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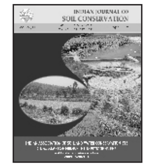

Homogeneity analysis of climatic parameters for the Gomti river basin

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ABSTRACT

Homogeneity in time series data of mean temperature, minimum temperature, maximum temperature, and annual rainfall for 14 districts of Gomti basin were analysed using homogeneity tests, namely Pettitt test, Standard Normal Homogeneity Test (SNHT), Buishand test and Von Neumann Ratio (VNR) test. The time series were classified as - useful, doubtful or suspect based on the test analysis. Results showed that a change point was observed during 1992 for 10 districts and 1993 for 4 districts in the time series of minimum temperature. It was observed that 14.29% of the minimum temperature data in the basin was classified as 'doubtful' and 85.71% as 'suspect'. No change point years were observed for mean and maximum temperature series and both series were classified as 'useful'. In case of annual rainfall, only Buishand test revealed a change point in 1985 for Lucknow and Unnao districts and in 1986 for Pratapgarh district and thus can also be classified as 'useful'.

1. INTRODUCTION

Studies on climate change and climate variability have gained significant importance in the last few decades. Increase in global surface temperature, rise in global mean sea level and change in precipitation patterns are the main characteristics of a changing climate (IPCC, 2013). Thus, detection of trends and change points in time series of temperature and rainfall has gained widespread interest all over the world (Zarenistanak *et al.*, 2014). However, it has been found that the changes in temperature and precipitation are not globally uniform and considerable spatial and temporal variations may exist at the regional level (Yue and Hashino, 2003; Mishra *et al.*, 1999 and Dash *et al.*, 2013).

Testing the time series data of climatic parameters for homogeneity is important for detection of variability trends. Homogenous data indicates that the measurement of the data was done using the same instruments and environmental conditions (Kang and Yusof, 2012). Inhomogeneity in time series data are normally caused by relocations of recording station, changes in measuring techniques and changes in observing practices (Wijngaard *et al.*, 2003). However, if the data was recorded continuously at the same station, same time with the same instrument, inhomogeneity may be triggered by climate variability.

Numerous attempts have been made throughout the world to find out the inhomogeneity in climatic parameters using non-parametric statistical methods. The non-parametric method does not require the time series data to be normally distributed and can accommodate outliers (Hamed and Rao, 1998). The Pettitt test is a common non-parametric test used for detecting the change point in the mean value of a time series (Pettitt, 1979 and Xie *et al.*, 2014). Rainfall data of climatic zones in Nigeria, collected for 90 years (1910-1999) were analyzed using the Pettitt test by Ogungbenro and Morakinyo (2014). They reported transitions from dry to wet in all climatic zones between 1969 and 1972. In the Abay/Upper Blue Nile basin in Ethiopia, three hydrometeorological variables, precipitation, temperature and streamflow were analyzed by Tekleab *et al.* (2013) using the Pettitt test to show that change points in the series varied considerably. Taxak *et al.* (2014) used the Pettitt test to detect the change point in annual and seasonal time series of rainfall in Wainganga river basin in Central India during the period of 1901-2012. They reported that 1948 was the most probable year of change for annual and monsoonal rainfall. Annual and monthly precipitation and river discharge time series for 56 years for 17 rain gauge stations and 13 hydrometric stations located in Southwestern Iran were analyzed using the Pettitt test to show significant change points in the 1970s (Sabzevari *et al.,* 2015). Radivojevic *et al.* (2015) used the Pettitt test along with the SNHT, Buishand Test and VNR test to detect a break point year in air temperature in the Sokobanja basin in Eastern Serbia. They reported that change points were observed in 1991 and 1997.

Wijngaard *et al.* (2003) used four homogeneity tests - SNHT, Buishand test, Pettitt test and VNR test for temperature and rainfall series from the European Climate Assessment (ECA) dataset for the period from 1901-99. The results were classified as - useful, doubtful and suspect, based on the number of tests rejecting the null hypothesis. The variables used for testing were annual mean of diurnal temperature range, annual mean of the absolute day-to-day differences and the annual number of wet days. They reported that in the period from 1901-99, 94% of the temperature series and 25% of the precipitation series were found to be 'doubtful' or 'suspect'.

