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Development of an ArcGIS Toolbar for Trend Analysis of Climatic Data

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***Abstract*—**Climate change is a cumulative change in weather patterns over a period of time. Trend analysis using non-parametric Mann-Kendall test may help to determine the existence and magnitude of any statistically significant trend in the climatic data. Another index called Sen slope may be used to quantify the magnitude of such trends. A toolbar extension to ESRI ArcGIS named Arc Trends has been developed in this study for performing the above mentioned tasks. To study the temporal trend of meteorological parameters, 32 years (1971-2002) monthly meteorological data were collected for 133 selected stations over different agro-ecological regions of India. Both the maximum and minimum temperatures were found to be rising. A significant increasing trend in the relative humidity and a consistent significant decreasing trend in the wind speed all over the country were found. However, a general increase in rainfall was not found in recent years.

***Keywords*—**Temporal trend, climate change, ArcGIS, Mann-Kendall test, Sen slope

I. Introduction

CLIMATE change is a change in the average weather conditions or a change in the distribution of weather events with respect to an average, for example, greater or fewer extreme weather events. It may be limited to a specific region, or occur across the whole earth. During past few decades much of concern has been expressed across the globe regarding climate change with particular reference to the modern climate. It may be qualified as anthropogenic climate change, more generally known as global warming or anthropogenic global warming (AGW). The modern climate is perceived to be changing worldwide and there has been growing concern as to the direction and effects of these changes. It refers to the gradual increase in the average temperature of the earth and is exemplified by the gradual decrease in the snow cover across the earth. Disappearance of glaciers has led to gradual increase in sea water level causing submergence of many islands. Increase in global temperature has drastically changed the weather patterns in many regions of the world.

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(CH_4), ozone (O_3), nitrous oxide (N_2O), and chloro-fluoro-carbons (CFCs). There is now clear evidence for an observed increase in global average temperature and change in rainfall pattern during the 20th century around the world [1]–[5]. Rainfall has significantly increased in eastern parts of North and South America, northern Europe, and northern and central Asia. On the contrary rainfall has decreased in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia. Xu et al. (2004) investigated the possible association between climate change and water resources variability, and detected the plausible long-term trends of the hydrologic variables by using non-parametric Mann-Kendall test [6]. Climate change scenario in India revealed that the annual mean temperature has increased by 0.48 °C in the past 100 years [7].

Temporal trend analysis is a tool to understand variations of different meteorological parameters with time. The knowledge of increasing/decreasing or no trend of an individual climatic parameter may lead to safer designs, proper planning, required corrective measures, and sustainable practices. Many researchers have investigated the nature and pattern of trends of different climatic parameters. In India, several meteorological studies have been conducted in the context of climate change using observed data as well as model results [8]–[12].

Parthasarathy and Dhar (1975) found that the mean annual rainfall of India is of the order of 1190 mm with a standard deviation of 95 mm [13]. The mean areal annual rainfall in the 30 years period from 1931-1960 showed a significant increase of about 5%. Although, researchers could not find any significant trend in rainfall on all India basis [14]–[18]; some of them advocated for significant regional decreasing/ increasing trends in rainfall [19]–[21]. Murugan et al. (2005) found rainfall has increased over all states except Punjab, Rajasthan, and Tamil Nadu, which showed slight decrease in precipitation during 1960-1990 [22]. Krishnakumar et al. (2009) revealed that there is a significant decrease in southwest monsoon rainfall while increase in post-monsoon rainfall over the state of Kerala and rainfall during winter and summer seasons show insignificant increasing trend [23].

Paramanik and Jagannathan (1954) had analysed surface temperature data series over India and inferred that the rise in annual mean temperature over India is comparable with the reported rise of global surface temperature by 0.6 °C [24]. Many studies have shown that there is observed increasing trend in surface temperature in different place of India [17], [21], [25]–[29].Assessing temporal trends for different meteorological parameters are essential to understand the local climate change pattern of a region. It helps in forecasting the future climate and its effect on hydrology and agriculture. If such trends can be determined directly in reference to stations in point coverage inside a GIS environment, visualizing the spatial patterns or further spatial analysis of such trends would be greatly improved.

Keeping the above mentioned facts in view, the present study is taken up with the following objectives:

1. To develop an ArcGIS toolbar using Arc Objects for temporal trend analysis of climatic data.
2. To determine the temporal trend of metrological parameters over India using the developed toolbar.

