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Trend Analysis of Air Temperature Time Series by Mann Kendall Test - A Case Study of Upper Ganga Canal Command (1901-2002)

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Authors' contributions

This work was carried out in collaboration between all authors. Author NM with the study performed the statistical analysis, result and manages the draft of the paper. Authors DK and RS managed the analyses the result and guided for the study. Author KK helped in the statistical analysis and in writing the manuscript. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Worldwide climatologists are investigating to find a possible relation of climate change with anthropogenic behavior by studying trends in different climatic parameters. However, the changes in temperature are not equal for all regions especially in India and have localized intensity and must be quantified locally to manage the natural resources. Aim of the study is to determine trend in annual mean and monthly Temperature time series using nonparametric methods (i.e. the Mann–Kendall and Sen's T tests). The magnitudes of trend in a Temperature time series have been estimated by Sen's estimator method. Auto correlation effect is reduced from the Temperature series before applying the Mann–Kendall test. In the present study, an investigation has been made to study the spatial and temporal variability in the maximum, the minimum and the mean air temperatures of Upper Ganga Canal Command located in Uttar Pradesh and Uttarakhand on monthly, annual and seasonal series from 1901 to 2002. The annual mean, maximum and minimum temperatures have increased by 0.60ºC, 0.60ºC and 0.62ºC, respectively, over the past 101 years. On a seasonal basis, the winters are warmer than summers. The temperature decreased during the less urbanized period of 1901 to 1951 and increased

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during the more urbanized period of 1961 to 2002. It is also found that the minimum temperature increased at higher rate (0.42ºC) followed by the mean (0.36ºC) and the maximum (0.32ºC) air temperatures, during the more urbanized period.

Keywords: Air temperature; non-parametric tests; trend analysis; auto correlation; mann–kendall and sen's t tests.

1. INTRODUCTION

Concurrence of scientific evidence shows that climate change has begun to manifest itself, globally, in the form of increased downpours and storms, rising temperature and sea level, retreating glaciers, etc. And the *Report of Fourth Assessment of the Inter-governmental Panel on Climate Change* [1] shows that the global mean surface air temperature increased by 0.74ºC while the global mean sea surface temperature (SST) rose by 0.67ºC over the last century. In India the increasing trend is found in the annual mean temperature, annual maximum temperature and annual minimum temperature [2-6]. Few research studies have been conducted separately on various cities in India [7,8] and found the mix trends in temperature series. In regional context, it has been shown diurnal asymmetry of temperature trends, indicating that the warming over India was solely contributed by maximum temperature [4]. It was emphasized on the temporal and spatial changes in temperature and temperature over several regions of India [3,9]. Comprehensive analysis was provided for extreme temperature events during Indian monsoon period with increase (decrease) in the frequency and magnitude of extreme (moderate) rain events over central India [10]. In recent studies, an increasing trend was indicated in the number of short spell heavy rain elements and decreasing trend in the occurrence of long spell rain events in India [9]. Further, it has been shown that changes in indices of climatic extremes associated with temperature and precipitation over central and south Asia [11]. Analysis of global observed changes in daily climate extremes of temperature and precipitation shows widespread significant changes in temperature extremes associated with warming [12]. Over the mountainous regions, such as the Swiss [[and Polish Alps, the Rockies [13,14], [15-19] and Andes [20,21] studies have shown significant increase in the surface air temperatures. In the mountainous region of the Himalayas, a limited number of studies in Nepal, covering some parts of the Himalayas and Tibet have also revealed similar trends based on earlier publications [22-24]. It was illustrated pre-monsoon temperature cooling over the WH during the latter part of the 20th century [25]. It was found that the time series of temperature for the period 1851–1975 over Nepal was characterized by decadal variations but no long-term trends [26]. Also, it was noted that the spring snow cover area has been declining and snow has been melting faster from winter to spring after mid 1990s over the western Himalayas region based on satellite derived data for the period 1986–2000 [27]. The effects of climatic change and variability have been analyzed by many researchers in terms of the availability of freshwater which is the prime concern for the last half-century, because of higher demographic pressure leading to climatic variability [28], [29-32]. The problem is more flimsy in India and China where population is very high and posing continuous threat to the fresh water. It was reported that these two countries use about 40% of global freshwater for the purpose of irrigation [33]. Some parts of the French Mediterranean area, studied by are sensitive to the climate change [34]. The main objective of this study to find out the monotonic trend (both for monthly and annual) of air temperature by using Mann-Kendall Test, for the Upper Ganga Canal Command Area in the districts of Uttarakhand and Uttar Pradesh.

2. METHODOLOGY

2.1 Study Area

The Upper Ganga Canal (UGC) system commissioned as far back as 1854-55 has its origin from the mythological Ganga. The Ganga rises in the Gangotri glacier in the Himalayas at an altitude of 7010 meter above mean sea level in the Uttarkashi district of Uttraranchal. The river is called Bhagirathi at its source. Descending down the valley it is joined by the Alaknanda at Dev Prayag; the Bhagirathi and Kharak at Satopanth. After the confluence with the Alakananda, river is called the Ganga.

Upper Ganga Canal was conceived & constructed by Proby T. Cautley during the period 1840-1854. In the beginning one of the branches of the river - a natural channel flowing near Haridwar - was made use of, to divert practically the entire winter flow by construction of temporary obstructions across other branches. This arrangement continued to work for almost fifty long years. With increase in demand, the state took up construction of permanent headwork in 1913 and completed it in 1920. It consisted of a weir about 550m long fitted with 1.8 m high falling shutters & located about 3 km upstream of old regulator. The UGC system then comprised 910 km of main canal and branches and 5280 km of distributaries to provide irrigation facilities in the district of Saharanpur, Muzaffarnagar, Meerut, Bulandshaher & Aligarh (Fig. 1).

