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Homogenizing monthly rainfall and temperature data series in Maharashtra & Goa

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सार – **महाराष्ट्र और गोवा के सभी जलवायु केंद्रों की वार्षिक वर्षा और तापमान डेटा श्रृंखला का डेटा एकरूपता के लिए सांख्यिकीय रूप से परीक्षण किया जाता है। किसी स्टेशन की एकरूपता का निरीक्षण करने के लिए, दो-चरणीय दृष्टिकोण का पालन किया जाता है। सबसे पहले, चार समरूपता परीक्षण मानक सामान्य समरूपता परीक्षण, पेटिट का परीक्षण, ब्यूशैंड की रेंज परीक्षण और** 5% **महत्व के स्तर पर वॉन न्यूमैन राशन परीक्षण का उपयोग वार्षिक वर्षा और तापमान के परीक्षण प्राचलों में एकरूपता के लिए परीक्षण परिकल्पना निर्धारित करने के लिए किया जाता है। दूसरा, इन सभी चार परीक्षणों के परिणामों को 'उपयोगी', 'संदेहात्मक' और 'संदिग्ध' के रूप में तीन अलग-अलग श्रेणियों में एकत्रित किया गया। यहां** 30 **वर्षा,** 29 **अधिकतम और न्यूनतम तापमान जलवायु स्टेशनों का परीक्षण किया गया। प्राप्त परिणामों ने** 80% **स्टेशनों को 'उपयोगी',** 7% **को 'संदिग्ध' और** 13% **स्टेशनों को वर्षा के लिए 'संदेहात्मक' के रूप में दिखाया है, अधिकतम तापमान श्रृंखला के लिए ये परिणाम** 17% **को 'उपयोगी',** 7% **को 'संदिग्ध' और** 76% **को दर्शाते हैं। 'संदिग्ध' के रूप में, जबकि न्यूनतम तापमान श्रृंखला के लिए ये परिणाम** 21% **'उपयोगी',** 10% **'संदिग्ध' और** 69% **'संदेहात्मक' हैं। इसके अलावा, इस अध्ययन में एकरूपता के लिए मासिक वर्षा और तापमान डेटा श्रृंखला को सही करने का भी प्रयास किया गया है। 'उपयोगी' के रूप में वर्गीकृत स्टेशनों को 'संदिग्ध' और 'संदेहात्मक' स्टेशनों से असमानताओं को दूर करने के लिए संदर्भ श्रृंखला के रूप में उपयोग किया जाता है। वर्षा को सही करने के लिए श्रृंखला अनुपात विधि का उपयोग किया जाता है जबकि तापमान के लिए श्रृंखला जोड़ विधि का उपयोग किया जाता है। सुधार परिणामों ने 'संदिग्ध' श्रेणी के स्टेशनों में महत्वपूर्ण सुधार को दिखाया गया है। असमान श्रृंखला के सुधार के बाद, परिणाम दर्शाते हैं कि सभी** 100% **वर्षा स्टेशन और** 65% **से अधिक तापमान मापी स्टेशन अब 'उपयोगी' श्रेणी में हैं। संशोधित स्टेशनों को आगे के जलवायु अनुसंधान अध्ययनों में शामिल किया जा सकता है।**

ABSTRACT. Annual rainfall and temperature data series of all climate stations in Maharashtra & Goa are statistically tested for data homogeneity. To inspect homogeneity of a station, a two-step approach is followed. First, four homogeneity tests Standard normal homogeneity test, Pettit's test, Buishand's range test and Von Neumann ration test at 5% level of significance are used to determine test hypothesis for homogeneity on testing parameters of annual rainfall and temperature. Second, results from all these four tests aggregated together into three different classes as 'useful', 'doubtful' and 'suspect'. Here 30 rainfall, 29 maximum and minimum temperature climate stations were tested. The results showed 80% stations as 'useful', 7% as 'suspect' and 13% as 'doubtful' for rainfall, for maximum temperature series these results are 17% as 'useful', 7% as 'suspect' and 76% as 'doubtful', while for minimum temperature series these results are 21% as 'useful', 10% as 'suspect' and 69% as 'doubtful'. Further, in this study an attempt is also made to correct the monthly rainfall and temperature data series for homogeneity. Stations categorised as 'useful' are used as reference series to remove in homogeneities from 'suspect' and 'doubtful' stations. To correct rainfall series ratio's method is used while for temperature series addition method is used. Correction results showed significant improvement in 'suspect' category stations. After correction of inhomogeneous series, the results show all 100% of rainfall stations and more than 65% of temperature stations are now in 'useful' category. The corrected stations may be included in further climate research studies.