II. Theoretical Considerations

A. General Statistics of Meteorological Parameters

The general statistical analysis may be performed to take a general overview of the data collected. The statistical parameters which are usually considered to look for gross data errors/outliers are:

- Minimum and maximum
- Mean
- Standard deviation
- Coefficient of variation

B. Temporal Trends of Meteorological Parameters

The trend analysis may be performed to determine the existence and magnitude of any statistically significant trend in meteorological parameters over the time period considered. The Mann-Kendall (MK) test has been used in this study for detection of trend. This is a non-parametric test, which makes no assumption for probability distribution of the variate and is less affected by missing values or outliers. However, MK test is a statistical yes/no type hypothesis testing procedure and, therefore, another index, Sen slope [30] has been used to quantify the magnitude of such trend. Being non-parametric, Sen slope also enjoys the same advantages mentioned earlier for the MK test.

Mann-Kendall test

The Kendall's statistic *S* is given by [31], [32]:

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

where,

$$\operatorname{sgn}\left(x_i - x_j\right) = \begin{cases} 1, & x_i > x_j \\ 0, & x_i = x_j \\ -1, & x_i < x_j \end{cases} \tag{2}$$

for a time series x_k, $k = 1, 2, \ldots, n$.

,

When $n \geq 10$, S becomes approximately normally distributed with mean = 0 and variance as:

$$\sigma_S^{\ 2} = \frac{n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)}{18} \tag{3}$$

where, t is the extent (number of x involved) of any given tie and $\sum_t$ denotes the summation over all ties. Then Z_c follows the standard normal distribution where:

$$Z_c = \begin{cases} \dfrac{(S-1)}{\sigma_S}, & S > 0 \\ 0, & S = 0 \\ \dfrac{(S+1)}{\sigma_S}, & S < 0 \end{cases} \tag{4}$$

The null hypothesis that there is no trend is rejected when:

$$\left|Z_c\right| > Z_{1-\frac{\alpha}{2}} \tag{5}$$

where, Z is the standard normal variate and α is the level of significance for the test.

To find out the effect of auto-correlation on MK test results, the modified MK test with effective sample size (ESS) approach, as suggested in [33], was attempted on detrended series. In this method, the variance, σ_S^2, is modified as:

$$\sigma^*{}_S^{\ 2} = \sigma_S^{\ 2} \cdot \frac{n}{n^*} \tag{6}$$

where, n^* is the effective sample size calculated as [34]:

$$n^* = \frac{n}{1 + 2 \cdot \dfrac{\rho_1^{\,n+1} - n \cdot \rho_1^{\,2} + (n-1) \cdot \rho_1}{n \cdot (\rho_1 - 1)^2}} \tag{7}$$

where, ρ_1 is the lag-1 auto-correlation coefficient, as given in [35], computed for the sample data after removing the trend as:

$$x^*_k = x_k - \beta \cdot (k-1),\ k = 1, 2, \ldots, n. \tag{8}$$

where, ρ_1 can be determined by:

$$\rho_1 = \frac{\sum_{i=1}^{n-1} (x^*_i - \bar{x}^*)(x^*_{i+1} - \bar{x}^*)}{\sum_{i=1}^{n} (x^*_i - \bar{x}^*)^2} \tag{9}$$

and β is the Sen slope calculated using (10).

Sen slope

The magnitude of the trend is given as [30]:

$$\beta = \text{Median}\left(\frac{x_i - x_j}{i - j}\right), \quad \forall\ j < i \qquad (10)$$

in which $1 < j < i < n$.

A positive value of β indicates an increasing trend whereas a negative value indicates a decreasing trend.

III. Data And Methodology

A. Development of Arc Trends Toolbar

ArcObjects is a development platform for ArcGIS that allows developers to enhance and extend the data processing capabilities of GIS [36]. It provides a way to integrate GIS with external models. Its components act jointly to serve every data management and map presentation function common to most GIS applications. Overall, ArcObjects is a handy tool for customizing any application that serves specific needs. The ArcGIS customization works with 'ArcObjects' using Visual Basic for Applications (VBA) capabilities to add new menus, tools, and work flows to ArcGIS applications that employ or extend existing ArcGIS applications and functions.

The interface and GIS functionality of the developed toolbar have been programmed with ArcObjects using VBA. The purpose of developing such toolbar is to free the user from complicated interactions required for temporal trend estimation by incorporating all functions into a custom ArcGIS toolbar. The toolbar estimates statistical parameters as well as temporal trends of the time series data pertaining to selected stations and is named as Arc Trends.

Arc Trends is neither a standalone application nor a dynamic link library (DLL) file, it is a toolbar extension to ESRI ArcMap. The package of Arc Trends contains the following:

- Arc Trends IMD map document (.mxd file)
- Workspace
- Projections
- Database

Workspace is a folder which contains GIS coverages of the stations and state boundary of India. Projections folder contains projection files that help to convert the map either to projected map coordinate system or to geographic coordinate system. And the Database folder is the place where the user needs to keep the data files in *.CSV format. Arc Trends.mxd document helps to load the ArcMap document with preloaded coverages (meteorological stations, state boundary, etc.) and the Arc Trends toolbar (Fig. 1). Fig. 2 shows the attributes of the point coverage with basic information such as station name, state to which they belong, elevation, etc.

