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Trend analysis of climatic variables in Pigeonpea growing regions in India

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सार – इस शोध पत्र में भारत के भिन्न-भिन्न स्थानों (कानपुर, हैदराबाद, बंगलुरू, पुसा, पंतनगर, परभणी, वाराणसी और पुणे) की जलवायु परिवर्तिता के ट्रेन्ड के विश्लेषण का अध्ययन किया गया है। ये स्थान दालों की विशेष रूप से अरहर की खेती के लिए अति महत्वपूर्ण हैं। इन स्थानों के अधिकतम तापमान (MaxT), न्यूनतम तापमान (MinT), वर्षा (RF) और तेज धूप के घंटों (BSH) का ऋतुवार (ग्रीष्म, खरीफ या वर्षाऋतु और रबी या वर्षाऋतु के बाद), मासिक (जनवरी से दिसम्बर) और साप्ताहिक (1 से 52 मौसम विज्ञान के मानक सप्ताह) समय पैमानों पर वर्ष 1970 - 2010 तक की अवधि में रहे ट्रेन्ड को विश्लेषित किया गया हैं। मान-केन्डॉल टेस्ट और सेन के स्लोप इस्टीमेटर के प्रयोग के द्वारा महत्वपूर्ण ट्रेन्डों की पहचान की गई है। अधिकांश स्टेशनों पर अधिकतम और न्यूनतम तापमान श्रृंखलाओं में बढ़ोतरी की प्रवृति का पता चला है। उत्तर और पूर्वोत्तर भारत में स्थित कुछ स्टेशनों पर तापमान में गिरावट की प्रवृति का पता चला है। दक्षिण, मध्य और पश्चिमी भारत में स्थित अधिकांश स्टेशनों पर वर्षा के सिवाय विभिन्न जलवायु-विषयक परिवर्तिताओं में बढ़ने की प्रवृति पाई गई है । इस ट्रेन्ड विश्लेषण में उपयोग किए गए अधिकतर डेटा शहरी क्षेत्रों में स्थित स्टेशनों के हैं जिन्हें ऊष्ण द्वीपों के रूप में जाना जाता है।

ABSTRACT. Trend analysis of the climate variables at different locations (Kanpur, Hyderabad, Bangalore, Pusa, Pantnagar, Parbhani, Varanasi and Pune) in India were studied. These locations are very important for growing of pulses especially pigeonpea. Trend in these locations were analyzed for the maximum temperature (MaxT), minimum temperature (MinT), rainfall (RF) and bright sunshine hours (BSH) on seasonal (summer, kharif or rainy season and rabi or post-rainy season), monthly (January to December), and weekly (1-52 standard meteorological week) time scales for the period 1970-2010. Significant trends were identified using the Mann-Kendall test and the Sen's slope estimator. Maximum and minimum temperature series showed a rising trend at most of the stations. Some stations located in the north and northeastern India showed a falling trend in temperature. At most of the stations in the south, central and western parts of India a rising trend was found in various climatic variables except rainfall. Most of the data used in trend analysis pertained to the stations located in urban areas considered as heat islands.

Key words – Climate variability, Trend analysis, Non-parametric test, Mann-Kendall test and Sen's slope estimator.

1. Introduction

Effect of climate change on agriculture or more precisely on insect pests and diseases of agricultural crops is multidimensional. Magnitude of this impact could vary with the type of species and their growth patterns. With the change in the temperature and rainfall pattern the natural vegetation over a region is facing a new phase of competition for survival. Local scale climate analysis can more realistically represent the complex climate that exists in India, and investigation of climate change at local scale is useful.

Traditionally, climate patterns have been investigated using trend analysis on a point-by-point basis. Temperature and precipitation trends from one location would be compared with surrounding locations. This is appropriate when large distances separate monitoring locations. However, advanced spatial analysis is possible when monitoring locations are clustered in a local region. Spatially analyzing climate variables on a local scale provides improved insight into local patterns over both space and time. In the 1980s, several studies were published that investigated climate change on a national and global scale, using surface observations and remote

TABLE 1

Value of Sen's slope, tau and *Z* statistics of Mann-Kendall test for three different seasons (S1: Summer season; S2: *kharf* season and S3: *rabi* season) for various meteorological variables