Kang and Yusof (2012) used the classification methodology adopted by Wijngaard *et al.* (2003) to check for homogeneity in the rainfall series from 33 stations in peninsular Malaysia. They reported that the annual mean and annual maximum rainfall for all the stations are homogenous and 'useful'. In case of annual median rainfall, 12.12% of the stations were 'doubtful' while 84.84% were homogenous and 'useful'.

Evaluation of homogeneity in data sets is important to ensure reliability and suitability of the time series for studies of climate change and variability (Tuomenvirta, 2002). This paper adopted the methodology of Wijngaard *et al.* (2003) to assess homogeneity in climatic parameters in 14 districts of the Gomti basin of India. The variables tested were annual mean, annual maximum and annual minimum temperatures from 1971-2007, and annual rainfall from 1971-2011. This study will help the researchers to identify the year and districts where break points were observed. This will help in further investigation and corroborate it with spatial and temporal climate variability in Gomti basin.

2. MATERIALS AND METHODS

The Gomti river basin is part of the Indo-Gangetic plains of India (Mali *et al.,* 2015) (Fig. 1). The basin extends between the Latitudes of 25°23'13" to 28°46'59"N and Longitudes of 79°57'34" to 83°11'14"E (Mali, 2015) and has a varying elevation of 58 to 238 m above mean sea level (msl) (Abeysingha *et al*., 2014). Comprising an area of 31240 km^2 in the state of Uttar Pradesh (Mali, 2015), the climate of the Gomti basin ranges from semi-arid to sub-humid tropical. The basin receives an average annual rainfall of 850 to 1100 mm, 75% of which occurs in the monsoon season (middle of June to middle of October) (Rai *et al.,* 2009). The average minimum and maximum temperature ranges from 4.5 to 46.0°C. The mean daily sunshine is 8 hours and the relative humidity varies between 10-90% (Mali, 2015).

Data Used

For analysis of trend and homogeneity in time series, a minimum of 30 years climatic data is

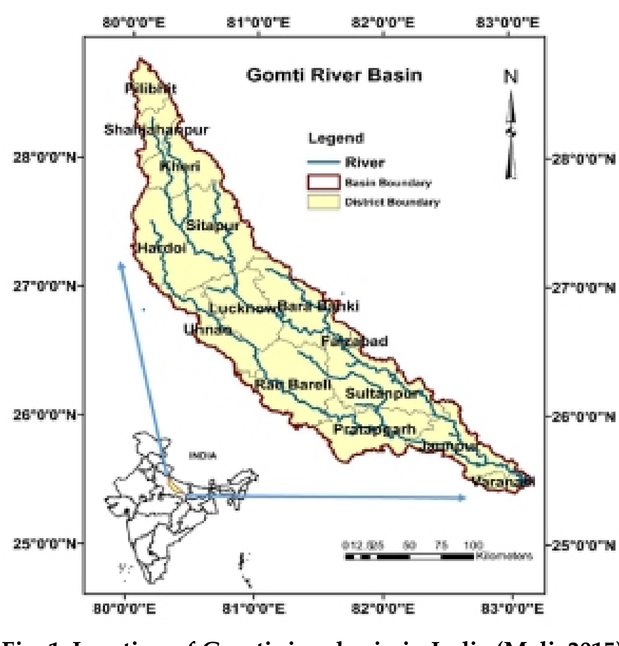


Fig. 1. Location of Gomti river basin in India (Mali, 2015)

required. Daily meteorological data of 37 years consisting of minimum and maximum temperature for the period of 1971-2007 and daily rainfall data of 41 years for the period of 1971-2011 for each district of Gomti basin available with NICRA (NICRA-ICAR, 2013) were used. Annual means were computed from the daily data of temperature and annual rainfall was computed from the daily rainfall data for each district of the Gomti basin to test the homogeneity in annual time series data. The means of climatic parameters are presented in Table 1.

Methods of Analysis

The Pettitt test, the SNHT, Buishand test and VNR test were used to detect the change point in each of the testing variables. Descriptions of these are presented in the following paragraphs.