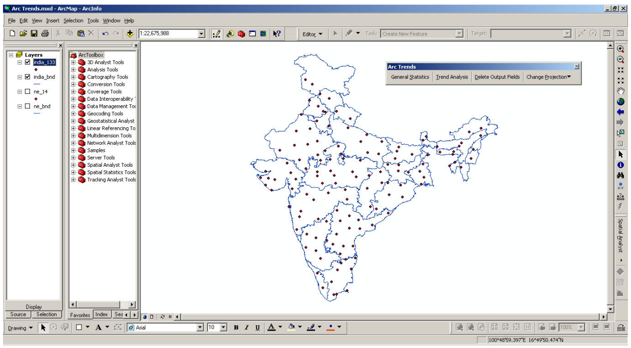
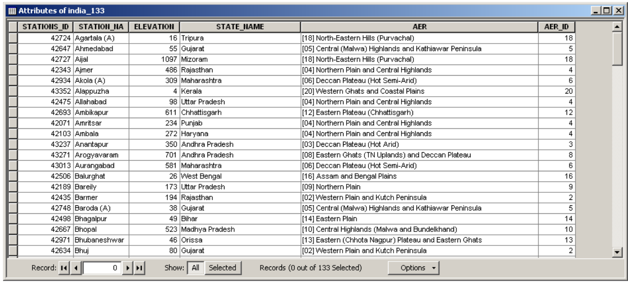


Fig. 1 Arc Trends toolbar and preloaded layers in Arc Trends map document



Attributes of india_133

STATIONS_ID	STATION_NA	ELEVATION	STATE_NAME	AER	AER_ID
42724	Agartala (A)	16	Tripura	[18] North-Eastern Hills (Purvachal)	18
42647	Ahmedabad	55	Gujarat	[05] Central (Malwa) Highlands and Kathiawar Peninsula	5
42727	Aijal	1097	Mizoram	[18] North-Eastern Hills (Purvachal)	18
42343	Ajmer	486	Rajasthan	[04] Northern Plain and Central Highlands	4
42934	Akola (A)	309	Maharashtra	[06] Deccan Plateau (Hot Semi-Arid)	6
43352	Alappuzha	4	Kerala	[20] Western Ghats and Coastal Plains	20
42475	Allahabad	98	Uttar Pradesh	[04] Northern Plain and Central Highlands	4
42693	Ambikapur	611	Chhattisgarh	[12] Eastern Plateau (Chhattisgarh)	12
42071	Amritsar	234	Punjab	[04] Northern Plain and Central Highlands	4
42103	Ambala	272	Haryana	[04] Northern Plain and Central Highlands	4
43237	Anantapur	350	Andhra Pradesh	[03] Deccan Plateau (Hot Arid)	3
43271	Arogyavaram	701	Andhra Pradesh	[08] Eastern Ghats (TN Uplands) and Deccan Plateau	8
43013	Aurangabad	581	Maharashtra	[06] Deccan Plateau (Hot Semi-Arid)	6
42506	Balurghat	26	West Bengal	[16] Assam and Bengal Plains	16
42189	Bareily	173	Uttar Pradesh	[09] Northern Plain	9
42435	Barmer	194	Rajasthan	[02] Western Plain and Kutch Peninsula	2
42748	Baroda (A)	38	Gujarat	[05] Central (Malwa) Highlands and Kathiawar Peninsula	5
42498	Bhagalpur	49	Bihar	[14] Eastern Plain	14
42667	Bhopal	523	Madhya Pradesh	[10] Central Highlands (Malwa and Bundelkhand)	10
42971	Bhubaneshwar	46	Orissa	[13] Eastern (Chhota Nagpur) Plateau and Eastern Ghats	13
42634	Bhuj	80	Gujarat	[02] Western Plain and Kutch Peninsula	2

Record: 0 Show: All Selected Records (0 out of 133 Selected) Options

Fig. 2 Attribute table of the point coverage

B. Toolbar Description

This toolbar consists of four interactive tools with a set of menu items. Fig. 3 shows the structure of the Arc Trends toolbar with the four buttons (*General Statistics*, *Trend Analysis*, *Delete Output Fields*, and *Change Projections*). The program uses data saved in CSV format (*.csv file), containing two columns, date (DD-MM-YYYY*)* and data, respectively, either in daily or monthly frequency. If any data for a particular date is not available then that data field should be filled with "NA" or left blank.