Location	Test value	MaxT (S1)	MaxT (S2)	MaxT (S3)	MinT (S1)	MinT (S2)	MinT (S3)	RF (S1)	RF (S2)	RF (S3)	BSH (S1)	BSH (S2)	BSH (S3)
Hyderabad	β	-0.027	0.019	0.025	-0.050	-0.060	0.011	-0.064	-0.061	0.198	-0.035	-0.038	-0.011
	TAU	-0.185	0.165	0.198	-0.429	-0.342	0.102	-0.102	-0.073	0.146	-0.577	-0.365	-0.154
	Z	1.443	1.281	1.541	3.341**	2.659*	0.795	0.795	0.568	1.135	4.492**	2.838**	1.200
Bangalore	β	-0.037	0.000	-0.011	-0.012	0.007	0.028	-0.400	-0.223	-0.800	-0.050	-0.033	-0.019
	TAU	-0.303	0.024	-0.082	-0.111	0.107	0.334	-0.352	-0.318	-0.283	-0.581	-0.354	-0.256
	Z	2.312*	0.187	0.629	0.850	0.816	2.549*	2.685**	2.430*	2.159**	4.436**	2.702**	1.955*
Kanpur	β	0.025	0.025	0.043	0.007	-0.017	-0.008	-0.021	-0.059	-0.733	-	-	-
	TAU	0.200	0.238	0.318	0.046	-0.154	-0.104	-0.163	-0.243	-0.311	-	-	-
	Z	1.797	2.134*	2.853**	0.416	1.382	0.932	1.460	2.179*	2.797**	-	-	-
Pantnagar	β	-0.004	-0.006	-0.025	-0.036	-0.060	-0.025	0.015	-0.028	0.008	-0.010	-0.014	0.000
	TAU	-0.022	-0.058	-0.182	-0.294	-0.358	-0.343	0.071	-0.044	0.004	-0.098	-0.191	-0.016
	Z	0.170	0.442	1.394	2.244*	2.736**	2.617*	0.544	0.340	0.034	0.748	1.462	0.119
Parbhani	β	-0.004	-0.006	-0.025	-0.036	-0.060	-0.025	0.015	-0.028	0.008	-0.010	-0.014	0.000
	TAU	-0.022	-0.058	-0.182	-0.294	-0.358	-0.343	0.071	-0.044	0.004	-0.098	-0.191	-0.016
	Z	0.170	0.442	1.394	2.244*	2.736**	2.617*	0.544	0.340	0.034	0.748	1.462	0.119
Pune	β	0.000	0.013	0.006	0.000	0.028	0.009	-0.080	0.025	0.335	-0.020	-0.034	-0.025
	TAU	0.033	0.163	0.060	0.021	0.190	0.221	-0.204	0.070	0.196	-0.402	-0.526	-0.330
	Z	0.272	1.362	0.504	0.177	1.580	1.839	1.703	0.586	1.635	3.351**	4.386**	2.751**
Pusa	β	0.025	0.025	0.043	0.007	-0.017	-0.008	-0.021	-0.059	-0.733	-	-	-
	TAU	0.200	0.238	0.318	0.046	-0.154	-0.104	-0.163	-0.243	-0.311	-	-	-
	Z	1.797	2.134*	2.853**	0.416	1.382	0.932	1.460	2.179*	2.797*	-	-	-
Varanasi	β	0.006	0.000	-0.011	0.014	0.014	0.005	0.046	0.075	-0.213	-0.033	-0.078	-0.031
	TAU	0.046	-0.070	-0.112	0.112	0.153	0.075	0.182	0.248	-0.095	-0.509	-0.754	-0.422
	Z	0.291	0.449	0.713	0.713	0.977	0.475	1.162	1.585	0.607	3.248**	4.807**	2.694**

* significant at 0.05 level; ** significant at 0.01 level
MaxT: maximum temperature; MinT: minimum temperature; RF: rainfall; BSH: bright sunshine hours.
(For Kanpur and Pusa, data on BSH is not available)

sensing platforms (Diaz and Quayle, 1980). Historically, climate researchers have used observations from a single location to represent the climate for a large area (Pielke *et al*., 2000). Many studies have attempted to determine the trend in rainfall and temperature on both country and regional scales because these two are the most important regarding climate change. Most of these deal with the analysis of annual and seasonal series for some individual stations or groups of stations. Jain and Kumar (2012) cited that there is no clear trend in average annual rainfall in India. Sen Roy and Balling (2004) analysed daily rainfall data for 1910-2000 at 129 stations and found generally increasing trend in a contiguous region extending from the northwestern Himalayas in Kashmir through most of the Deccan Plateau in the south and decreasing values in the eastern part of the Gangetic Plains and parts of Uttarakhand. Pal and Al-Tabbaa (2009) studied the trends in seasonal rainfall extremes in Kerala, using gridded daily data for the period 1954-2003. They found winter and post-monsoon extreme rainfall having an increasing tendency with statistically significant changes in some regions and decreasing trends in spring seasonal extreme rainfall. Kothawale *et al*. (2010) studied the association between El Niño Southern Oscillation (ENSO) and monsoon rainfall over India and reported a strong association between El Niño events and deficient

TABLE 2

Monthly value of Sen's slope, tau and *Z* statistics of Mann-Kendall test for maximum temperature (MaxT)

