting a parcel of air at 850 hPa up to 500 hPa. The lifted index (Galway 1956) is calculated in a similar manner as the Showalter index, except that the theoretical parcel near the surface has different properties. Vertical total index (Miller, 1972) is the temperature difference between the 850hPa level and the 500hPa level. Cross total index is the difference of the dew-point temperature in 850hPa and the temperature in 500hPa. The totals totals index (Miller, 1972) is the sum of vertical totals and cross totals. Totals totals index therefore increases with increasing humidity in the lower levels of the atmosphere and increasing vertical temperature gradients. The K index is developed by George (1960). Like the vertical totals it is based on the vertical temperature gradient between 850hPa and 500hPa. Higher humidity in 850hPa, expressed by higher Td;850 increases K. Furthermore, lower humidity in higher levels, expressed by the dew-point depression in 700hPa decreases the chance of thunderstorms to occur.

Stability indices are a measure of the atmospheric static stability. Lifted Index (LI) has proved useful for indicating the likelihood of severe thunderstorms. The chances of a severe thunderstorm occur when the lifted index is less than or equal to -6. This is because air rising in these situations is much warmer than its surroundings and can accelerate rapidly and create tall, violent thunderstorms. Values less than -9 reflect extreme instability. An LI of between 0 and -2 indicates that there is a small chance of having a severe thunderstorm. Airmass thunderstorms can occur when the LI is slightly positive. The K-Index has proved useful in indicating the probability of air mass thunderstorms. As the K-Index increases, so does the probability of having an airmass thunderstorm. If K index exceeds 40 then there is probability of severe thunderstorms. The Showalter Index(SI) is the measure of the local static stability of the atmosphere. Positive values indicate the lifted parcel is colder than its new environment, and thus the atmosphere is stable. Thunderstorms are likely to develop in regions where the SI are less than -3. The total totals index is actually a combination of the vertical totals, VT = T850 - T500, and the cross totals, CT = Td850 - T500, so that the sum of the two products is the total totals. TT values more than 45 indicate probable moderate thunderstorms, with a possibility of scattered severe t-storms.

Regression analysis

Because of its simplicity to interpret the variation of variable, the linear regression equation has been used to calculate trend magnitude for each station. The linear regression is (y=mx + c) equation, where x represents time in months, y represents indices monthly mean value, m is the slope or trend magnitude and c is intercept.

Mann-Kendall test

Mann-Kendall test (MK) is a non-parametric statistical test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). The null hypothesis for this test is that there is no monotonic trend in the series. The alternate hypothesis is that a trend exists. This trend can be positive, negative, or non-null. The procedure assumes that there exists only one data value per time period. The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the MK statistic, S, is assumed to be 0 (e.g., no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S. Let X1, X2 ….Xn represent n data points where jx represents the data point at time j. Then the Mann-Kendall statistic (S) is given by

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sign(X_j - X_k)$$

where $sign(X_j - X_k) = 1$ if $X_j - X_k > 0$

$= 0$ if $X_j - X_k = 0$

$= -1$ if $X_j - X_k < 0$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. Variance of S, VAR(S), is calculated by the following equation:

$$VAR(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)]$$

where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and p t is the number of data points in the p^{th} group. Test statistic Z is computed as follows:

$Z = (S-1)/\sqrt{(VAR(S)}$ if $S > 0$

$= 0$ if $S = 0$

$= (S+1)/\sqrt{(VAR(S)}$ if $S < 0$

4. Results and discussion:

Stability indices of 31 stations are divided into six regions such as East coast, West coast, North west, Central and internal peninsula were listed in table1 below. Significant difference were found in each region.