The Upper Ganga Canal takes off from the right flank of Bhimgoda barrage which replaced the old weir at Haridwar in 1991-92. The canal with a head discharge of 190 cumecs (6750 cusecs) presently provides irrigation in a gross command area of about 20 lakh ha in 10 districts of Western Uttar Pradesh. There are 4 major cross drainage works in initial 36 km of the main canal. In the revised proposal, the canal has to carry an increased discharge of 295 cumecs (10419 cusecs). The maximum capacity of the canal in head reaches is proposed to be 370 cumecs (13068 cusecs) which includes 20% extra inflow for silt ejector.

The Ganges or Ganga Canal is a canal system that irrigates the Doab region between the Ganges River and the Yamuna River in India. The canal is primarily an irrigation canal, although parts of it were also used for navigation, primarily for its construction materials. Separate navigation channels with lock gates were provided on this system for boats to negotiate falls. Originally constructed from 1842 to 1854, for an original head discharge of 6000 ft^3/s, the Upper Ganges Canal has since been enlarged gradually for the present head discharge of 10,500 ft^3/s ($295m^3/s$). The system consists of main canal of 272 miles and about 4000 miles long distribution channels. The canal system irrigates nearly 9,000 km^2 of fertile agricultural land in ten districts of Uttar Pradesh and Uttarakhand. Today the canal is the source of agricultural prosperity in much of these states, and the irrigation departments of these states actively maintain the canal against a fee system charged from users.

2.2 Trend Analysis

In trend, analysis (Fig. 2) it is necessary to remove the auto correlation effect from the rainfall and temperature time series If there is a positive auto correlation in the time series, then the non-parametric test will suggest a significant trend in a time series that is, in fact, random more often than specified by the significance level [35].

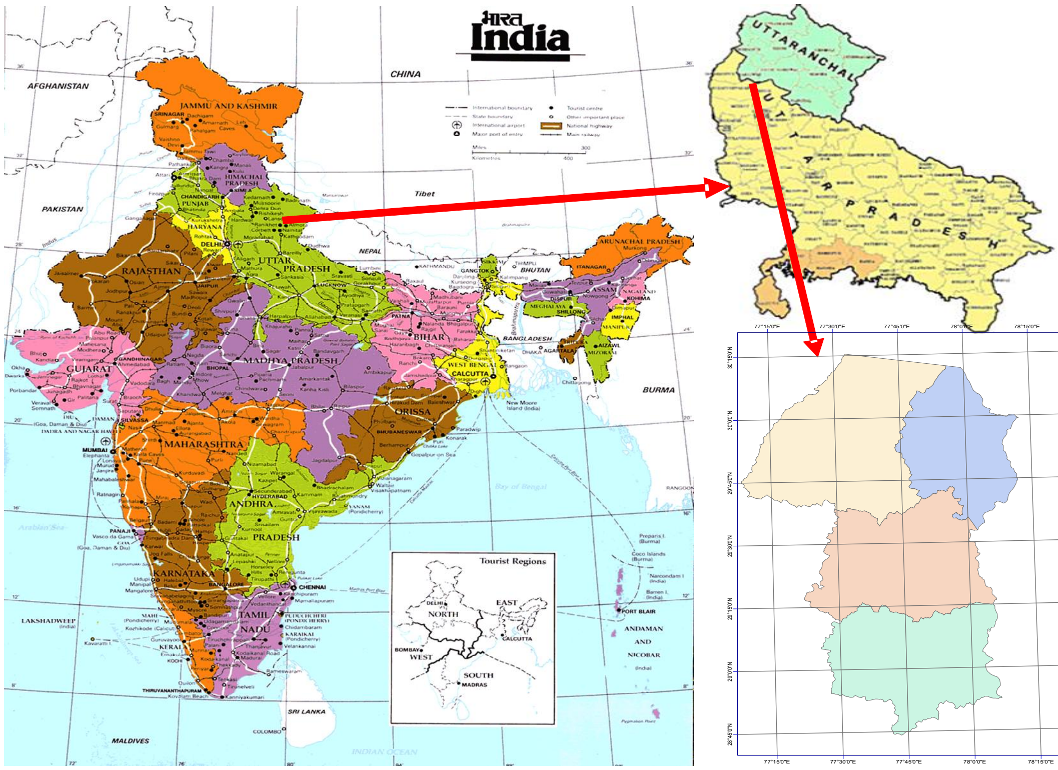

Fig. 1. Location of study area

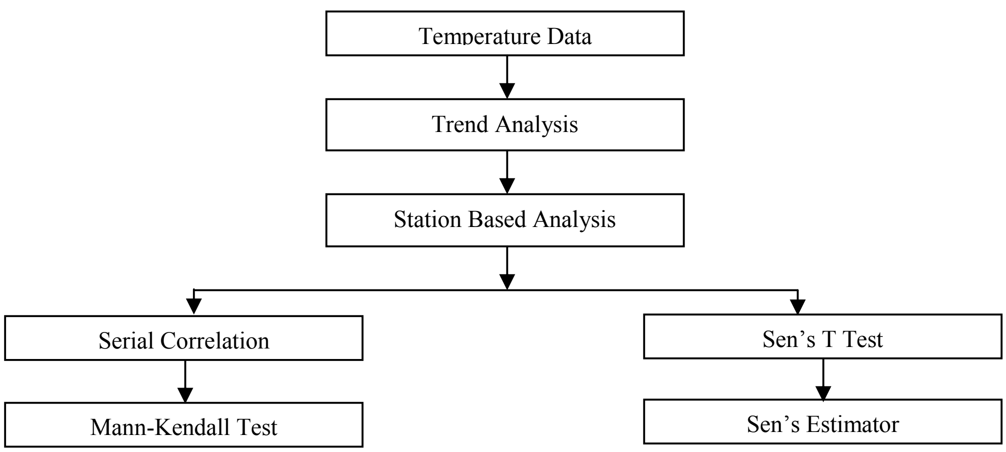

Fig. 2. Procedures of analysis methodology used in Upper Ganga canal command area

For this, it was suggested that the time series should be pre-whitened. The Pre-whiting technique is applied to eliminate the effect of serial correlation on the non-parametric test [35,36].

$$^{pw}x_j = x_j - cx_{i-1} \tag{1}$$

Where ^{pw}x is the pre-whitened data to be used in the subsequent trend analysis and c is the lag-1 serial correlation coefficient as determined directly from the data using Equation 1.