Location	Test value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bangalore	β	0.0294	-0.0040	-0.0120	-0.0333	-0.0500	-0.0167	-0.1300	-0.0111	-0.0133	-0.0222	-0.0200	-0.0125
	TAU	0.1958	-0.0267	-0.120	-0.2425	-0.3048	-0.1157	-0.0245	-0.0868	-0.1157	-0.1535	-0.1602	-0.1001
	Z	1.4957	0.2040	0.1530	1.8526	2.3285	0.8838	0.1870	0.6629	0.8838	1.1728	1.2237	0.7648
Hyderabad	β	0.0000	-0.0258	-0.0314	0.0000	-0.0273	0.0490	0.0535	0.0250	0.0143	0.0417	0.0218	0.0374
	TAU	0.0021	-0.1292	-0.1208	0.0125	-0.1500	0.1792	0.2771	0.2458	0.0813	0.2792	0.2146	0.1354
	Z	0.0162	1.0054	0.9406	0.0973	1.1676	1.3946	2.1568*	1.9135*	0.6324	2.1730*	1.6703	1.0541
Kanpur	β	-0.0083	0.0369	0.0557	0.0462	-0.0079	0.0200	0.0479	0.0545	0.0509	0.0271	0.0333	0.0362
	TAU	-0.0313	0.1826	0.3139	0.2276	-0.0288	0.0888	0.1951	0.4315	0.2952	0.1864	0.2552	0.2839
	Z	0.2808	1.6399	2.819*	2.042*	0.2583	0.7975	1.7522	3.8750	2.6507*	1.6736	2.2913*	2.5496*
Pantnagar	β	-0.0762	0.0000	-0.0154	0.0111	-0.0583	-0.0536	-0.0152	-0.0083	-0.0160	-0.0269	0.0000	-0.0345
	TAU	-0.4143	0.0095	-0.0690	0.0476	-0.2071	-0.1810	-0.1167	-0.0810	-0.1714	-0.2286	0.0167	-0.3167
	Z	3.10**	0.0714	0.5174	0.3568	1.5522	1.3559	0.8742	0.6066	1.2846	1.7127	0.1249	2.3729*
Parbhani	β	-0.0167	-0.0125	0.0000	0.0100	-0.0111	0.0000	-0.0160	-0.0167	-0.0400	-0.0154	0.0059	0.0172
	TAU	-0.1023	-0.0667	0.0156	0.0578	-0.0645	-0.0133	-0.0979	-0.1335	-0.1913	-0.1001	0.0267	0.0823
	Z	0.7818	0.5099	0.1190	0.4419	0.4929	0.1020	0.7478	1.0198	1.4617	0.7648	0.2040	0.6289
Pune	β	0.0123	0.0156	0.0000	0.0079	0.0136	0.0114	0.0000	0.0111	0.0000	0.0000	0.0085	0.0295
	TAU	0.1209	0.1029	0.0163	0.0801	0.1258	0.0588	0.0131	0.1209	0.0180	-0.0114	0.0850	0.2369
	Z	1.0079	0.8581	0.1362	0.6674	1.0488	0.4904	0.1090	1.0079	0.1498	0.0953	0.7083	1.9750
Pusa	β	-0.1095	-0.0381	0.0000	0.0250	-0.0111	-0.0091	0.0125	-0.0050	-0.0087	-0.0667	-0.0158	-0.0381
	TAU	-0.4286	-0.2048	0.0048	0.0595	-0.0548	-0.0381	0.0667	-0.0571	-0.1333	-0.3905	-0.2071	-0.2024
	Z	3.21**	1.5343	0.0357	0.4460	0.4103	0.2855	0.4995	0.4282	0.9991	2.9259*	1.5522	1.5165
Varanasi	β	-0.0333	-0.0400	0.0235	0.0091	-0.0222	-0.0444	0.0133	0.0077	0.0095	0.0050	0.0091	-0.0062
	TAU	-0.1491	-0.1491	0.0828	0.0414	-0.1698	-0.0870	0.0580	0.0911	0.0497	0.0331	0.0704	-0.0538
	Z	0.9508	0.9508	0.5282	0.2641	1.0828	0.5546	0.3697	0.5810	0.3169	0.2113	0.4490	0.3433

* Significant trend at the 0.05 level ** Significant trend at the 0.01 level.

monsoon rainfall. Nearly 60% of major droughts over India have occurred in association with El Niño events. Kumar *et al*. (2010) showed that the monsoon rainfall in India exhibited no significant trend over a long period of time, particularly on the all-India scale.