Pettitt Test

A single change-point in the time series with continuous data was calculated by the procedure laid by Pettitt (1979). The Pettitt test is useful since it is more sensitive to breaks in the middle of the time series (Wijngaard *et al.*, 2003). The null hypothesis [H_0: The T variables follow one or more distributions that have the same location parameter (no change)], is tested against the alternative hypothesis H_a: a change point exists. First the U_k statistic is computed by eq. 1.

Table: 1
Means of climatic parameters of Gomti basin

District	Mean of maximum temperature (1971-2007) (°C)	Mean of minimum temperature (1971-2007) (°C)	Mean of annual rainfall (1971-2011) (mm)
Bara Banki	31.80	18.99	994
Faizabad	31.91	18.97	978
Hardoi	31.56	18.81	888
Jaunpur	31.98	18.97	898
Kheri	30.56	17.98	1088
Lucknow	31.83	18.95	872
Pilibhit	29.82	17.31	1035
Pratapgarh	32.12	18.95	871
Rae Bareli	31.94	19.04	878
Shahjahanpur	30.80	18.11	964
Sitapur	31.56	18.83	988
Sultanpur	31.91	19.00	960
Unnao	31.90	18.94	840
Varanasi	31.93	18.97	898

$$U_k = 2\sum_{i=0}^{n} m_i - k(n+1) \quad ...(1)$$

Where, m_i is the rank of the i_{th} observation when the values $x_1, x_2, \ldots, x_n$ in the series are arranged in ascending order and k takes values from 1, 2,……., *n*. Then the non-parametric statistic, K is defined by eq. 2:

$$\max_{1 \le k \le n} |U_k| \quad ...(2)$$

A change point occurs when U_k attains maximum value of K in a series. The following relation tests the significance of such a change point (eq. 3).

$$K_\alpha = \sqrt{[-1n\,\alpha\,(n^3 + n^2)/6]} \quad ...(3)$$

Where, *n* is the number of observations and α is the level of significance.

Standard Normal Homogeneity Test (SNHT)

A statistic $T(k)$ was described by Alexandersson (1986) to compare the mean of the first *y* years with that of the last (*n-y*) years. The equation can be written as:

$$T_y = y\bar{z}_1 + (n - y)\,\bar{z}_2,\ y = 1, 2, \ldots, n \quad ...(4)$$

Where, $\bar{z}_1 = \frac{1}{y}\sum_{i=1}^{n}\frac{(Y_i - \bar{Y})}{S}$ and

$$\bar{z}_2 = \frac{1}{n-y}\sum_{i=y+1}^{n}\frac{(Y_i - \bar{Y})}{S} \quad ...(5)$$

A break year is located at Y if $T(y)$ reaches a maximum at the year $y = Y$. The test statistic T_0 is given by eq. 6.

$$T_0 = \max_{1 \le y \le n} T_y \quad ...(6)$$

Buishand Test

Adjusted partial sums in this test are given by eq. 7.

$$S_0^* = 0 \quad \text{and} \quad S_k^* = \sum_{i=1}^{k}(Y_i - \bar{Y}),\ k = 1, 2, \ldots, n \quad ...(7)$$

Where, S_k^* is the Buishand test statistic. For a homogenous series, the value of S_k^* will fluctuate around zero. If a break year occurs at y, then the value of S_k^* reaches a maximum (negative shift) or minimum (positive shift). The significance of the shift can be tested by the rescaled adjusted range, R given by eq. 8.

$$R = \frac{(\max_{0 \le k \le n} S_k^* - \max_{0 \le k \le n} S_k^*)}{S} \quad ...(8)$$

The critical values of $R/\sqrt{n}$ are given by Buishand (1982).

Von Neumann Ratio (VNR) Test

This is a test developed by von Neumann (1941) that uses the ratio of mean square successive (year to year) difference to the variance. The test statistic, N is given by eq. 9.

$$N = \frac{\sum_{i=1}^{n-1} (Y_i - Y_{i+1})^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2} \quad ...(9)$$

The expected value $N = 2$ when the series is homogeneous. When the series has a break, then the value of N must be lower than 2, otherwise it indicates that the sample has rapid variation in the mean.

Classification System

Results of homogeneity test are grouped into useful, doubtful and suspect categories depending on the number of tests rejecting the null hypothesis (*i.e.* data are homogenous) (Wijngaard *et al.,* 2003 and Schönwiese and Rapp, 1997). In this study, the null hypothesis was tested at 5% level of significance and grouped into useful, doubtful and suspect categories. Details of the classes are described below.