2.2.1 Mann-kendall test

This test, which is usually known as Kendall's *r* statistic, has been widely used to test for randomness against trend in hydrology and climatology. It is a rank-based procedure, which is robust to the influence of extremes and good for use with skewed variables. According to this test, the null hypothesis H_0 states that the deseasonalized data ($x_1, \ldots\ldots\ldots, x_n$) is a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all *k, j* < *n* with *k* = *j*. The test statistic S, which has mean zero and a variance computed by Equation (4), is calculated using Equations (2) and (3), and is asymptotically normal [37].

$$S = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \tag{2}$$

$$\operatorname{sgn}(x_j - x_k) = \begin{Bmatrix} +1 \text{ if } (x_j - x_k) > 0 \\ 0 \text{ if } (x_j - x_k) = 0 \\ -1 \text{ if } (x_j - x_k) < 0 \end{Bmatrix} \tag{3}$$

$$Var(S) = \left[\frac{\mathrm{n(n-1)(2n+5)} - \sum_{\mathrm{t}} t(t-1)(2t+5)}{18} \right] \tag{4}$$

The notation t is the extent of any given tie and t denotes the summation over all ties. When cases arise when the sample size, n, is greater than 10, the standard normal variety, z, is computed by using Equation (5) [38]. In a two-sided test for trend, H_0 should thus be accepted if $|z| \leq z_{1-\alpha/2}$ (here $\alpha = 0.1$) at the level of significance. A positive value of S designates an 'increasing trend'; likewise, a negative designates 'descending trend'

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

2.2.2 SEN'S slope estimator

The magnitude of trend is estimated with the help of Sen's estimator. In this case linear trend is present and hence the true slope is estimated by this method. Here, the slope (T_i) of all data pairs is first computed as [39].

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

In which x_j and x_k are represented as data values at time j and k (j>k) correspondingly. The median of these N values of T_i is considered as Sen's estimator of slope which is given as

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

Sen's estimator is calculated as $Q_i=T_{(N+1)/2}$ if N is odd, and it is computed as $Q_i=[T_{N/2}+T_{(N+2)/2}]/2$ if N is even. Lastly Q_i is estimated by a two sided test at 100 (1-α)% confidence interval and then a true slope can be derived by the non-parametric test Q_i with a positive value indicates an upward or increasing trend and a negative value of Q_i signifies a downward or decreasing trend in the time series.

3. RESULTS

Trend analysis of temperature for the period of 1901-2002 (101 years) in Upper Ganga Canal Command located in Uttar Pradesh and Uttarakhand has been done in the present study. Mann-Kendall and Sen's Slope Estimator have been used for the determination of the temperature trend detection (Fig. 2). The values of Serial correlation coefficients, after pre-whiting the maximum, minimum and average monthly temperature series for 1901-2002 (101 years) of all the four stations are given in Tables 1a, 1b and 1c with their latitudes and longitudes. Pre-whiting is the process of removing any discrepancies in the data acquired from the source and generating a homogenous set of data for further analysis. The values given in Tables 1a, 1b and 1c were then used to run the Z test and get the value of Q and the significance for maximum, minimum and average temperatures of all the four stations, on a monthly and annual basis.

Trend analysis of four cities represent almost same trend in temperature except Saharanpur. From the analysis of average temperature, as computed in Table 2c, it is found that a reverse trend is observed in the months of Monsoon. The term 'reverse' indicating a decreasing trend as opposed to the increasing trend exhibited in the pre-monsoon, post-monsoon and winter seasons.

Temperature variation may also depend upon location of city. Ideally, since Haridwar is near the mountains with most of the Himalayan streams and vegetation, its temperature trend should be impacted by its location [40]. But, as can be observed in Fig. 3a, 3b and 3c, the temperature trend for all the four regions show an equable trend, irrespective of their location.

Decreasing trend in monsoon is also due to more rainfall in monsoon. It is clear that in summer, temperature is increasing (Refer to Tables 2a, 2b and 2c: Under the sub-heading "Summer"). Higher temperature leads to more evaporation and hence, more rainfall in monsoon. This has greater impact on cities near the mountains because that area experiences more rainfall. This eventually results in floods and extreme conditions of climate. But this changing trend also affects cities which are not in the way of easterly monsoon, like Saharanpur. This city receives less rainfall in two seasons, in the months of December and January from northerly cyclones, mostly coming from the Black Sea. But nonetheless, the rate of increase and decrease in temperature, when compared to others is less for this city. Thus, we can say that this represents average conditions.

If we compare Haridwar with Saharanpur with respect to its average temperature, we see that variation for monsoon for Haridwar is between -2.30 to -1.50 while in Saharanpur it is -2.48 to -1.55 (as seen in Table 2c). Overall trend for Pre-Monsoon is increasing in Saharanpur with a maximum of 1.72. Meerut has a maximum increasing trend of 4.16 for winter season. Muzaffarnagar has the maximum decreasing trend of -3.5, when compared to the other three cities. (Refer Table 2c)

We can say that the Earth is going through an intermediate zone of climate change. If this trend continues for as long as hundred years, climate will try to reset its eco-balance system. This shall result in floods, droughts and forest fires. From analysis of these four cities we can say that Earth's climate is cooling down during the hot seasons and warming up during the cold seasons. This indicates longer summers and shorter winters. Trend data represents very less change in variation in the month of October, which for Haridwar is 0.13 and for Muzaffarnagar is -0.16 (Table 2c).

From the analysis of both maximum and minimum temperatures, it was found that they both follow the same trend (Referring Fig. 3a and 3b). From June to September or the monsoon season, the trend is decreasing, while all other months observe an increasing trend.