Key words – Homogeneity tests, Standard normal homogeneity test, Pettit's tests, Buishand's range test, Von neumann ration test, Rainfall series, Temperature series.

1. Introduction

Data homogeneity is very important part of data quality control and historical data archival. Homogenizing a climate data series is the procedure for removing non-climatic changes from respective time series. A data series contains breaks or shifts in time series, which are result of change in climate itself or resulted from non-climatic

TABLE 1

Stations summary & data availability details

Index	District	Station	Latitude	Longitude	Period	Total Number of Years				Class of OBSY
						Including Missing	Excluding Missing			
							PRE	MAX	MIN	
42851	Jalgaon	Jalgaon	21.03	75.34	1937-2008	72	70	70	70	II b
42920	Nashik	Ozar	20.08	73.55	1965-2006	42	41	41	41	I
42921	Nashik	Nashik	19.58	73.49	1949-1983	35	31	32	28	I
42925	Nashik	Malegaon	20.33	74.32	1901-2008	108	107	101	107	II b
43075	Osmanabad	Osmanabad	18.07	76.01	1976-2008	33	26	26	24	II b
43001	Thane	Dahanu	19.58	72.43	1944-2017	74	68	67	67	I
43003	Greater Mumbai	Santacruz	19.07	72.51	1951-2017	67	67	67	67	I
43009	Ahmednagar	Ahmednagar	19.05	74.48	1901-2013	113	105	99	100	II b
43011	Beed	Beed	19.00	75.24	1961-1996	36	34	34	34	II b
43013	Aurangabad	Aurangabad	19.53	75.20	1902-1983	82	82	82	82	IIb
43014	Aurangabad	Chikalthana	19.51	75.24	1952-2017	66	66	66	66	I
43021	Nanded	Nanded	19.05	77.20	1960-2007	48	37	37	38	II c
43057	Mumbai	Colaba	18.54	72.48	1901-2017	117	117	117	117	I
43058	Raigad	Alibag	18.38	72.52	1933-2015	83	80	80	80	II b
43061	Pune	Khandala	18.46	73.22	1951-1973	23	21	0	0	Vb
43062	Raigad	Bhira	18.27	73.24	1963-2008	46	43	43	42	II b
43063	Pune	Pune	18.32	73.51	1901-2016	116	116	116	116	I
43069	Pune	Baramati	18.09	74.35	1954-1993	40	40	40	39	II b
43071	Solapur	Jeur	18.12	75.12	1951-2003	53	46	46	45	II b
43109	Ratnagiri	Harnai	17.49	73.06	1943-2014	72	69	69	69	II a
43110	Ratnagiri	Ratnagiri	16.59	73.20	1901-2017	117	111	111	111	I
43111	Satara	Mahabaleshwar	17.56	73.40	1932-2014	83	79	77	77	I
43113	Satara	Satara	17.42	74.01	1976-2015	40	38	38	38	II a
43117	Solapur	Solapur	17.40	75.54	1901-2017	117	117	117	117	I
43153	Sindhudurg	Devgad	16.23	73.21	1945-2006	62	49	49	49	II b
43157	Kolhapur	Kolhapur	16.42	74.14	1946-2016	71	69	68	69	II a
43158	Sangli	Sangli	16.51	74.36	1932-2015	84	69	69	69	II a
43192	Goa	Panjim	15.29	73.49	1964-2016	53	53	53	53	I
43193	Sindhudurg	Vegurla	15.52	73.38	1949-2008	60	51	52	50	II b
43196	Goa	Mormugao	15.25	73.47	1964-2007	44	44	44	44	I

jumps due to relocation or changes in recording instrumentation, urban heat island effects, changes in observing methods and surroundings of instrument *etc*. Various studies have shown that sometimes inhomogeneities can cause biased trends in raw data and inhomogeneities in historical data will affect the outcome of data analysis and forecasts. Therefore, homogenizing climate data is necessary in order to obtain reliable regional or global trends, which in result will improve the quality of forecasting. Time series quality control and homogenization is a part of World Meteorological Organization (WMO) guidelines for Global Framework for Climate Services (GFCS) & Climate Services Information System (CSIS), which is to be implemented by National Hydrological & Meteorological Services (NHMS) & Regional Climate Centre (RCC). Here, the concept is to test whether a given data is said to be homogenous over time. In other words, if there is a significant break in trend of particular time series it is classified as inhomogeneous. To identify these breaks in trend one should use metadata to detect any climatic breaks in time series. Upon unavailability of metadata, to identify these breaks there several statistical methods are available but very few methods are available to remove these breaks.