Class 1: Useful

Of the four tests, if one or none of the tests reject the null hypothesis at 5% significance level, then the series is classified as useful. No clear inhomogeneities are present in the series and it can be suitably used for trend and variability analysis.

Class 2: Doubtful

Of the four tests, if two tests reject the null hypothesis at 5% significance level, then the series is classified as doubtful. There are signals of inhomogeneity and the series should be critically examined before using for analysis.

Class 3: Suspect

If three or all four tests reject the null hypothesis at 5% significance level, then the series is classified as suspect. It is likely that an inhomogeneity is present in the series and the series lacks credibility. This type of series should be ignored for trend and variability analysis.

3. RESULTS AND DISCUSSION

Annual mean, annual minimum and annual maximum temperature from 1971-2007 and annual rainfall from 1971-2011 for all districts of the Gomti basin were tested for homogeneity using the Pettitt test, SNHT, Buishand test and VNR test. The results are summarized below.

Homogeneity in Temperature

The annual maximum temperature and annual mean temperature showed no break point years in any of the tests. These time series can be classified 'useful' and are homogenous for trend and variability analysis.

In case of annual minimum temperature, significant break point years exist in all the districts. The results are presented in Table 2.

Fig. 2 shows the district-wise graphical representation of the break point years in annual minimum temperature in Gomti basin.

Homogeneity in Rainfall

For rainfall, break point years were observed only for 3 districts by Buishand test as depicted in Table 3.

Fig. 3 shows the district-wise graphical representation of the break point years in annual rainfall in Gomti basin.