If this trend continues for several thousand years, then it appears that there will be no effect of Earth's position with respect to the sun on temperature variation, due to air temperature equilibrium. In other words, we can say summer is following the cooling trend during monsoon season while winter is following the warming trend (Fig. 3a and 3b).

The number of months that follow the cooling trend is less than the number of months that follow the warming trend. Therefore, overall, the annual trend is found to be increasing (Tables 2a, 2b, 2c). If on an average day, maximum temperature is high then minimum will also be high, compared to other conditions. Annual trend is increasing in all conditions. The change rate of minimum temperature v/s maximum temperature is maximum i.e. minimum temperature has less variation than maximum temperature trend (Fig. 3a and 3b).

Table 1a. Values of Serial correlation coefficient after pre-whiting the maximum temperature series

Stations	Latitude	Longitude	Annual	Pre-monsoon (Mar-May)	Monsoon (June-Sept)	Post monsoon (Oct-Nov)	Winter (Dec-Feb)
Haridwar	29.9639	78.1732	0.044824733	0.024930171	0.114121246	0.126766302	0.050854697
Meerut	28.9845	77.7064	0.031409295	0.012503711	0.056841044	0.094912336	0.052502896
Muzaffarnagar	29.4667	77.6833	0.036085719	0.020747404	0.096668663	0.102594994	0.037682213
Saharanpur	30.6167	77.9167	0.042512441	0.032528191	0.134356859	0.116409691	0.031977901

Table 1b. Values of Serial correlation coefficient after pre-whiting the minimum temperature series

Stations	Latitude	Longitude	Annual	Pre-monsoon (Mar-May)	Monsoon (June-Sept)	Post monsoon (Oct-Nov)	Winter (Dec-Feb)
Haridwar	29.9639	78.1732	0.059170223	0.01045971	0.127882687	0.166224799	0.099061424
Meerut	28.9845	77.7064	0.043945958	0.00355154	0.054058159	0.090818318	0.093383847
Muzaffarnagar	29.4667	77.6833	0.049816593	0.008043408	0.085890167	0.113851069	0.079736841
Saharanpur	30.6167	77.9167	0.057213131	0.015482229	0.131771951	0.143412778	0.073335258

Table 1c. Values of Serial correlation coefficient after pre-whiting the average temperature series

Stations	Latitude	Longitude	Annual	Pre-monsoon (Mar-May)	Monsoon (June-Sept)	Post monsoon (Oct-Nov)	Winter (Dec-Feb)
Haridwar	29.9639	78.1732	0.056934339	0.014213996	0.109359063	0.152538998	0.076590637
Meerut	28.9845	77.7064	0.041107332	0.003843721	0.044517169	0.105898009	0.07470918
Muzaffarnagar	29.4667	77.6833	0.047126856	0.01027676	0.082102474	0.119503898	0.059644615
Saharanpur	30.6167	77.9167	0.055187652	0.019206425	0.122944437	0.13908958	0.053217161

Maximum, Minimum and Monthly Average Temperature Trend in Upper Ganga Canal Command region is presented station wise (1901-2002) namely: Haridwar, Meerut, Muzaffarnagar, Saharanpur (Tables 2a, 2b and 2c)

Table 2a. Maximum temperature trend in upper Ganga canal command region is presented station wise (1901-2002)

Time series	Haridwar			Saharanpur			Muzaffarnagar			Meerut		
	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q
EB	2.77	**	0.014	2.92	**	0.013	2.89	**	0.014	2.83	**	0.013
MAR	1.35		0.008	1.31		0.008	1.30		0.008	1.33		0.007
APR	1.43		0.008	1.68	+	0.010	1.77	+	0.010	1.82	+	0.009
MAY	0.36		0.002	0.67		0.004	0.47		0.002	0.23		0.001
JUN	-1.20		-0.006	-1.26		-0.006	-1.58		-0.007	-1.84	+	-0.009
JUL	-2.69	**	-0.008	-2.88	**	-0.009	-2.49	*	-0.008	-2.14	*	-0.007
AUG	-1.76	+	-0.004	-1.88	+	-0.005	-1.54		-0.004	-1.10		-0.003
SEP	-2.17	*	-0.006	-2.60	**	-0.007	-2.34	*	-0.007	-1.94	+	-0.006
OCT	0.33		0.001	-0.42		-0.001	-0.01		0.000	0.34		0.001
NOV	1.93	+	0.006	1.96	*	0.006	2.27	*	0.007	2.46	*	0.008
DEC	2.52	*	0.010	2.65	**	0.009	3.19	**	0.010	3.29	**	0.010
Annual	1.08		0.002	1.11		0.002	1.24		0.002	1.46		0.002
Pre-monsoon (Mar-May)	1.58		0.006	1.92	+	0.007	1.93	+	0.006	1.89	+	0.006
Monsoon (June-Sept)	-2.43	*	-0.005	-2.98	**	-0.006	-3.25	**	-0.007	-3.06	**	-0.006
Post-monsoon (Oct-Nov)	1.44		0.004	1.19		0.002	1.35		0.003	1.83	+	0.004
Winter (Dec-Feb)	3.24	**	0.009	3.39	***	0.009	3.55	***	0.009	3.63	***	0.009

Table 2b. Minimum temperature trend in upper ganga canal command region is presented station wise (1901-2002)