The *General Statistics* button is used for calculating the statistical parameters (minimum, maximum, mean, standard deviation, and coefficient of variation) of the metrological data. Prior to clicking any of these buttons, the point coverage on which the process will be operated, needs to be selected. Otherwise an error message comes up which reminds the user to select the coverage.

Fig. 3 The Arc Trends toolbar

On clicking the *General Statistics* button the *Select Stations* window (Fig. 4) shows up on the screen. The station selection is possible in four different ways: by elevation range, by agro-ecological regions, by states, and by directly selecting stations. On selecting the elevation range the *Select Elevation Range* frame gets activated. On entering the lower and upper range of elevation, the station(s) having elevation within the entered range (as per the attribute table) gets updated in the station list. On choosing selection by agro-ecological regions, the list of AER is loaded from the attribute table and displayed. On selecting one or more AER(s), the stations falling under the selected AER(s) gets updated in the station list. On choosing selection by state, the list of states is loaded from the attribute table and displayed. On selecting one or more state(s), the stations falling under the selected state(s) gets updated in the station list. On choosing selection by station itself, all the stations in the coverage are loaded in the station list. Once the station list is updated, station(s) for which the calculation is to be done can be selected. For multiple selections of items on any list, the CTRL key is to be pressed and held while clicking other items. For selection of continuous range of items, the SHIFT key is to be pressed and held while clicking the first and last item of the range. For full list selection, the *Select All* button can be clicked. After selection of station(s) the Ok button has to be clicked to proceed to calculations.

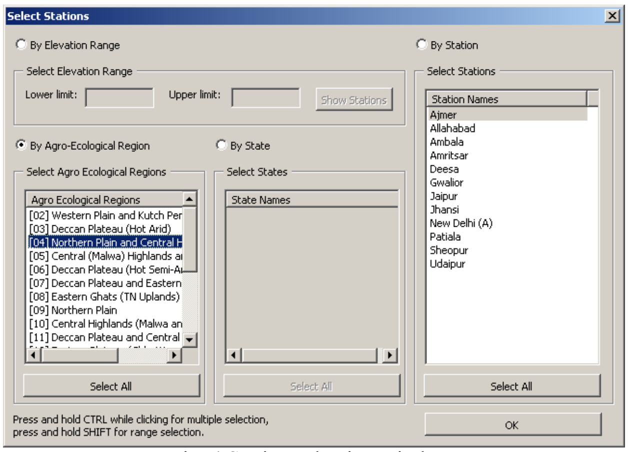


Fig. 4 Station selection window

The *General Statistics* window (Fig. 5) shows up on screen next. The parameter(s) to be included in the calculation, statistic(s) to be calculated, and the output format (full dataset, monthly, yearly) needs to be selected on this window. On selecting *Full dataset* as output format, the selected statistic(s) will be calculated on the complete dataset available for selected meteorological parameter(s). On selecting *Monthly* as output format, the selected statistic(s) will be calculated for selected meteorological parameter(s) for each of the 12 months separately. On selecting *Yearly* as output format, the selected statistic(s) will be calculated for selected meteorological parameter(s) based on yearly averages. The calculated results are updated in the attribute table against selected station(s) by creating new field(s) or over-writing existing field(s).

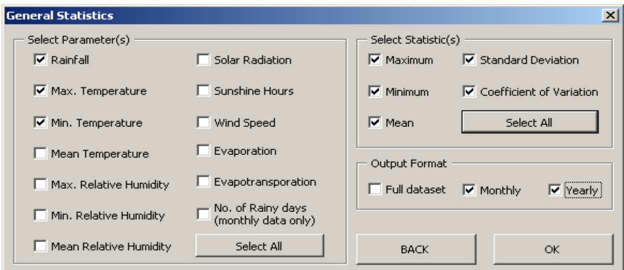


Fig. 5 General statistics window

The *Trend Analysis* button is used for trend detection of the metrological data using MK Test or Sen slope. On clicking the *Trend Analysis* button on the toolbar, the *Select Station*s window (Fig. 4) shows up on the screen. The station selection procedure for trend analysis is exactly same as the general statistics described above. After selection of station(s) the *Trend Analysis* window (Fig. 6) shows up on screen.