Most of the temperature trend studies in India focus on the analysis of annual and seasonal temperature data for a single station or a group of stations. Pramanik and Jagannathan (1954) studied the trends in the annual mean maximum and minimum temperatures over the whole country who did not find any general tendency for an increase or decrease in these temperatures. Hingane *et al*. (1985) reveals that the mean annual temperature was increasing over the west coast, interior peninsula, north central and northeastern regions of India along with the all India average during the period 1901-1982. Pant and Hingane (1988) found decreasing trend in mean annual surface air temperature for the period 1901-1982 over the northwest Indian region consisting of the meteorological sub-divisions of Punjab, Haryana, west Rajasthan, east Rajasthan and west Madhya Pradesh. Rao (1993) analysed the data from seven stations for 1901-1980 and showed highly significant warming trend in the mean maximum, mean minimum and average mean temperatures of the Mahanadi river basin. Rupa Kumar *et al*. (1994) studied the trend analyses at 121 stations in India for 1901-1987, which showed that maximum temperatures show increasing trend and there is no trend in minimum temperature, resulting in rise in mean and diurnal range of

TABLE 3

Monthly value of Sen's slope, tau and *Z* statistics of Mann-Kendall test for minimum temperature (MinT)

Location	Test value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bangalore	β	0.0154	0.0000	-0.0143	-0.0187	-0.0050	0.0143	0.0292	0.0296	0.0200	0.0167	0.0294	0.0000
	TAU	0.0578	0.0311	-0.0979	-0.1824	-0.0601	0.1646	0.2981	0.3426	0.2581	0.1646	0.1935	0.0178
	Z	0.4419	0.2379	0.7478	1.3937	0.4589	1.2577	2.277*	2.6174*	1.9716*	1.2577	1.4787	0.1360
Hyderabad	β	-0.1240	-0.0742	-0.0615	-0.0394	-0.0220	0.0196	0.0195	0.0045	0.0000	-0.0106	-0.0500	-0.0950
	TAU	-0.3792	-0.3250	-0.3958	-0.2729	-0.2000	0.0979	0.1688	0.0563	0.0104	-0.0771	-0.1375	-0.3354
	Z	2.954*	2.529*	3.081*	2.124*	1.5568	0.7622	1.3135	0.4378	0.0811	0.6000	1.0703	2.6108
Kanpur	β	-0.0333	0.0176	0.0200	-0.0071	0.0038	-0.0240	0.0000	-0.0077	0.0000	-0.0306	-0.0049	-0.0160
	TAU	-0.1851	0.0826	0.1551	-0.0338	0.0225	-0.1839	-0.0013	-0.1438	-0.0125	-0.1413	-0.0488	-0.1063
	Z	1.6623	0.7413	1.3928	0.3033	0.2022	1.6511	0.0112	1.2917	0.1123	1.2692	0.4380	0.9547
Pantnagar	β	0.0059	0.0625	0.0333	0.0286	0.0500	0.0333	0.0333	0.0182	0.0400	0.0286	0.0067	0.0333
	TAU	0.0429	0.3000	0.2595	0.1881	0.3119	0.2667	0.3857	0.3786	0.2881	0.1690	0.0500	0.2381
	Z	0.3211	2.240*	1.9447	1.4094	2.337*	1.9982	2.890*	2.8367*	2.158*	1.2667	0.3747	1.7841
Parbhani	β	-0.0917	-0.0286	-0.0167	-0.0364	-0.0652	-0.0222	-0.0235	-0.0375	-0.0368	-0.0591	-0.0500	-0.0619
	TAU	-0.3137	-0.1135	-0.0801	-0.1669	-0.3359	-0.1357	-0.2647	-0.4027	-0.4227	-0.2603	-0.1268	-0.2314
	Z	2.396*	0.8668	0.6119	1.2747	2.566*	1.0368	2.022*	3.076**	3.223**	1.988*	0.9688	1.7676
Pune	β	0.0200	0.0234	0.0000	-0.0135	0.0143	0.0064	0.0107	0.0071	0.0179	-0.0062	0.0340	0.0224
	TAU	0.1242	0.1324	0.0229	-0.0654	0.1291	0.1078	0.2402	0.1275	0.2026	-0.0507	0.0703	0.1242
	Z	1.0352	1.1033	0.1907	0.5448	1.0761	0.8990	2.002*	1.0624	1.6890	0.4222	0.5857	1.0352
Pusa	β	0.0542	0.0563	0.0565	0.0833	0.0500	0.0800	0.0667	0.0667	0.0579	0.0737	0.1190	0.0810
	TAU	0.2571	0.2905	0.2333	0.3405	0.1762	0.3262	0.3238	0.4952	0.3976	0.3119	0.3310	0.2952
	Z	1.9268	2.176*	1.7484	2.551*	1.3202	2.442*	2.426*	3.710**	2.975*	2.332*	2.479*	2.212*
Varanasi	β	-0.0286	0.0474	0.0250	0.0111	-0.0143	-0.0208	0.0000	0.0188	0.0278	0.0455	0.0083	0.0111
	TAU	-0.1118	0.2443	0.1573	0.0663	-0.0621	-0.1863	0.0207	0.2609	0.2733	0.2277	0.0207	0.0828
	Z	0.7131	1.5582	1.0036	0.4226	0.3962	1.1885	0.1321	1.6639	1.7431	1.4526	0.1321	0.5282

* Significant trend at the 0.05 level ** Significant trend at the 0.01 level.