Time series	Haridwar			Saharanpur			Muzaffarnagar			Meerut		
	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q
JAN	1.71	+	0.008	1.60		0.006	1.43		0.006	1.41		0.006
FEB	2.82	**	0.013	2.87	**	0.013	3.04	**	0.013	3.08	**	0.013
MAR	1.50		0.008	1.48		0.008	1.42		0.008	1.45		0.008
APR	1.60		0.008	1.82	+	0.010	1.82	+	0.009	1.78	+	0.010
MAY	0.61		0.003	0.82		0.004	0.57		0.003	0.36		0.002
JUN	-1.62		-0.007	-1.65	+	-0.007	-1.86	+	-0.008	-2.07	*	-0.009
JUL	-2.64	**	-0.007	-2.76	**	-0.008	-2.51	*	-0.008	-2.28	*	-0.007
AUG	-1.19		-0.003	-1.33		-0.003	-0.97		-0.002	-0.48		-0.001
SEP	-2.18	*	-0.005	-2.51	*	-0.006	-2.10	*	-0.006	-1.78	+	-0.005
OCT	0.17		0.000	-0.62		-0.002	-0.35		-0.001	0.09		0.000
NOV	1.56		0.005	1.68	+	0.005	2.09	*	0.006	2.34	*	0.007
DEC	2.91	**	0.011	3.01	**	0.010	3.48	***	0.010	3.61	***	0.011
Annual	1.34		0.002	1.27		0.002	1.36		0.002	1.69	+	0.003
Pre-monsoon (Mar-May)	1.64		0.006	1.83	+	0.007	1.78	+	0.006	1.64		0.006
Monsoon (June-Sept)	-2.63	**	-0.005	-2.87	**	-0.006	-3.45	***	-0.006	-3.13	**	-0.006
Post-monsoon (Oct-Nov)	1.43		0.003	0.95		0.002	1.36		0.003	1.67	+	0.004
Winter (Dec-Feb)	3.93	***	0.009	4.16	***	0.009	4.33	***	0.009	4.33	***	0.009

Table 2c. Monthly average temperature trend in upper Ganga canal command region is presented station wise (1901-2002)

Time series	Haridwar			Saharanpur			Muzaffarnagar			Meerut		
	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q	Test Z	Signific.	Q
JAN	1.49		0.007	1.53		0.006	1.46		0.006	1.48		0.005
FEB	2.90	**	0.014	3.02	**	0.014	3.01	**	0.014	3.12	**	0.014
MAR	1.42		0.008	1.44		0.008	1.39		0.008	1.38		0.007
APR	1.59		0.009	1.72	+	0.010	1.87	+	0.010	1.87	+	0.010
MAY	0.50		0.002	0.74		0.003	0.42		0.002	0.27		0.001
JUN	-1.50		-0.007	-1.55		-0.007	-1.82	+	-0.008	-2.06	*	-0.009
JUL	-2.76	**	-0.008	-2.90	**	-0.008	-2.53	*	-0.008	-2.17	*	-0.007
AUG	-1.38		-0.003	-1.64		-0.004	-1.27		-0.003	-0.72		-0.002
SEP	-2.30	*	-0.006	-2.48	*	-0.007	-2.34	*	-0.006	-1.93	+	-0.006
OCT	0.13		0.000	-0.43		-0.001	-0.16		0.000	0.20		0.001
NOV	1.94	+	0.006	1.91	+	0.006	2.19	*	0.007	2.49	*	0.007
DEC	2.84	**	0.010	2.98	**	0.009	3.58	***	0.010	3.74	***	0.011
Annual	1.11		0.002	1.19		0.002	1.45		0.002	1.82	+	0.003
Pre-monsoon (Mar-May)	1.68	+	0.006	1.92	+	0.007	1.93	+	0.007	1.87	+	0.006
Monsoon (June-Sept)	-2.68	**	-0.005	-3.03	**	-0.006	-3.50	***	-0.006	-3.26	**	-0.006
Post-monsoon (Oct-Nov)	1.35		0.003	1.20		0.002	1.52		0.003	1.89	+	0.005
Winter (Dec-Feb)	3.67	***	0.009	3.91	***	0.009	4.11	***	0.009	4.16	***	0.009

*Note:-*** if trend at α = 0.001 level of significance, ** if trend at α = 0.01 level of significance ,* if trend at α = 0.05 level of significance, + if trend at α = 0.1 level of significance*