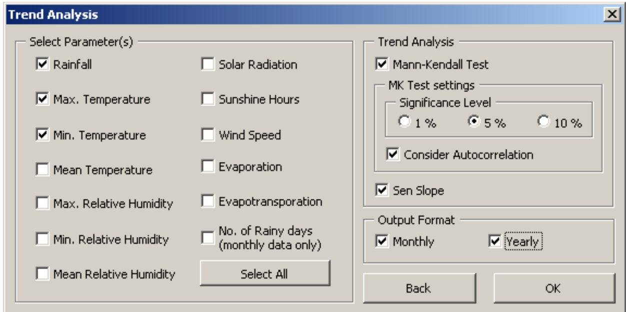


Fig. 6 Trend analysis window

The meteorological parameter(s) and the test(s) to be performed for trend analysis can be selected in this window. As discussed earlier, for trend analysis, Mann-Kendall test and Sen slope are used. *The MK Test settings* frame gets activated on checking *Mann-Kendall Test* checkbox. Presence of autocorrelation in the time series may be considered or avoided suitably by checking/un-checking the *Consider Autocorrelation* checkbox. Level of significance can be selected among 1%, 5%, and 10% as per the requirement of the user. Selection of output formats is also exactly same as described above with general statistics except the fact that, in this case, calculation on full dataset is not possible. Completion message and writing of results in the attribute table are also same as described earlier.

Deletion of output fields

As the user goes on calculating general statistics or performing trend analysis, the toolbar keeps on creating new fields for saving the outputs in the attribute table as per requirements. Altogether, there may be about 1000 such additional fields created. Sometimes that may create problems for the user wanting to look at some very specific results. Hence this *Delete Output Fields* button on the toolbar may be used by the user to delete all the output fields created after running the program. The fields are created back afresh when user carries out the calculation again. Both before and after the deletion process, message boxes confirm the action from/to the user.

The fourth interactive tool in Arc Trends toolbar is the *Change Projection* dropdown menu, which is helpful in displaying the map in either geographical or projected coordinate systems. Any location on earth can be referenced by a point with longitude and latitude coordinates. *Geographic* Lat Long is a flat, two dimensional representation of the earth. On the other hand, *Polyconic* is a reference system that uses three dimensional spherical surface to determine locations on earth. It is also based on geographic coordinate system, but it uses linear units of measure for coordinates.

C. Data Acquisition

Monthly meteorological data (max. and min. air temperatures, mean RH, wind speed, solar radiation or sunshine hour, and rainfall) for the period of 32 years (1971 - 2002) were procured from IMD, Pune, for 133 selected stations evenly distributed over 19 AERs of India [37]. The AER 21 was excluded for spatial discontinuity, whereas, suitable IMD station could not be located within AER 1. Table 1 presents the distribution of the selected 133 IMD stations among the 19 agro-ecological regions.