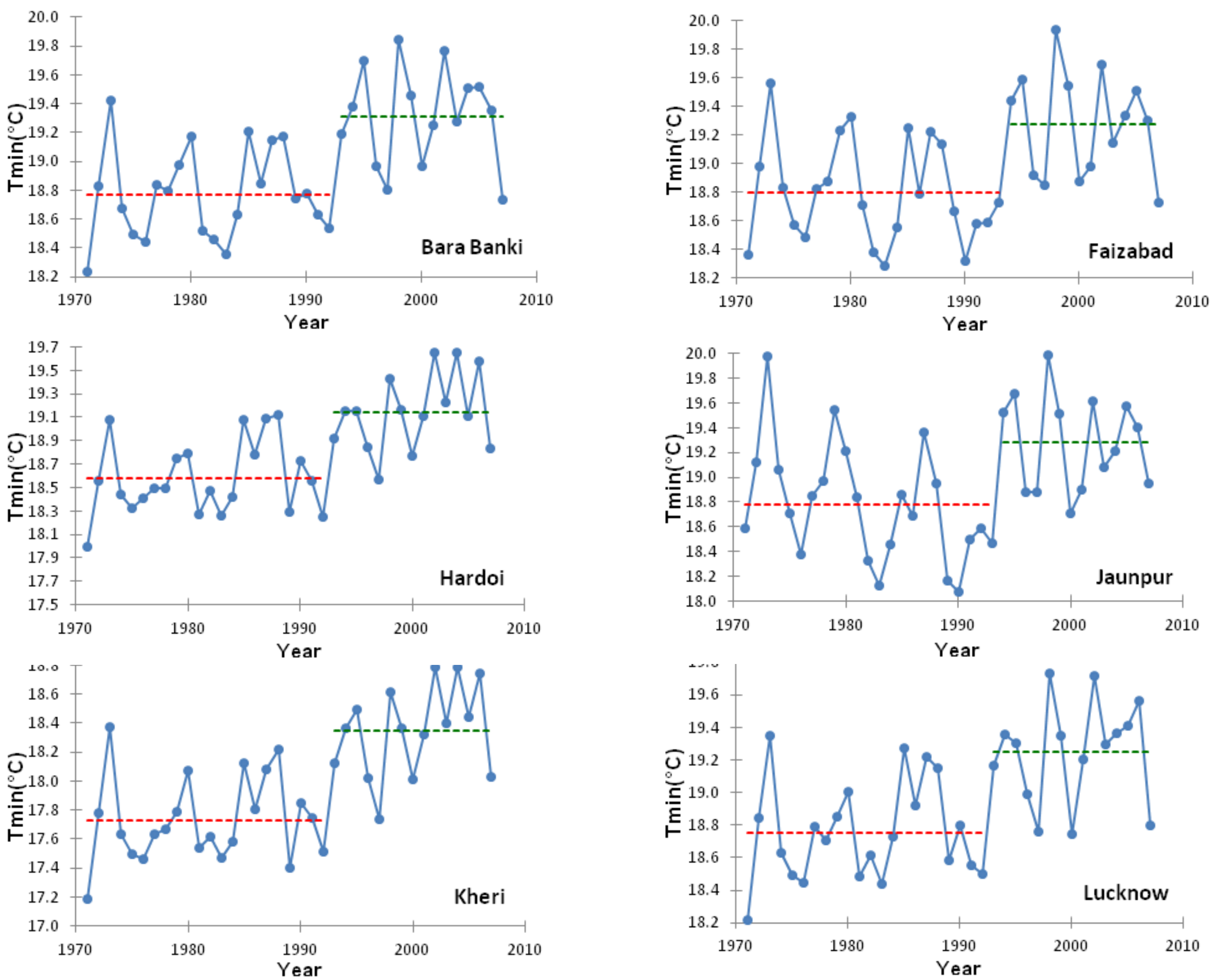
Discussion

The absence of a break point in the time series of mean and maximum temperature indicates that the data are homogenous and that the data was recorded without any changes in observation conditions or changes in measuring techniques. These time series have thus been classified as 'useful'. In case of minimum temperature, 1992 and 1993 were the change point years for the Gomti basin when the average minimum temperature significantly increased after the break point year (Fig. 2). This may have been triggered by climate variability. It has been reported that the minimum temperature is increasing in several regions of India (Abeysingha *et al*., 2014; Rao *et al.* 2014; Duhan *et al*. 2013; Kumar *et al.* 2014 and Patle *et al.* 2013). Therefore, the break point is expected in minimum temperature. Due to the presence of a break point, this time series have been classified as either 'doubtful' (14.29% of the basin data) or 'suspect' (85.71% of the basin data). However, since both the maximum and minimum temperature have been recorded at the same place using the same measuring techniques under the same observing practices, the presence of the break point in the

Table: 2
Homogeneity tests for annual minimum temperature for Gomti basin

District	Homogeneity tests for annual minimum temperature (1971-2007)					Classification
	Pettitt Test	SNHT	Buishand Test	Von Neumann Test	Break point year observed at	
Bara Banki	√	√	√	√	1992	Suspect
Faizabad	√	√	√	√	1993	Suspect
Hardoi	√	√	√	√	1992	Suspect
Jaunpur	√	√	√	√	1993	Suspect
Kheri	√	√	√	√	1992	Suspect
Lucknow	√	√	√	√	1992	Suspect
Pilibhit	√	√	√	√	1992	Suspect
Pratapgarh			√	√	1992	Doubtful
Rae Bareli	√	√	√	√	1992	Suspect
Shahjahanpur	√	√	√	√	1992	Suspect
Sitapur	√	√	√	√	1992	Suspect
Sultanpur	√	√	√	√	1993	Suspect
Unnao	√	√	√	√	1992	Suspect
Varanasi			√	√	1993	Doubtful

Null hypothesis (H_0): Data are homogenous; Alternate hypothesis (H_a): There is a date at which there is a change in the data; √: Null hypothesis H_0 rejected