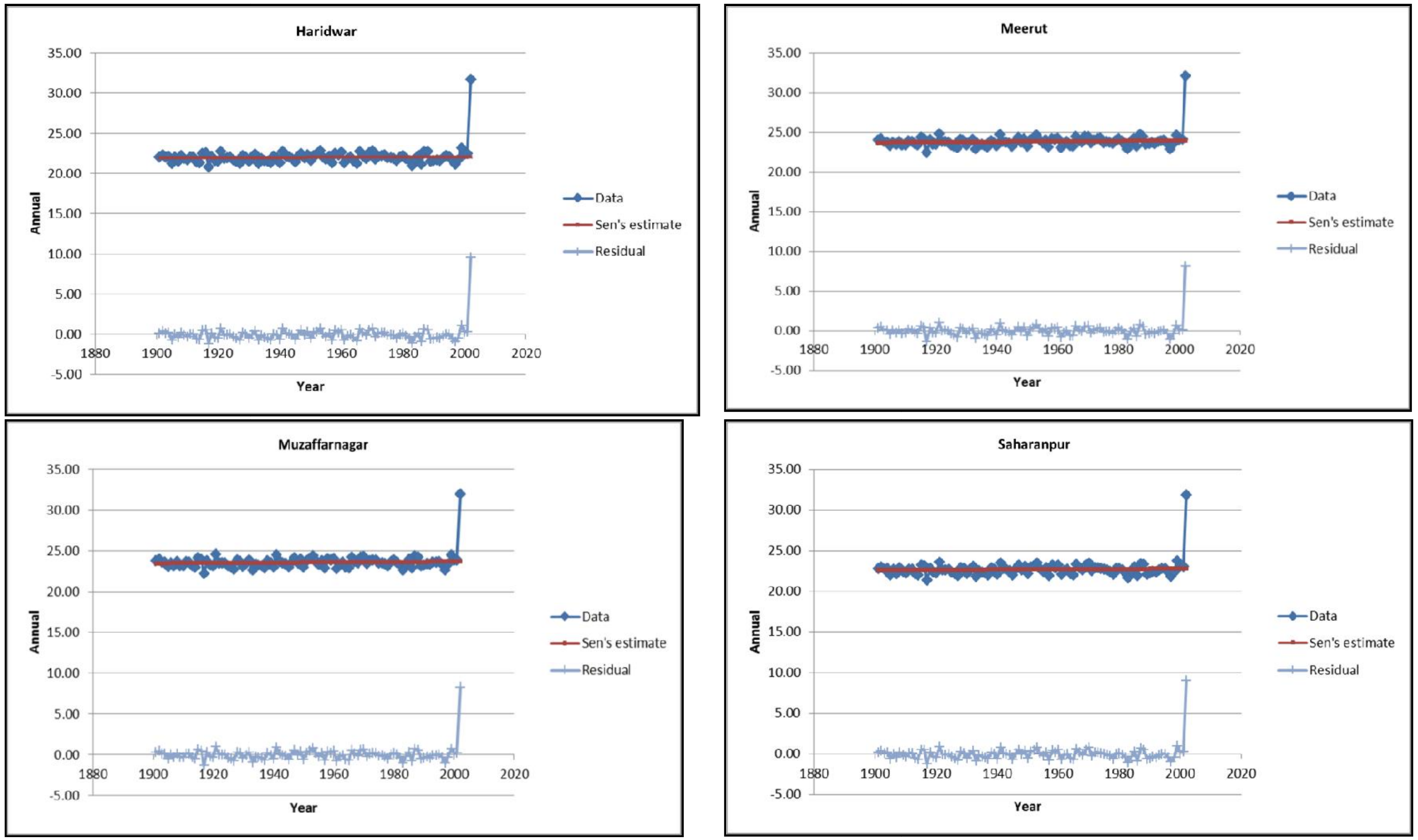

Fig 3a. Maximum temperature trend in upper Ganga canal command region is presented station wise (1901-2002)

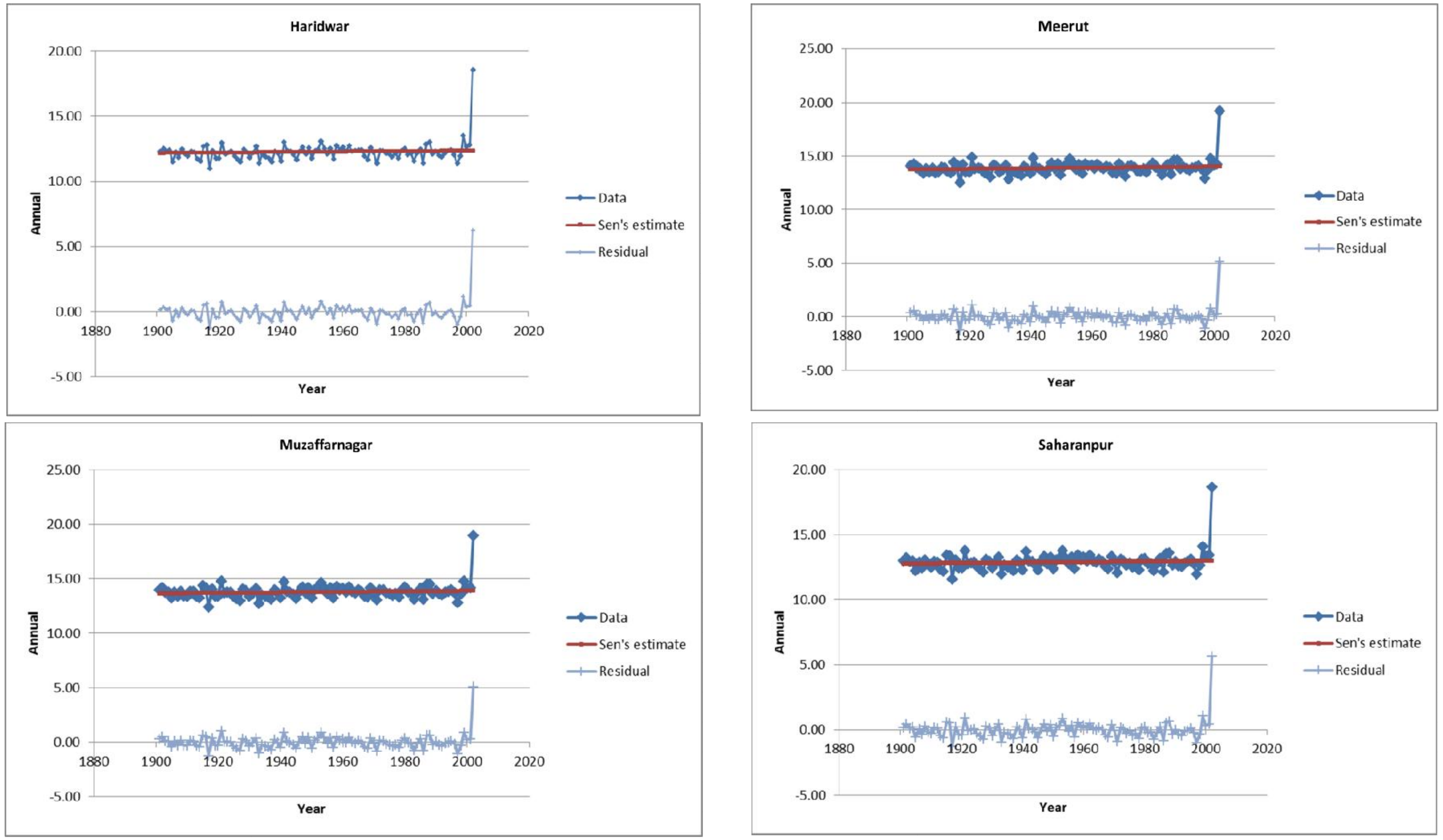

Fig. 3b. Minimum temperature trend in upper Ganga canal command region is presented station wise (1901-2002)