Table 1: Stability indices of different regions

S.No	Region	Lifted Index	K Index	S Index	TT Index
1	East Coast	-9.5 to 8	43	-4 to 9	35 to 40
2	West Coast	-7 to 2	35 to 40	-2.7 to 8	40 to 45
3	North West	-6.6 to 13.8	38 to 40	-4 to 16.5	45
4	North East	-6.3 to 15	40 to 45	-3.4 to 12	40
5	Central	-5.6 to 20	35 to 40	-2 to 12	42
6	Internal Peninsula	-6.5 to 17	25 to 40	-3.4 to 12	50

(a) Lifted Index (LI): The lifted index (LI) is the temperature difference between the environment Te(p) and an air parcel lifted adiabatically Tp(p) at a given pressure height in the troposphere (lowest layer where most weather occurs) of the atmosphere, usually 500 hPa (mb). The temperature is measured in Kelvin. When the value is positive, the atmosphere (at the respective height) is stable and when the value is negative, the atmosphere is unstable. LI is the indicator for deep convection (Galway, 1956), negative lifted indices are indicative of a potential for deep convection; values below -9 indicate the potential for severe convection. LI estimated from GPS RO is able to indicate more instability over Gadanki (Y.D. Santhi et al.). More details on the diurnal variation of the convective indices are obtained using high temporal resolution radiosonde observations over this station are provided in Ratnam et al. (2013).

LI and its trend variation for different regions are shown Fig1 and values lay around -8. This study focuses on trend detection of four indices based on Mann Kendall test statistics (Z_{MK}) and Linear Regression. An analysis of trend for the indices in different regions provides interesting insights on how they differ from region to region. It is observed that on an average, LI is high in the inland regions and lower in both the coastal regions. The important point is few regions (Vishakhapatnam, Bhopal and Cochin) show increasing trend for the duration and are significant at the 95 % confidence level (1.966). Earlier Saha et al. has pointed out LI has fairly increased from 3 K to 6 K in the last 16 years over Kolkata and Ahmadabad. Few inland stations (Aurangabad, Bangalore and Nagpur) show decreasing trend.

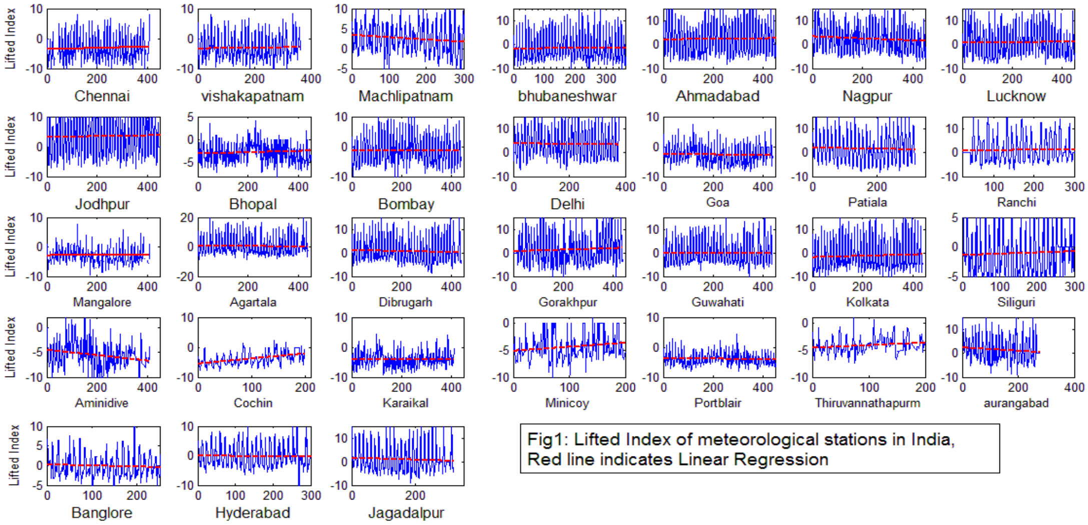

Fig1: Lifted Index of meteorological stations in India, Red line indicates Linear Regression

(b) K Index:

The KI is particularly useful for identifying convective and heavy-rain-producing environments. Its computation takes into account the vertical distribution of both moisture and temperature. The KI is a useful tool for diagnosing the potential indicator of convective instability. When KI values are in the range 35 to 40, there is a possibility for maximum percentage of occurrence convection over Thiruvantapuram and Cochin [1].

In this study the trends of KI for different regions over India are shown in Fig2. For most of the regions Chennai, Nagpur, Jodhpur, Bombay, Guwahati, Kolkata, Amindivi, Minicoy, Portblair, Thiruvanantapuram and Bangalore show decreasing trend which are significant at the 95 % confidence level and few regions show increasing trend but not at significant level.