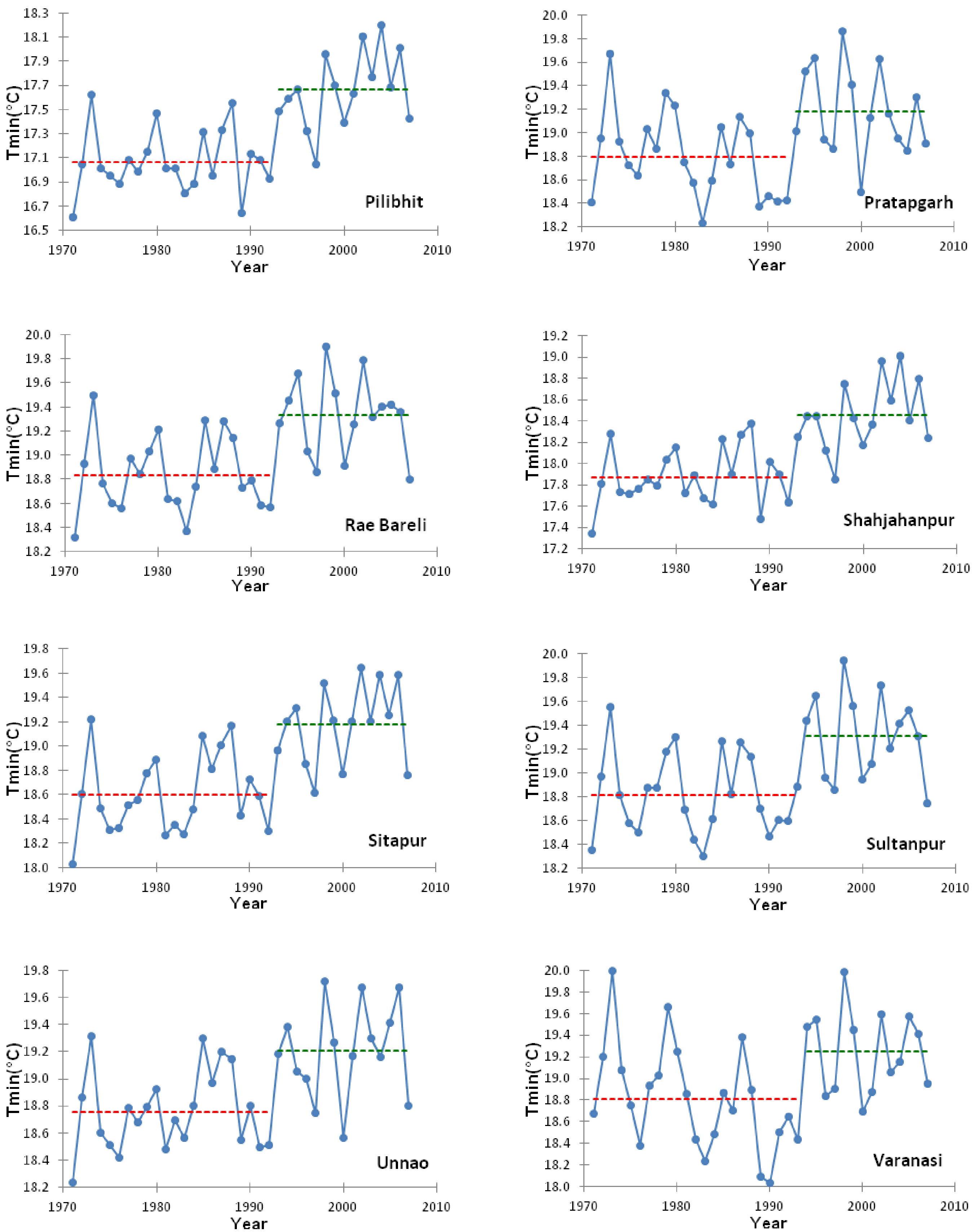


Fig. 2. Homogeneity test results for annual minimum temperature for all districts of Gomti basin

Table: 3
Homogeneity tests for annual rainfall for Gomti basin

District	Homogeneity tests for annual rainfall (1971-2011)					Classification
	Pettitt Test	SNHT	Buishand Test	Von Neumann Test	Break point year observed at	
Bara Banki						Useful
Faizabad						Useful
Hardoi						Useful
Jaunpur						Useful
Kheri						Useful
Lucknow			√		1985	Useful
Pilibhit						Useful
Pratapgarh			√		1986	Useful
Rae Bareli						Useful
Shahjahanpur						Useful
Sitapur						Useful
Sultanpur						Useful
Unnao			√		1985	Useful
Varanasi						Useful

Null hypothesis (H_0): Data are homogenous; Alternate hypothesis (H_a): There is a date at which there is a change in the data; √: Null hypothesis H_0 rejected