temperature. Bhutiyani *et al*. (2007) found increasing trend in maximum, minimum, mean and diurnal temperature range over the northwestern Himalayan region during the 20th century. Pal and Al-Tabbaa (2010) studied the long-term trends and variations in the monthly maximum and minimum temperatures in various climatological regions in India. Their result revealed increasing monthly average maximum temperature, though unevenly, over the last century. Minimum temperature changes were found more variable than maximum temperature changes, both temporal and spatial, with results of lesser significance. In this study, trend analysis of the climate variables maximum temperature (MaxT), minimum temperature (MinT), rainfall (RF) and bright sunshine hours (BSH) for different seasons (kharif or rainy season, rabi or post-rainy season and summer), monthly (January to December), and weekly (1-52 standard meteorological week or SMW) for different pigeonpea growing areas of India were studied.

2. Materials and methods

2.1. *Data*

Time series of weekly, seasonal and monthly data were analysed in this study. Data for standard meteorological weeks (SMW) were obtained from eight locations (Kanpur: 1971-2011; Hyderabad: 1980-2010; Bangalore: 1980-2010; Pusa: 1980-2010; Pantnagar: 1970-2008; Parbhani: 1980-2010; Varanasi: 1980-2008;

TABLE 4

Monthly value of Sen's slope, tau and *Z* statistics of Mann-Kendall test for rainfall (RF)

Location	Test value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bangalore	β	-0.2450	0.1480	-0.3152	-0.0063	-0.8207	-0.5727	-0.6000	-0.4800	-1.6261	-0.7455	-0.2857	-0.0296
	TAU	-0.1513	0.0067	-0.0912	-0.0156	-0.4427	-0.5028	-0.4027	-0.2247	-0.3582	-0.2914	-0.3226	-0.1290
	Z	1.1558	0.0510	0.6969	0.1190	3.38**	3.84**	3.07**	1.7166	2.736*	2.226*	2.464*	0.9858
Hyderabad	β	0.0000	0.0000	-0.0120	-0.0290	-0.0021	-0.3750	0.2105	0.6806	0.1634	-0.3230	0.0000	0.0000
	TAU	-0.1167	0.2083	-0.0979	-0.0563	-0.0292	-0.1875	0.0708	0.1833	0.0583	-0.1354	0.0604	-0.1292
	Z	0.9081	1.6216	0.7622	0.4378	0.2270	1.4595	0.5514	1.4270	0.4541	1.0541	0.4703	1.0054
Kanpur	β	-0.0254	-0.1452	-0.0154	0.0000	0.0000	-0.2461	-1.0806	-1.1569	-0.5531	-0.0333	0.1580	-0.0029
	TAU	-0.2139	-0.0288	-0.1964	0.0075	-0.0325	-0.2164	-0.3202	-0.2439	-0.2151	-0.1789	0.0801	-0.1826
	Z	1.9207	0.2583	1.7634	0.0674	0.2920	1.9431	2.8754*	2.190*	1.9319	1.6062	0.7188	1.6399
Pantnagar	β	-0.057	0.1353	-0.0211	0.0050	0.1412	0.0385	-0.5579	0.6538	0.4409	0.1050	0.2300	0.2405
	TAU	-0.0024	0.1238	-0.0571	0.0262	0.1429	0.0167	-0.1190	0.1167	0.0857	-0.0452	-0.0357	-0.0833
	Z	0.0178	0.9277	0.4282	0.1963	1.0705	0.1249	0.8921	0.8742	0.6423	0.3390	0.2676	0.6244
Parbhani	β	-0.0452	0.2145	0.1265	0.4561	0.0080	-0.3857	-0.4923	0.2000	-0.0792	0.0286	0.1192	0.0000
	TAU	-0.0868	0.0067	0.0289	0.1513	0.0356	-0.1023	-0.1669	0.0289	-0.0111	0.0289	0.2469	-0.2113
	Z	0.6629	0.0510	0.2210	1.1558	0.2719	0.7818	1.2747	0.2210	0.0850	0.2210	1.8866	1.6147
Pune	β	0.0000	0.0000	0.0000	0.0000	-0.1167	0.4262	0.5875	0.2435	-0.0368	0.1340	0.0000	0.0000
	TAU	0.1013	-0.1029	-0.1601	-0.0098	-0.2059	0.1928	0.1846	0.1144	-0.0065	0.0882	-0.0310	0.0131
	Z	0.8445	0.8581	1.3348	0.0817	1.7162	1.6073	1.5392	0.9535	0.0545	0.7355	0.2588	0.1090
Pusa	β	-0.0253	0.16980	-0.0364	-0.0587	0.4867	0.2960	-0.2308	0.1783	-0.9050	0.3517	-0.1890	-0.1023
	TAU	-0.1024	0.0786	-0.1524	-0.0310	0.2524	0.0786	-0.0452	0.0357	-0.2119	0.2810	-0.1214	-0.1500
	Z	0.7672	0.5888	1.1418	0.2319	1.8911	0.5888	0.3390	0.2676	1.5879	2.1052*	0.9099	1.1240
Varanasi	β	-0.0571	0.2292	-0.0048	0.1256	0.0357	0.5905	-0.9179	0.2200	-0.4556	0.0462	-0.1875	-0.0053
	TAU	-0.0745	0.2484	-0.0745	0.0580	0.1077	0.2981	-0.1449	0.0994	-0.1035	0.0870	-0.1905	-0.1905
	Z	0.4754	1.5846	0.4754	0.3697	0.6867	1.9016	0.9244	0.6339	0.6603	0.5546	1.2149	1.2149