TABLE I
DETAILS OF 133 IMD STATIONS SELECTED

Sl.	Station ID	Station	State/UT	AER
1	42435	Barmer	Rajasthan	2
2	42634	Bhuj	Gujarat	2
3	42165	Bikaner	Rajasthan	2
4	42170	Churu	Rajasthan	2
5	42131	Hissar	Haryana	2
6	42339	Jodhpur	Rajasthan	2
7	42730	Okha	Gujarat	2
8	42123	Sriganganagar	Rajasthan	2
9	43237	Anantapur	Andhra Pradesh	3
10	43205	Bellary	Karnataka	3
11	43201	Gadag	Karnataka	3
12	42343	Ajmer	Rajasthan	4
13	42475	Allahabad	Uttar Pradesh	4
14	42103	Ambala	Haryana	4
15	42071	Amritsar	Punjab	4
16	42539	Deesa	Gujarat	4
17	42361	Gwalior	Madhya Pradesh	4
18	42348	Jaipur	Rajasthan	4
19	42463	Jhansi	Uttar Pradesh	4
20	42181	New Delhi (A)	Delhi	4
21	42101	Patiala	Punjab	4
22	42456	Sheopur	Madhya Pradesh	4
23	42543	Udaipur	Rajasthan	4
24	42647	Ahmedabad	Gujarat	5
25	42655	Banswara	Rajasthan	5
26	42748	Baroda (A)	Gujarat	5
27	42754	Indore	Madhya Pradesh	5
28	42734	Jamnagar	Gujarat	5
29	42555	Jhalawar	Rajasthan	5
30	42855	Khandwa	Madhya Pradesh	5
31	42451	Kota	Rajasthan	5
32	42830	Porbandar (A)	Gujarat	5
33	42737	Rajkot (A)	Gujarat	5
34	42662	Ujjain	Madhya Pradesh	5
35	42909	Veraval	Gujarat	5
36	42934	Akola (A)	Maharashtra	6
37	43013	Aurangabad	Maharashtra	6
38	43197	Belgaum	Karnataka	6
39	43121	Gulbarga	Karnataka	6
40	42925	Maegaon	Maharashtra	6
41	43111	Mahabaleshwar	Maharashtra	6
42	43081	Nizamabad	Andhra Pradesh	6
43	43063	Pune	Maharashtra	6
44	43117	Solapur	Maharashtra	6
45	43241	Cuddapah	Andhra Pradesh	7
46	43181	Gannavaram	Andhra Pradesh	7
47	43087	Hanamkonda	Andhra Pradesh	7
48	43128	Hyderabad (A)	Andhra Pradesh	7
49	43136	Kothagudem	Andhra Pradesh	7
50	43213	Kurnool	Andhra Pradesh	7
51	43177	Rentachintala	Andhra Pradesh	7
52	43271	Arogyavaram	Andhra Pradesh	8
53	43263	Hassan	Karnataka	8
54	43339	Kodaikanal	Tamil Nadu	8
55	43278	Madras	Tamil Nadu	8
56	43376	Palayamkottai	Tamil Nadu	8
57	43363	Pamban	Tamil Nadu	8
58	43325	Salem	Tamil Nadu	8
69	43258	Shimoga	Karnataka	8
60	43302	Tiruppattur	Tamil Nadu	8
51	43379	Tuticorin	Tamil Nadu	8
62	43303	Vellore	Tamil Nadu	8
63	42189	Bareily	Uttar Pradesh	9
64	42591	Gaya	Bihar	9
65	42369	Lucknow	Uttar Pradesh	9
66	42099	Ludhiana	Punjab	9
67	42483	Varanasi	Uttar Pradesh	9
68	42667	Bhopal	Madhya Pradesh	10
69	42559	Guna	Madhya Pradesh	10
70	42763	Hoshangabad	Madhya Pradesh	10
71	42675	Jabalpur	Madhya Pradesh	10
72	42860	Betul	Madhya Pradesh	11
73	42776	Mandla	Madhya Pradesh	11
74	42867	Nagpur	Maharashtra	11
75	42571	Satna	Madhya Pradesh	11
76	42562	Tikamgarh	Madhya Pradesh	11
77	42693	Ambikapur	Chhattisgarh	12
78	42587	Daltonganj	Jharkhand	12
79	42699	Hazaribagh	Jharkhand	12
80	42779	Pendra	Madhya Pradesh	12
81	42884	Raigarh	Chhattisgarh	12
82	42875	Raipur	Chhattisgarh	12
83	42971	Bhubaneshwar (A)	Orissa	13
84	43029	Chandrapur	Maharashtra	13
85	43041	Jagdalpur	Chhattisgarh	13
86	42886	Jharsuguda	Orissa	13
87	42891	Keonjhargarh	Orissa	13
88	43097	Koraput	Orissa	13
89	42966	Phulbani	Orissa	13
90	42705	Purulia	West Bengal	13
91	42701	Ranchi (A)	Jharkhand	13
92	42273	Bahraich	Uttar Pradesh	14
93	42498	Bhagalpur	Bihar	14
94	42379	Gorakhpur	Uttar Pradesh	14
95	42387	Muzaffarpur	Bihar	14
96	42491	Patna	Bihar	14
97	42045	Banihal	Jammu & Kashmir	15
98	42081	Bhuntar (A)	Himachal Pradesh	15
99	42059	Dalhausie	Himachal Pradesh	15
100	42111	Dehra Dun	Uttaranchal	15
101	42026	Gulmarg	Jammu & Kashmir	15
102	42147	Mukteswar	Uttaranchal	15
103	42506	Balurghat	West Bengal	16
104	42603	Berhampore	West Bengal	16
105	42709	Burdwan	West Bengal	16
106	42807	Calcutta	West Bengal	16
107	42414	Chaparmukh	Assam	16
108	42406	Dhubri (A)	Assam	16
109	42314	Dibrugarh	Assam	16
110	42618	Kailashahar (A)	Tripura	16
111	42415	Tezpur	Assam	16
112	42295	Darjeeling	West Bengal	17
113	42299	Gangtok	Sikkim	17
114	42220	Pasighat	Arunachal Pradesh	17
115	42312	Ziro	Arunachal Pradesh	17
116	42724	Agartala (A)	Tripura	18
117	42727	Aijal	Mizoram	18
118	42515	Cherrapunji	Meghalaya	18
119	42623	Imphal (A)	Manipur	18
120	42527	Kohima	Nagaland	18
121	42516	Shillong (C.S.O.)	Meghalaya	18
122	42511	Tura	Meghalaya	18
123	43329	Cuddalore	Tamil Nadu	19
124	43189	Kakinada	Andhra Pradesh	19
125	43105	Kalingapatanam	Andhra Pradesh	19
126	43245	Nellore	Andhra Pradesh	19
127	42903	Sagar Island	West Bengal	19
128	43352	Alappuzha	Kerala	20
129	43057	Bombay	Maharashtra	20
130	43153	Devgad	Maharashtra	20
131	43226	Honavar	Karnataka	20
132	43314	Kozhikode	Kerala	20
133	42840	Surat	Gujarat	20