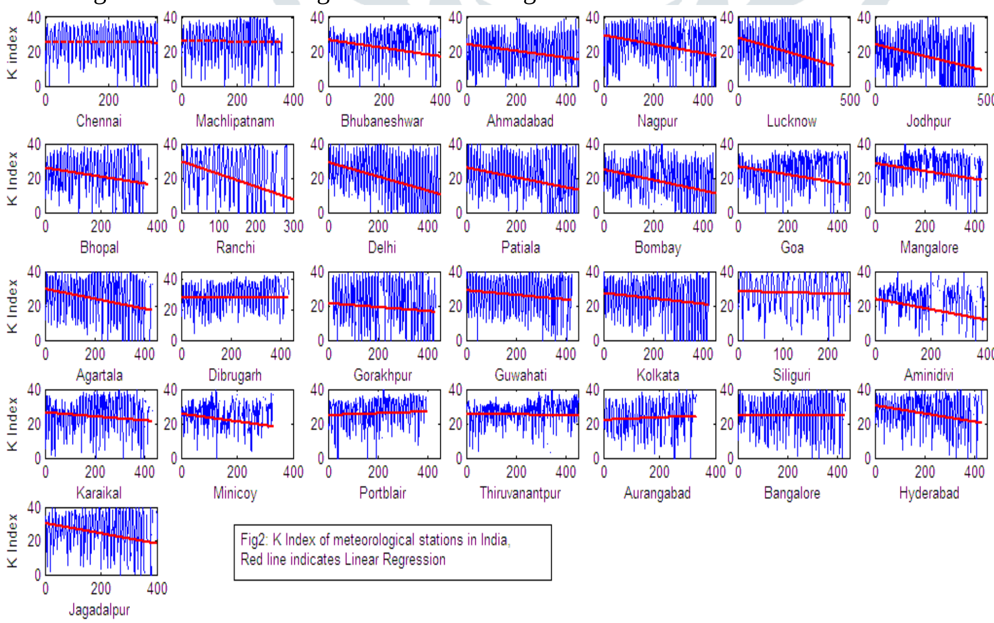

Fig2: K Index of meteorological stations in India, Red line indicates Linear Regression

(c) Showalter Index (SI):

The Showalter index (Showalter 1953) is calculated byadiabatically lifting a parcel of air at 850 hPa up to 500 hPa. The temperature (in °C, as will be the case for all uses of temperature in calculating these indices) the actual environment at 500 hPa is then subtracted from the temperature of the theoretical parcel. Forecasters have generally looked for a small negative number, generally -3°C or less as a sign of strong convection. SI indicates increasing instability with decreasing value has its own significance for predicting severe weather. The SI index was found to be a fairly good indicator of rain conditions and good agreement with MWR observations (M.V. Ratnam et al.). In our study few regions (Machilipatnam Karaikal, Minicoy, Portblair, Thiruvanantapuram, Aurangabad and Bangalore) show steep decreasing trend having large negative ZMK value and few regions show increasing trend but not at significant level as shown in Fig3.