* Significant trend at the 0.05 level ** Significant trend at the 0.01 level.

Pune: 1971-2008) on maximum temperature (MaxT), minimum temperature (MinT), rainfall (RF) and bright sunshine hours (BSH). For each location 52 weekly series (1st to 52nd SMW), 3 seasonal series (Summer season: 9-22 SMW; kharif : 23-39 SMW; rabi: 40-8 SMW) and 12 monthly series (January to December) were obtained.

2.2. *The statistical test for trend analysis*

Trend analysis of a time series consists of the magnitude of trend and its statistical significance. To ascertain the presence of statistically significant trend in climatic variables with reference to climate change, non-parametric Mann-Kendall (MK) test has been employed. According to Ahani *et al*. (2012), if a time series presents a linear trend, the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen (1968). Sen's slope estimator, the same as MK statistics, is a well-known statistical test (Dinpashoh *et al*., 2011; Tabari *et al*., 2011; Ahani *et al*., 2012). The total change during the observed period was obtained by multiplying the slope by the number of years (Tabari and Talaee 2011).

Mann (1945) presented a non-parametric test for randomness against time, which constitutes a particular application of Kendall's test for correlation commonly known as the Mann-Kendall test. As stated in Zhai and Feng (2008), this test has a number of advantages: (*i*) the data do not need to conform to a particular distribution;

TABLE 5

Monthly value of Sen's slope, tau and *Z* statistics of Mann-Kendall test for bright sunshine hours (BSH)

Location	Test value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bangalore	β	-0.0125	-0.0300	-0.0524	-0.0455	-0.0500	0.0136	-0.0353	-0.0421	-0.0385	-0.0292	-0.0235	-0.0417
	TAU	-0.1201	-0.1958	-0.4828	-0.5295	-0.3982	0.0868	-0.2848	-0.3003	-0.2091	-0.1802	-0.1224	-0.1846
	Z	0.9178	1.4957	3.68**	4.04**	3.04**	0.6629	2.175*	2.294*	1.5977	1.3767	0.9348	1.4107
Hyderabad	β	-0.0278	-0.0455	-0.0385	-0.0300	-0.0342	0.0000	-0.0100	0.0000	-0.0229	-0.0222	-0.0710	-0.0400
	TAU	-0.2375	-0.4292	-0.3958	-0.2792	-0.2292	-0.0083	-0.0604	0.0104	-0.1188	-0.1583	-0.3521	-0.2500
	Z	1.8487	3.340**	3.08**	2.1730	1.7838	0.0649	0.4703	0.0811	0.9243	1.2325	2.740*	1.9460
Pantnagar	β	-0.0500	-0.0438	0.0200	0.0000	0.0105	0.0300	-0.0143	0.0280	-0.0111	-0.0091	-0.0294	-0.0667
	TAU	-0.3952	-0.3762	0.2333	-0.0405	0.1381	0.1929	-0.1286	0.2000	-0.0905	-0.0976	-0.3119	-0.5000
	Z	2.961*	2.818*	1.7484	0.3033	1.0348	1.4451	0.9634	1.4986	0.6780	0.7315	2.337*	3.74**
Parbhani	β	0.0000	-0.0200	-0.0125	-0.0143	0.0111	0.0143	-0.0111	-0.0050	-0.0313	-0.0217	-0.0235	0.0000
	TAU	0.0156	-0.2492	-0.1824	-0.1424	0.0601	0.0578	-0.0845	-0.0222	-0.1513	-0.1669	-0.1580	-0.0445
	Z	0.1190	1.9036	1.3937	1.0878	0.4589	0.4419	0.6459	0.1700	1.1558	1.2747	1.2067	0.3399
Pune	β	-0.0364	-0.0267	-0.0250	-0.0250	-0.0208	-0.0350	-0.0333	-0.0133	-0.0372	-0.0357	-0.0313	-0.0455
	TAU	-0.5114	-0.4641	-0.4444	-0.2729	-0.1748	-0.2255	-0.2614	-0.1520	-0.2337	-0.2810	-0.2386	-0.5261
	Z	4.26**	3.86**	3.70**	2.274*	1.4574	1.8797	2.179*	1.2667	1.9478	2.342*	1.988*	4.385*
Varanasi	β	-0.0762	-0.1000	-0.0250	-0.0412	-0.0583	-0.0545	0.0000	-0.0263	-0.0182	-0.0429	-0.0786	-0.1059
	TAU	-0.4596	-0.5963	-0.2484	-0.4348	-0.4928	-0.3188	-0.0041	-0.1863	-0.0952	-0.3478	-0.6128	-0.5921
	Z	2.936*	3.80**	1.5846	2.773*	3.14**	2.033*	0.0264	1.1885	0.6074	2.218*	3.90**	3.77**