IV. Results And Discussion

The results of the MK tests (with 5% significance level) conducted on the meteorological parameters, namely, maximum and minimum temperature, mean relative humidity, wind speed, and solar radiation are given in Table 2, whereas, corresponding Sen slopes are given in Table 3. The maximum temperature gave a mixed response to the MK test. Out of 19, 10 AERs were having more number of stations with a significant rising trend, six had more stations with significant falling trend, and three AERs had equal number of stations showing rising/falling trend. Altogether 67 stations showed significant rising trend, 45 showed significant falling trend, and no significant trend was found in 20 stations. Patna in AER 14 did not have sufficient data for conducting MK test on any of the five meteorological parameters considered. The Sen slope for regional average yearly maximum temperature was found to be positive in nine and negative in seven out of total 19 AERs. The other three AERs were in no or negligible slope condition. The highest positive slope 0.06 °C per year was found in AER 15 (Western Himalayas, Warm Subhumid), whereas, the highest negative slope 0.10 °C per year was found in AER 17 (Eastern Himalayas), both in the Himalayan region. The monthly Sen slope (not reported here due to limitation of space) showed that there is not much annual variation in maximum temperature trends. However, maximum temperature was steadily increasing throughout the year in both the coastal regions (AERs 19 and 20) and steadily decreasing throughout the year in north-east India (AERs 16, 17, and 18). In the central India also (AERs 6, 10, and 12), the maximum temperature was found decreasing in some of the months.

In the case of minimum temperature, 16 AERs were having comparatively more number of stations with significant rising trend leading to a total of 84 stations with rising trend, 37 stations with falling trend, and 11 stations with no significant trend. The minimum temperature was found to be rising in north-west India (AERs 2, 4, and 5) and falling in AER 3 and 18 with high Sen slope magnitudes. Except April and October, number of AERs with positive Sen slope were more than that with negative Sen slope throughout the year. Overall, both maximum and minimum temperatures were found to be rising in the study period with minimum temperature showing more inclination towards rising than maximum temperature.

The mean relative humidity (RH) was found mostly increasing all over India throughout the year which was clearly in disagreement with what one would normally expect in rising temperature conditions. In 83 stations, mean RH was found to have significant rising trend, while in 30 stations it showed significant falling trend. No significant trend was present in 19 stations. Only in the smallest AER 3 (Deccan Plateau, Hot Arid), mean RH was found to be decreasing consistently. Such rising trend of RH indicates that the specific humidity increase is large enough to produce positive RH trends despite the warming conditions [38]. These results are in accordance with the findings of Chattopadhyay and Hulme (1997) who also suggested that the main cause of decreasing potential evaporation trend in India in recent years is increase in RH [39]. Such increasing concentration of water vapour, being a greenhouse gas, may add to the ongoing global warming adversely. Throughout the year wind speed was found falling steadily all over the country in the period of study without any exception. No other meteorological parameter showed such clear and consistent trend as wind speed. The reason of this universal falling trend of wind speed may be attributed to obstruction to wind flow offered by increasing construction works.

Solar radiation showed an overall falling trend in most part of the country except south India. This decreasing trend of solar radiation, together with increasing trend of mean RH, leads to the fact that cloudiness has been increasing in India in recent years. However, the trends of monthly rainfall and number of rainy days in a month did not support this fact too well as the test results were of mixed nature and region dependent. If generalized, both these parameters showed more inclination towards downward slope with considerable number of stations having no significant trend. Negative rainfall slope was observed in north-west India (AERs 2 and 4), south India (AERs 7 and 8), central India (AERs 10 and 11), and Western Himalayas (AER 15). AER 18 (North-Eastern Hills, Purvachal), with the highest rainfall receiving station, resulted in the maximum decline with a negative slope of 5.00 mm per year in monthly rainfall, steepest of it being in June and July. Number of rainy days in a month, on the other hand, showed a falling trend in the monsoon months, but, did not show much change in the other months of the year.

V. Conclusions

Among the meteorological parameters, both the maximum and minimum temperatures were found to be rising with minimum temperature more inclined towards rising than maximum temperature. The mean relative humidity (RH) was found mostly increasing all over India throughout the year which was clearly in disagreement with what one would normally expect in rising temperature conditions. Such rising trend of RH indicates that specific humidity increase was large enough to produce positive RH trends despite the warming conditions. Throughout the year wind speed was found falling steadily all over the country in the period of study without any exception. The reason of this universal falling trend of wind speed may be attributed to obstruction to wind flow offered by increasing construction works. Solar radiation, also found to be decreasing in general, together with increasing trend of mean RH, concludes that cloudiness has been increasing in India in recent years. However, the trends of monthly rainfall and number of rainy days in a month did not support this fact too well as the test results were of mixed nature and region dependent. If generalized, both these parameters showed slight downward trend with large number of stations having no significant trend.