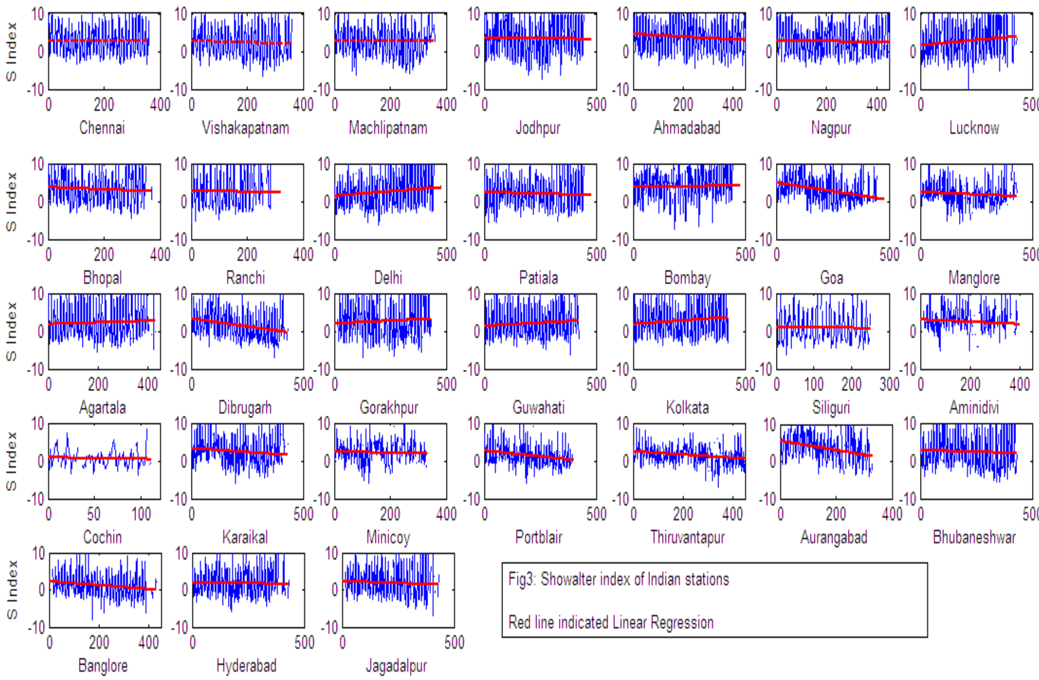

Fig3: Showalter index of Indian stations

Red line indicated Linear Regression

(d) Total toal Index (TTI):

The total totals index (Miller 1967) is simply the sum of the cross totals and vertical totals. The threshold value for TTI is found to be between 50 and 55 over Thiruvananantapuram and Cochin and more percentage of convection [1]. R. Chakraborty et al. (2017) showed decreasing values in the eastern coasts. However, as expected, other regions, leaving a few have not shown such prominent changes in the recent past. Fig4 depicts TTI trends and as pointed by R. Chakraborty et al. regions in east coast (Agartala, Karaikal, Thiruvanantapuram, Kolkata and Guwahati) show decreasing trend at 95% significant confidence level from ZMK value.

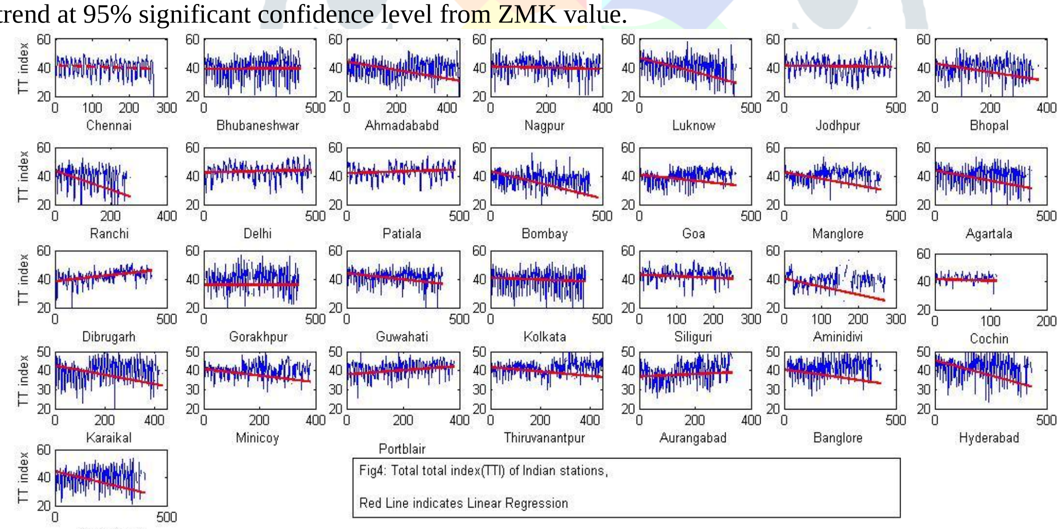

Fig4: Total total index(TTI) of Indian stations,

Red Line indicates Linear Regression

Summary and conclusions:

It is observed that few stations show positive trend indicating that LI values are increasing and hence there is a decrease in precipitation. Similarly KI which is indicator for thunderstorms also show decreasing trend. The magnitude of decrease and increase is calculated by Linear Regression slope and tabulated in table 2. The important point is few regions (Vishakhapatnam, Bhopal and Cochin) show increasing trend significant at the 95 % confidence level (1.966). SI show steep decreasing trend having large negative Z_{MK} value and few regions show increasing trend

Table 2									
	Mann Kendall Test Z values Z_{MK}					Linear Regression Slope Q values			
Station Names	L index	SI	KI	TTI		L index	SI	KI	TTI
Chennai	-1.3338	-0.5965	1.1295	-4.5614		-0.0007	-5.6e-004	-0.0415	-0.0728
Visakhapatnam	0.0853	-0.1474				0.0068	-0.0023		

Machilipatnam	-1.3495	-1.7509	2.3371	1.7579		-0.0018	-0.0028	0.0087	0.0313
Bhubaneswar	0.3602	0.6691	-1.0139	-2.0437		0.0109	-0.0037	-0.0265	-0.0410
Ahamad	0.5363	-0.9368	-1.3405	-5.4914		0.0072	-0.0028	-0.0310	-0.0917
Nagpur	-2.5925	-0.4514	-2.7332	-6.4849		-0.0038	6.9e-004	-0.0715	-0.1160
Lucknow	1.3621	0.1747	-1.5674	-4.5932		0.0031	0.0142	-0.0422	-0.0756
Jodhpur	0.9129	0.2518	-2.2887			0.0099	0.0068	-0.0578	
Bhopal	3.7047	0.4877	-0.2563	-0.4650		-0.0038	8.7e-004	-0.0038	-0.0098
Ranchi	0.5699	-0.2790	0.7962	0.6419		-0.0010	0.0100	0.0149	0.0118
Delhi	-0.8577	0.5512	-1.4222			-0.0056	0.0166	-0.0459	
Patiala	-1.0734	1.0865	-1.4948			0.0012	0.0026	-0.0362	
Bombay	0.3910	-1.9167	-2.4202	-6.8524		-0.0011	0.0148	-0.0537	-0.0984
Goa	-1.6487	-7.0783	-0.5013	-1.5447		0.0073	-0.0053	-0.0082	-0.0200
Mangalore	-1.4675	-4.5990	-1.0432	1.6581		-0.0013	-0.0045	-0.0185	0.0238
Agartala	-1.2178	0.8188	-1.3315	-2.7877		0.0096	0.0093	-0.0263	-0.0441
Dibrugarh	-3.5281	-7.4346	-1.3541			-0.0025	2.9e-004	-0.0252	
Gorakhpur	0.6548	-0.0204	-1.8259	-3.5861		-0.0044	0.0117	-0.0473	-0.0915
guwahati	0.1668	1.7624	-3.2640	-6.4804		0.0046	0.0089	-0.0752	-0.0969
Kolkata	1.0053	0.4242	-2.5155	-5.6184		0.0043	0.0110	-0.0688	-0.1098
Siliguri	1.8227	-0.0159	-1.4630	-3.6224		-0.0053	0.0041	-0.0227	-0.0506
Amindivi	-2.1264	-1.0820	-3.8356	-4.2030		-0.0053	0.0088	-0.0533	-0.0790
Cochin	6.8308	-0.0136		-2.8466		0.0218	0.0020	-0.0289	-0.0433
Karaikal	0.1297	-4.0825	-1.7125	-3.1914		0.0065	0.0122	-0.0384	-0.0478
Minicoy	-1.1467	-2.3522	-3.0145	-4.7656		0.0062	-0.0028	-0.0429	-0.0609
Portblair	-0.2209	-5.1421	-2.3794	-4.2983		0.0050	8.6e-004	-0.0666	-0.0638
Thiruvantapuram	0.3551	-5.8926	-4.3754	-6.4622		0.0146	-0.0011	-0.0159	-0.1107
Aurangabad	-1.7427	-7.6077	-0.6963	-3.1460		-0.0134	-0.0123	-0.0519	-0.0451
Bangalore	-3.0075	-4.0547	-2.3159	-8.1180		-0.0059	-0.0036	-0.0220	-0.1346
Hyderabad	-0.2003	0.0658	-0.9867	-1.2906		-0.0015	0.0023	-0.0196	-0.0243
Jagadalpur	-1.1754	-0.1338	-0.8279	-1.8259		-0.0027	0.0078	-0.0415	-0.0278
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5. Acknowledgement