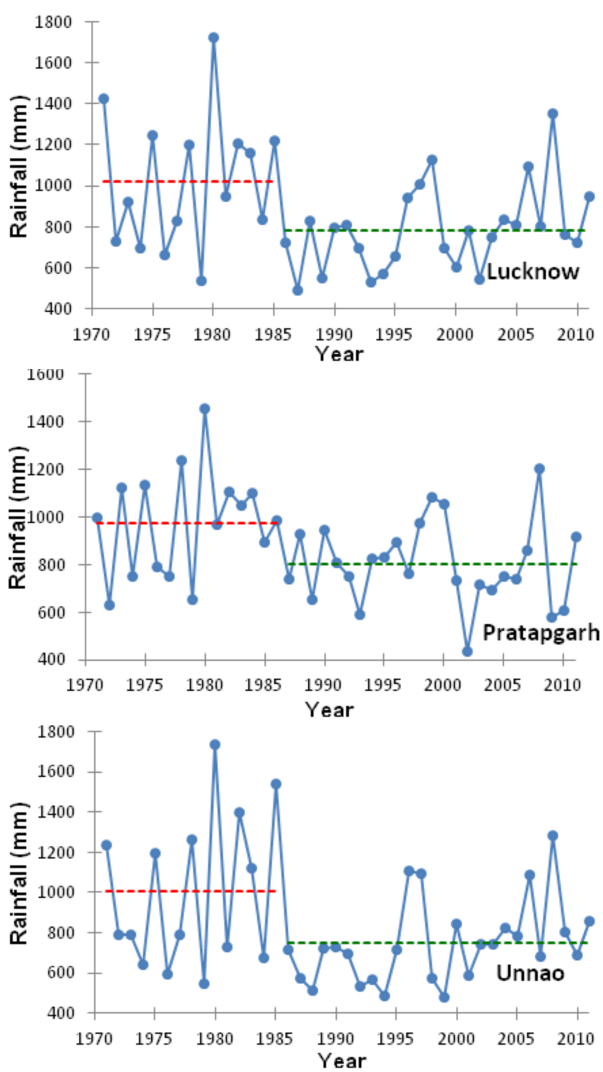


Fig. 3. Buishand test results for annual rainfall

minimum temperature time series may be due to variations in local climate rather than in homogeneity.

For annual rainfall, 100% of the basin data was found to be 'useful'. Three districts, Lucknow, Pratapgarh and Unnao showed a break point in Buishand test at 1985 and 1986 when the average annual rainfall significantly decreased after the break point year (Fig. 2). Despite its classification as 'useful' it should be noted that fewer breaks are observed in the annual rainfall time series due to its larger variability across the basin. Any significant trend detected in such a series should be interpreted with caution (Wijngaard *et al.*, 2003). This study suggests that in general, there is no break in annual rainfall time series except in the western part of the Gomti basin. In a similar study, Taxak *et al.*, 2014 have reported a break point in rainfall time series in the Wainganga basin (consisting of Madhya Pradesh, Maharashtra and Chattisgarh) which is a sub-basin of the Godavari river basin in Central India.

Through various tests, it has been concluded that there is climate variability particularly in minimum temperature. As of now, no break point was observed in case of mean and maximum temperature. However, if the trend continues, there would be significant increase in mean temperature also which will affect the crop water requirement. In such circumstances, farmers have to go for crops that require less water as the water availability for agriculture is declining.

Such studies may help in deciding the cropping pattern for the future.

4. CONCLUSIONS

Homogeneity in the time series of annual mean, annual minimum and annual maximum temperature and annual rainfall of the 14 districts of Gomti basin was successfully studied using the 4 tests for homogeneity. The results were classified as useful, doubtful or suspect. Annual mean and annual maximum temperatures from 1971-2007 and annual rainfall from 1971-2011 for all the districts of the basin were found to be homogenous and 'useful'. However, in the rainfall time series, large variations in the basin may be a reason for absence of a break point. Annual minimum temperature showed significant break point years at 1992 and 1993. It was observed that 14.29% of the basin data was classified as 'doubtful' and 85.71% as 'suspect'. Despite this classification, break points may be observed due to variations in local climate instead of in homogenous conditions in recording data and observing practices. There is no break point in mean and maximum temperatures as there is no significant increasing or decreasing trend in maximum temperature. Finding of this study may help in crop planning in event of climate change. It is suggested that such tests should be carried out for other study regions as well to study the homogeneity of a time series before using it for trend and variability analysis.

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