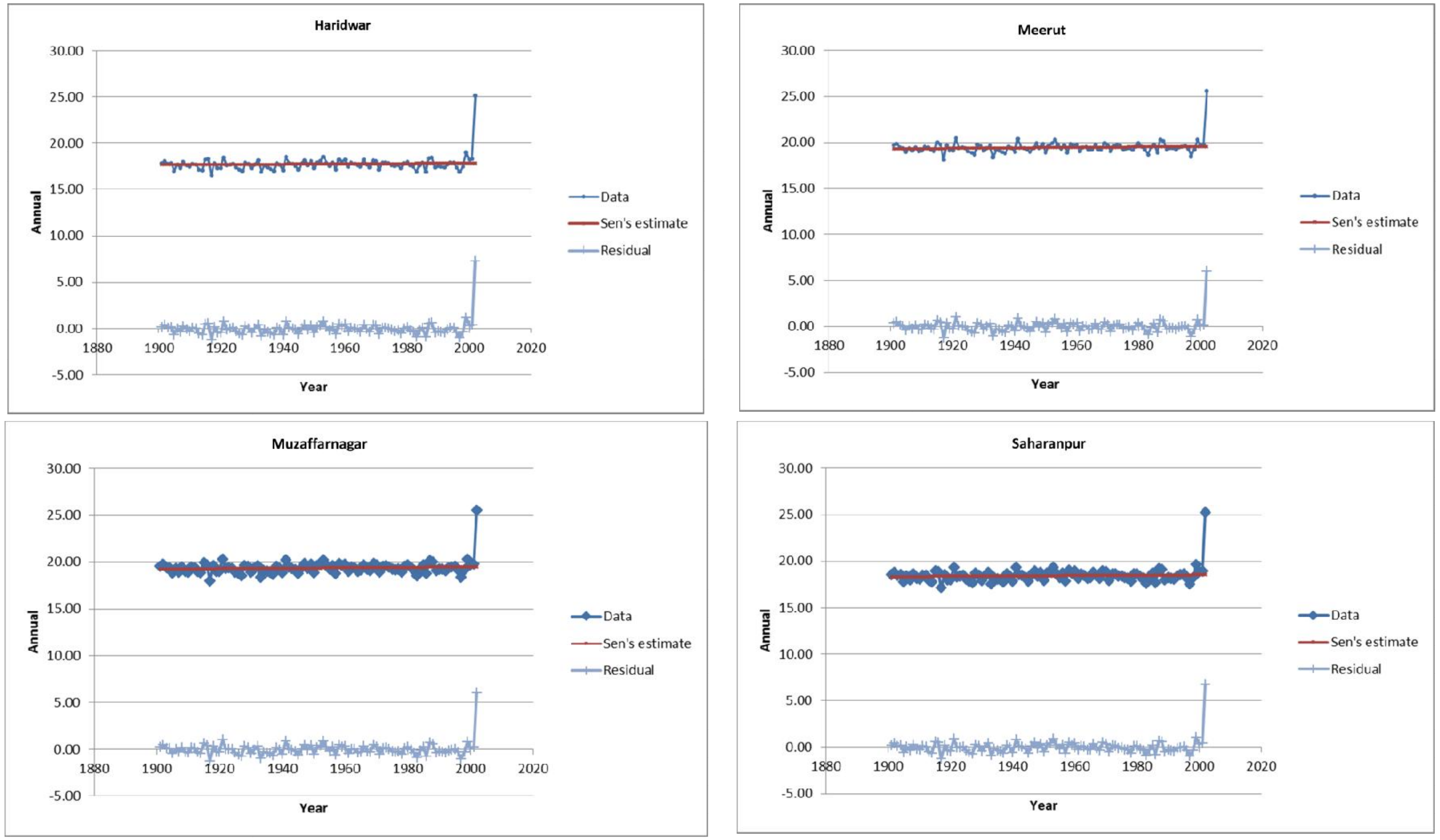

Fig 3c. Average temperature trend in upper Ganga canal command region is presented station wise (1901-2002)

But among the four cities, Meerut is observed to follow the reverse or decreasing trend, i.e. minimum temperature trend is increasing at higher speed than the maximum temperature trend (Fig. 3a and 3b). Very less variation in trend has been found for Saharanpur, which is 0.14 for maximum temperature. Meerut is observed to be warming up with higher speed with an annual rate as high as 1.82 (Table 2c). But conditions are more critical in the month of December with values as high as 3.74 (Table 2c). This is the most affected city as far as climate change is concerned. It lies on the maximum traffic area. Its pollution levels may also be higher than other cities, as it is affected as a result of its location and not by physical parameters which determine local weather.

For Saharanpur variation for maximum temperature is less than minimum temperature. This city also observes a reverse or decreasing trend. Maximum temperature is increasing at a lower speed, but minimum temperature is increasing at a higher speed. For maximum temperature, its trend is 0.14 and for minimum it is 1.27 (Table 2a and 2b). For the monsoon months, maximum cooling affect is found for Saharanpur which is -2.88 for the month of July, in case of maximum temperature (Table 2a). Saharanpur is the only city which follows a warming trend during the monsoon month.

4. CONCLUSION

The study analyzed the temperature data of 101 years from 1901 to 2002 to determine the trend of temperature in the Upper Ganga Canal Command region. As this region is rapidly growing, any change in the temperature trend pattern may have considerable impact on the people of this region. The Z values of the MK Test revealed an increasing trend in temperature. It can, therefore, be concluded that there may be an impact on climate change, contributing to the prolonged and higher temperatures which are rising with time. Similarly, Sen's Slope Estimator has also estimated an increasing magnitude of slope for the temperature data. This study was done to find the monotonic trend (annual) for temperature time series, which was found to be increasing (positive) with level of non-significance trend.

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COMPETING INTERESTS

Authors declare that there are no competing interests.

REFERENCES

1. IPCC. Climate change: Climate change impacts, adaptation and vulnerability. Working Group II contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Summary for policymakers. 2007;23.
2. Arora M, Goel NK, Singh P. Evaluation of temperature trends over India. Hydrological Sciences Journal. 2005;50(1):81-93.
3. Dash SK, Hunt JCR. Variability of climate change in India, Current Science. 2007;93(6):782-788.