We thank NOAA to download the IGRA radiosonde data. We thank NARL, Gadanki scientists Dr. M.V. Ratnam and Dr. Ghouse Basha for valuable suggestions and guidance. The first author thanks Vice Chancellor, Registrar and Principal, Maulana Azad National Urdu University, Hyderabad, for providing R & D lab for data analysis and for their kind support and encouragement.

References

[1] Angell, K., 1999. Comparison of surface and tropospheric temperature trends estimated from a 63- station radiosonde network, 1958- 1998. Geohys Res. Lett., 2 6, 2761-2764.

[2] Basha, G., Ouarda, T.B.M.J., Marpu, P.R., 2015. Long-term projections of temperature, precipitation and soil moisture using non-stationary oscillation processes over the UAE region. Int. J. Climatol.. doi: 10.1002/joc.4310.

[3] Hamed KH (2009) Enhancing the effectiveness of prewhitening in trend analysis of hydrologic data. J Hydrol 368:143–155.

[4] Hingane LS (1995) Is a signature of socio-economic impact written on the climate? Clim Change 32:91–101 Hirsch RM, Slack JR, Smith RA (1982) Techniques of trend analysis for monthly water quality data. Water Resour Res 18:107–121.

[5] KENDALL, M.G. (1975) Rank Correlation Methods. London: Griffin

[6] P. R. Jayakrishnan, C. A. Babu, Assessment of Convective Activity Using Stability Indices as Inferred from Radiosonde and MODIS Data Atmospheric and Climate Sciences, 2014, 4, 122-130 Published Online January 2014 (http://www.scirp.org/journal/acs) http://dx.doi.org/10.4236/acs.2014.41014

[7] P. Kishore, S. Jyothi, Ghouse Basha, S. V. B. Rao, M. Rajeevan, Precipitation climatology over India: validation with observations and reanalysis datasets and spatial trends, Clim Dyn (2016) 46:541–556, DOI 10.1007/s00382-015-2597.

[8] Narendra Babu, A., Nee, J.B., Kumar, K.K., 2010. Seasonal and diurnal variation of convective available potential energy (CAPE) using COSMIC/FORMOSAT-3 observations over the tropics. J. Geophys. Res. 115 (D4). http://dx.doi.org/10.1029/2009JD012535.

[9] Ratnam, M.V., Durga Santhi, Y., Rajeevan, M., Vijaya Bhaskara Rao, S., 2013.Diurnal variability of stability indices observed using radiosonde observations over a tropical station: comparison with microwave radiometer measurements. Atmos. Res. 124, 21–33.

[10] Rohit Chakrabortya, Upal Sahab, A.K. Singhb, Animesh Maitraa, 2017, Association of atmospheric pollution and instability indices: A detailed investigation over an Indian urban metropolis. Atmos. Res. 196, 83–96.

[11] Showalter, A.K., 1953. A stability index for thunderstorm forecasting. Bull. Am. Meteorol. Soc. 34, 250–252.

[12] Galway, J.G., 1956. The lifted index as a predictor of latent instability. Bull. Am. Meteorol. Soc. 37, 528–529.

[13] Sinha Ray and Srivastava, Precipitation climatology over India: validation with observations and reanalysis datasets and spatial trends, Clim Dyn (2016) 46:541–556, DOI 10.1007/s00382-015-2597.

[14] Siegel, S. & Castellan, N.J. 1956, Non-parametric statistics for the behavioral sciences, McGraw-Hill, New York, USA.

[15] World Meteorological Organisation 1997, A comprehensive assessment of the freshwater resources of the world, WMO, Geneva.

[16] Zhang, X., Zwiers, F.W. & Li, G. 2004, 'Monte Carlo experiments on the detection of trends in extreme values', Journal of Climate, Vol. 17, No. 10, pp. 1945-1952.