* Significant trend at the 0.05 level, ** Significant trend at the 0.01 level.

thus extreme values are acceptable (Hirsch *et al*., 1993), (*ii*) missing values are allowed (Yu *et al*., 1993), (*iii*) relative magnitudes (ranking) are used instead of the numerical values, which allows for 'trace' or 'below detection limit' data to be included, as they are assigned a value less than the smallest measured value, and (*iv*) in time series analysis, it is not necessary to specify whether the trend is linear or not (Yu *et al*., 1993; Silva, 2004). For M-K test, the null hypothesis is H_0 of no trend, *i.e.*, the observations of series are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values.

2.3. *Mann-Kendall non-parametric test*

To ascertain the presence of statistically significant trend in climatic variables such as temperature, rainfall and bright sunshine hour non-parametric Mann-Kendall (M-K) test has been employed. The MK test checks the null hypothesis H_0 states that the data (x_1, x_2, x_3,…x_N) has no trend versus the alternative hypothesis (H_1) of the existence of increasing or decreasing trend. The statistics (S) is defined as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \text{sgn}\,(x_j - x_i) \tag{1}$$

where, x_j and x_i are data values at time j and k ($j > i$) and N is the number of data points. Assuming the $x_j - x_i = \theta$, value of sgn (θ) is computed as follows:

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

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. The test statistic τ (Tau) can be computed as:

$$\tau = \frac{S}{N(N-1)/2}$$

TABLE 6

The increasing trends of climate variables in various months for different locations

Location	MaxT	MinT	RF	BSH
Bangalore	Jan	All months except Mar- Apr	Feb	Jun
Hyderabad	Jan, Apr, Jun-Dec	Jun-Sep	Feb, Jul, Aug, Sep, Nov	Aug
Kanpur	Feb-Apr and Jun-Dec	Feb, Mar, May, Jul and Sep	Apr and Nov	NA
Pantnagar	Feb and Apr	Jan to Dec	All months except Jan, Mar, Jul	May, Jun and Aug
Parbhani	Mar, Apr, Jun, Nov, Dec	Jan to Dec	All months except Jan, Jun, Jul and Sep	Jan, May and Jun
Pune	Jan to Dec	All months except Apr and Oct	Jan, Jun, Jul, Aug, Oct and Dec	Data not available
Pusa	Mar, Apr, Jul	Jan-Dec	Feb, May, Jun, Aug and Oct	Data not available
Varanasi	Mar, Apr Jun to Nov	All months except Jan, May and Jun	Feb, Apr, May, Jun, Aug and Oct	Jan to Dec

MaxT: maximum temperature; MinT: minimum temperature; RF: rainfall; BSH: bright sunshine hours

TABLE 7

The overall trends for weekly meteorological variables for different locations

Location	MaxT	MinT	RF	BSH
Bangalore	↓	↑	↓	↓
Hyderabad	↑	↓	↓	↓
Kanpur	↑	↓	↓	NA
Pantnagar	↓	↑	↓	↓
Parbhani	↑	↑	↓	↓
Pune	↑	↑	↓	↑
Pusa	↓	↑	↓	NA
Varanasi	↑	↑	↓	↓

(↑ showed in increasing trends while ↓ showed decreasing trends)
MaxT: maximum temperature; MinT: minimum temperature; RF: rainfall; BSH: bright sunshine hours. For Kanpur and Pusa, data on BSH is not available)

which has a range of -1 to +1 and is analogous to the correlation coefficient in regression analysis. The null hypothesis of no trend is rejected when S and τ are significantly different from zero. If a significant trend is found, the rate of change can be calculated using the Sen's slope estimator. For large samples the test is conducted using a normal distribution, with the mean and the variance as follows:

$$\mathrm{E}(S) = 0 \tag{3}$$

$$\operatorname{var}(S) = \frac{\mathrm{N}(\mathrm{N}-1)(2\mathrm{N}+5) - \sum_{k=1}^{n} t_k (t_k - 1)(2t_k + 5)}{18} \tag{4}$$

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

$$\mathrm{Z} = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{var}(S)}} & \text{if } S < 0 \end{cases} \tag{5}$$

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.