4. Kothawale DR, Rupa Kumar K. On the recent changes in surface temperature trends over India. Geophysical Research Letters. 2005;32. L18714, DOI: 10.1029/2005GL023528.
5. Pant GB, Kumar KR: Climate of South Asia. Chichester: John Wiley & Sons Ltd; 1997.
6. Sinha Ray KC, De US. Climate change in India as evidenced from instrumental records. Bulletin of the World Meteorological Organization. 2003;52:53–59.
7. Gadgil A, Dhorde A. Temperature trends in Twentieth Century at Pune, India. Atmospheric Environment. 2005;35(39):6550-6556.
8. Dhorde A, Dhorde A, Gadgil AS. Long Term temperature trends at four largest cities of India during the twentieth century; J. Indian Geophys. Union. 2009;13:85-97.
9. Dash SK, Jenamani RK, Kalsi SR, Panda SK. Some evidence of climate change in twentieth-century India, Climatic change. 2007;85:299-321.
10. Goswami BN, Venugopal V, Sengupta D, Madhusoodanan MS, Xavier PK. Increasing trend of extreme rain events over India in a warming environment. Science. 2006;314:1442–1445. DOI:10.1126/science.11320.
11. Klein Tank AMG, Peterson TC, Quadir DA, Dorji S, Zou X, et al. Changes in daily temperature and precipitation extremes in central and south Asia. Journal of Geophysical Research; 2006. 111:D16105.
12. Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG et al. J. L. Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research – Atmospheres; 2006. 111, D05109.
13. Beniston M. Climatic change in mountainous regions: a review of possible impacts. Climate Change. 2003;9:5–31.
14. Beniston M, Diaz FD, Bradley RS. Climatic change at high elevation sites: An overview. Climate Change. 1997;36:233–251.
15. Brown TB, Barry RG, Doesken NJ. An exploratory study of temperature trends for Colorado paired mountain-high plains stations. American Meteorological Society sixth conference on mountain meteorology, Portland, OR. 1992;181–184.
16. David GV, Gareth JM, Connolley WM, Parkinson C, Mulavaney R, Hodgson DA, et al. Recent rapid regional climatic warming on the Antarctic Peninsula. Climate Change. 2003; 60:243–274.
17. Diaz HF, Bradley RS. Temperature variations during the last century at high elevation sites. Climate Change. 1997;6:253–279.
18. Rebetez M. Summer 2003 maximum and minimum daily temperature over a 3,300 m altitudinal range in the Alps. Climate Res. 2004;27:45–50.
19. Wibig J, Glowicki B. Trends in minimum and maximum temperature in Poland. Climate Res. 2002;20:123–133.
20. Villaba R, Lara A, Boninsegna JA, Masiokas M, Delgado S, Aravena JC et al. Large-scale temporal changes across the southern Andes: 20th century variations in the context of the past 400 years. Climate Change. 2003;59:177–232.
21. Vuille M, Bradley RS, Werner M, Keimig F. 20th century climate change in the tropical Andes: observations and model results. Climate Change. 2003;59:75–99.
22. Li C, Tang M. Changes of air temperature of Qunghai–Xizang plateau and its neighbourhood in the past 30 years. Plateau Meteorol. 1986;5:322–341.
23. Pant GB, Borgaonkar HP. Climate of the hill regions of Uttar Pradesh. Himal Res Dev. 1984;3:13–20.
24. Seko K, Takahashi S. Characteristics of winter precipitation and its effects on glaciers in Nepal Himalaya. Bull Glacier Res. 1991;9:9–16.
25. Thompson LG, Yao T, Mosley-Thompson E, Davis ME, Henderson KA, Lin PN. A high resolution millennial record of the South Asian monsoon from Himalayan ice cores. Science. 2000;289:16–19.

26. Yadav RR, Park W-K, Singh J, Dubey B. Do the western Himalaya defy global warming? Geophys Res Lett; 2004. 31:L17201.
27. Kripalani RH, Inamdar SR, Sontakke NA. Temperature variability over Bangladesh and Nepal; Comparison and Connection with features over India Int. J. Clomatol; 1996.
28. Kripalani RH, Kulkarni A, Sabade SS, Khandekar ML. Indian monsoon variability in a global warming scenario. Natural Hazards. 2003;29:189-206.
29. Gleick PH. Water in Crisis: A Guide to the World's Fresh Water Resources. Oxford University Press. 1993;504.
30. Gleick PH. The World's Water 2000–2001: The Biennial Report on Freshwater Resources. Island Press, Washington, D.C.; 2000.
31. Milliman JD, Farnsworth KL, Jones PD, Xu KH, Smith LC. Climatic and anthropogenic factors affecting river discharge to the global ocean, 1951–2000. Global and Planetary Change. 2008;62(3–4):187–194.
32. Shiklomanov IA, Rodda JC. World Water Resources at the Beginning of the Twenty-First Century (International Hydrology Series). Cambridge University Press. 2003;435.
33. Vörösmarty CJ. Green P. Salisbury J. Lammers RB. Global water resources: Vulnerability from climate changes and population growth. Science. 2000;289:284–288.
34. Chaouche K, Neppel L, Dieulin C, Pujol N, Ladouche B, Martin E, et al. Analyses of precipitation, temperature and evapotranspiration in a French Mediterranean region in the context of climate change. C.R. Geoscience. 2010;342:234–243.
35. Kulkarni A, Von Storch H. Monte Carlo experiments on the effect of serial correlation on the Mann–Kendall test of trend. Meteorologische Zeitschrift. 1995;4(2):82–85.
36. Von Storch H, Navarra A. Analysis of Climate Variability—Applications of Statistical Techniques. Springer-Verlag: New York; 1995.
37. Hirsch RM, Slack JR. Non-parametric trend test for seasonal data with serial dependence. Water Resources Research. 1984;20(6):727–732.
38. Douglas EM, Vogel RM, Kroll CN. Trends in floods and low flows in the United States: impact of spatial correlation. Journal of Hydrology. 2000;240:90–105.
39. Sen PK. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association. 1968;63:1379–1389.
40. James Hansen, Sergej Lebedeff. Global Trends of Measured Surface Air Temperature Journal of Geophysical Research. 1987;92:13,345-13,372.

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