TABLE II
MK TEST (5% SIGNIFICANCE) RESULTS

AER	Total No. of Stations	Maximum temperature		Minimum temperature		Mean relative humidity		Wind speed		Solar radiation		Monthly rainfall		No. of rainy days in a month	
		Rising Trend	Falling Trend	Rising Trend	Falling Trend	Rising Trend	Falling Trend	Rising Trend	Falling Trend	Rising Trend	Falling Trend	Rising Trend	Falling Trend	Rising Trend	Falling Trend
2	8	6	0	7	1	5	2	1	7	2	6	2	5	2	6
3	3	2	1	2	1	0	3	1	2	2	1	1	0	2	0
4	12	7	4	8	4	10	1	2	9	3	8	1	5	0	10
5	12	8	3	10	0	5	3	2	10	2	8	3	5	1	8
6	9	3	5	5	2	6	1	1	8	3	5	4	3	5	2
7	7	4	2	3	4	4	1	0	6	2	2	3	4	2	3
8	11	8	3	6	3	7	3	0	11	8	2	2	4	2	4
9	5	1	4	3	2	5	0	1	4	1	4	1	2	0	3
10	4	2	2	4	0	3	0	0	4	0	4	0	3	0	3
11	5	3	0	1	2	3	1	1	4	4	1	0	4	0	3
12	6	1	3	4	1	5	1	0	6	1	3	4	1	2	3
13	9	4	4	2	6	6	3	0	9	6	3	3	3	4	3
14	5	1	3	3	0	2	1	0	4	1	2	0	2	0	2
15	6	4	0	4	2	3	3	1	3	3	3	0	5	1	5
16	9	2	6	6	3	6	3	1	8	1	7	3	2	3	3
17	4	1	1	3	1	3	1	1	3	2	1	1	2	1	2
18	7	4	1	4	3	3	2	2	5	4	1	3	2	1	3
19	5	2	3	5	0	3	1	0	5	1	3	3	1	3	2
20	6	4	0	4	2	4	0	1	5	5	1	3	3	2	2
Total	**133**	**67**	**45**	**84**	**37**	**83**	**30**	**15**	**113**	**51**	**65**	**37**	**56**	**31**	**67**

TABLE III
SEN SLOPES FOR YEARLY AVERAGE METEOROLOGICAL PARAMETERS

AER	Tx, °C	Tn, °C	RHm, %	WS, km h^{-1}	SR, MJ m^{-2} d^{-1}	MRF, mm	NRD
2	0.02	0.03	0.10	-0.14	-0.01	-0.34	-0.02
3	0.00	-0.04	-0.08	-0.03	0.02	0.12	0.01
4	0.02	0.04	0.11	-0.08	-0.02	-0.36	-0.02
5	0.01	0.04	0.03	-0.12	-0.04	0.02	-0.01
6	-0.02	-0.01	0.25	-0.11	-0.02	0.09	0.01
7	0.00	0.00	0.00	-0.11	0.02	-0.41	-0.03
8	0.02	-0.01	0.10	-0.11	0.02	-0.06	-0.01
9	0.00	0.00	0.26	-0.17	-0.02	0.14	0.00
10	-0.01	0.01	0.08	-0.12	-0.04	-0.35	-0.01
11	0.02	0.00	0.21	-0.06	0.01	-0.59	-0.02
12	-0.02	0.01	0.26	-0.07	-0.02	0.54	-0.01
13	0.02	0.00	0.09	-0.11	-0.01	0.19	0.00
14	-0.01	0.01	0.01	-0.14	-0.02	-0.10	-0.01
15	0.06	0.02	0.11	-0.04	-0.02	-1.52	-0.03
16	-0.04	0.02	0.05	-0.03	-0.04	1.07	0.09
17	-0.10	-0.01	0.16	-0.10	-0.07	0.37	0.07
18	-0.02	-0.05	-0.07	-0.02	0.01	-5.00	-0.01
19	0.03	0.02	0.01	-0.17	0.00	0.04	0.00
20	0.02	0.01	0.08	-0.12	0.02	0.18	0.00

AER = agro-ecological regions, Tx = maximum temperature, Tn = minimum temperature, RHm = mean relative humidity, WS = wind speed, SR = solar radiation, MRF = monthly rainfall, and NRD = no. of rainy days in a month.

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