TABLE 8

The overall trends in meteorological variables at different locations for different seasons

Met. Var.	Season	Location							
		Bangalore	Hyderabad	Kanpur	Pantnagar	Parbhani	Pune	Pusa	Varanasi
MaxT	S1	↓	↓	↑	↓	↓	↑	↑	↑
	S2	↓	↑	↑	↓	↓	↑	↑	↓
	S3	↑	↑	↑	↓	↓	↑	↑	↑
MinT	S1	↓	↓	↑	↓	↓	↑	↑	↑
	S2	↑	↑	↓	↓	↓	↑	↓	↑
	S3	↑	↓	↓	↓	↓	↑	↓	↑
RF	S1	↓	↓	↓	↑	↑	↓	↓	↑
	S2	↓	↑	↓	↑	↑	↑	↓	↓
	S3	↓	↓	↓	↓	↓	↑	↓	↑
BSH	S1	↓	↓	NA	↓	↓	↑	NA	↓
	S2	↓	↓	NA	↓	↓	↓	NA	↓
	S3	↓	↓	NA	↓	↓	↓	NA	↓

(↑ shows increasing trends while ↓ shows decreasing trends)
MaxT: maximum temperature; MinT: minimum temperature; RF: rainfall; BSH: bright sunshine hours, S1: summer; S2: kharif (rainy): S3: rabi (post-rainy)

2.4. *Sen's slope estimator*

Sen's slope estimator has been widely used for determining the magnitude of trend in meteorological time series data. If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen (1968). The slope estimates of N pair of data are first computed by

$$T_i = \frac{x_j - x_k}{j-k} \quad \text{for} \quad i = 1, 2, 3, \ldots \text{N} \qquad (6)$$

where, x_j and x_k are data values at time j and k ($j > k$) respectively. If there are n values xj in the time series we get as many as N = n (n-1)/2 slope estimates Si. The median of these N values of T_i is Sen's estimator (β) of slope, which is calculated as:

$$\beta = \begin{cases} S_{\frac{N+2}{2}} & \text{N is odd} \\ \frac{1}{2}\left(S_{\frac{N}{2}} + S_{\frac{N+2}{2}}\right) & \text{N is even} \end{cases} \qquad (7)$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series. Finally, β is tested with a two-sided test at the 100 (1-α)% confidence interval and the true slope may be obtained with the non-parametric test (Partal and Kahya, 2006).

3. Results and discussion

The non-parametric tests Mann-Kendall and Sen's slope estimators for eight locations pertaining to the climatic variables were attempted. For each location, 52 weekly series (1^{st} to 52^{nd} SMW), 3 seasonal series [summer season (S1), kharif (S2) and rabi (S3)] and 12 monthly series (January to December) were obtained. The value of Sen's slope (β), tau (τ) and Z statistics of Mann Kendall test for three different seasons for various meteorological variables are shown in Table 1.

This table reveals that maximum temperature in rabi and kharif, minimum temperature in rabi season and rainfall in rabi season showed increasing trends in Hyderabad. Maximum temperature in kharif, minimum temperature in rabi and kharif showed increasing trends at Bangalore. Maximum temperature in all three seasons and minimum temperature in summer showed increasing trends in Kanpur. Rainfall in summer and rabi seasons showed increasing trends in Pantnagar as well as Parbhani. Rainfall in summer season and bright-sunshine hour in all three seasons showed decreasing trends in Pune. Maximum temperature in all three seasons and minimum temperature in summer season showed increasing trends in Samastipur (Pusa). Maximum temperature and rainfall in rabi season and bright sunshine hour in all three seasons showed decreasing trends in Varanasi. The significance level were based on the Z values of more than 1.96 that represent upward significant trend, while values less than -1.96 show decreasing trend at $\alpha < 0.05$.

Tables (2-5), showed the monthly value of Sen's slope, tau and Z statistics of Mann-Kendall test for climate variables [maximum temperature (MaxT), minimum temperature (MinT), rainfall (RF) and bright sunshine hours (BSH)]. These tables indicate, that there was significant variation in weather variables over years for different locations [Pantnagar, Kanpur, Pusa, Parbhani, Hyderabad (Patancheru), Bangalore, Varanasi and Pune].

Table 6 shows the increasing trends of climate variables in various months for different locations while Table (7-8) indicate the overall trends for weekly and seasons in meteorological variables for different locations.

4. Conclusion

Trends in maximum temperature series showed a rising trend at most of the stations; it showed a falling trend at some stations. The mean minimum temperature showed a rising as well as a falling trend. At most of the stations in the south, central and western parts of India a rising trend was found. Some stations located in the north and north-eastern India showed a falling trend in annual mean temperature. Most of the data used in trend analysis pertained to the stations located in urban areas and these areas are sort of heat islands. The analysis of data indicates that there is change in climate at different locations of India, which belong to various regions growing pigeonpea. Changes in various parameters of climate could trigger a shift in pathogen and insect-pest status in the relevant locations growing pigeonpea crop.

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