A study on European climate data by Wijngaard *et al*., (2003) shows a detailed approach for testing homogeneity using four different statistical tests namely standard normal homogeneity test, Pettit's tests, Buishand's range test and Von Neumann ration test. These statistical tests were applied on various testing parameters of temperature and rainfall and based on the number of tests rejecting the null hypothesis the results were categorised into three classes, as useful, doubtful and suspect. There is no study in India so far to test the data homogeneity let alone an attempt to correct it. Monthly rainfall and temperature data from all climate stations in state of Maharashtra and Goa is used in this study, which is provided by India Meteorological Department for all available period since 1901. In order to test data homogeneity, we have adopted the Wijngaard *et al*., (2003) approach. Annual rainfall amount and annual mean temperature are used as testing variables in this study. Stations with significant inhomogeneities are needed to be removed and adjustment for homogeneity should be made. Homogeneity correction methods for temperature and rainfall are different in approach. Hanssen and Forland (1994) had shown a method to correct inhomogeneous rainfall data series using a reference station and Morozova and Valente (2012) constructed a procedure to correct temperature data series, both of which we have implemented to correct monthly rainfall and temperature data series for all climate stations in state of Maharashtra and Goa.

2. Data and methodology

Monthly rainfall and temperature data from all climate stations in states of Maharashtra and Goa is collected from India Meteorological Department (IMD) Pune. Table 1 shows stations with their geographical coordinates with data availability statistics. Stations with higher percentage of missing data are not considered for this study. Annual mean temperature and rainfall amount are used as testing variables.

2.1. *Statistical methods*

Firstly, original series is visually analysed for detection of any possible breaks such as outliers, which could arrive due to typing or OCR errors. Further, all four homogeneity tests are applied to the data series. The break dates from homogeneity tests are compared with metadata to identify climatic and non-climatic jumps or breaks in series. It is possible that metadata could not provide all the information regarding changes in stations, observation procedure, changes in surroundings etc. and in this study, we could not find any significant breaks which are associated with metadata or any climate forcing data records. After the testing procedure is over, results from testing are collected and stations are categorised to be selected for correction procedure. For a station, break dates that are common for most tests are selected for correction and in case of different break dates for same station, the later one is selected for correction. For correction of data series with significant inhomogeneities, different methods are used for rainfall and temperature, respectively. Rainfall has more variability throughout the year as compared to temperature, because of that; a use of reference station is must for rainfall series correction. An adjustment factor is computed for each station using the method suggested by Hanssen and Forland (1994) and Morozova and Valente (2012) for rainfall and temperature, respectively. Accordingly, adjustment factor is then used to correct rainfall series by ratio's method and temperature series by additive method. Corrected stations again undergo the homogeneity testing procedure to check for any remaining inhomogeneities and same procedure repeated until most significant non-climatic breaks are removed.

2.2. *Homogeneity testing*

Four statistical tests are used to test the homogeneity of rainfall and temperature data. Standard normal homogeneity test (SNHT), Pettit's test (PT), Buishand's test (BT) and Von Neumann ratio test (VNR) are used to test the data homogeneity. There are several studies in the past by González-Rouco *et al*., (2001), Tuomenvirta (2001), Kang and Yusof (2012), Ahmad and Deni (2013),

TABLE 2

1% and 5% critical values for X_m of the Pettit's test as a function of *n*; values are based on simulation.

n	20	30	40	50	70	100
1%	71	133	208	293	488	841
5%	57	107	167	235	393	677

Taxak *et al*., (2014), Guhathakurta *et al*., (2015), Agha *et al*., (2017) and Byakatonda *et al*., (2018) where these tests are used for testing homogeneity of data series. These tests have different sensitivities in different parts of series based on their characteristics as parametric, non-parametric and maximum likelihood, which would help in obtaining results that are more significant. The null hypothesis for these tests is that annual values Y_i of the testing variable *Y* are independent and identically distributed while the alternate hypothesis for SNHT, PT and BT assume that there is a shift in the mean is present, this significant break in series is considered as inhomogeneous. These tests will identify the year where the break is significant which would be the year where inhomogeneity first occurred. On the other hand, VNR test assume that series is not randomly distributed under alternate hypothesis and the VNR tests does not provide information about a year where break occurs.

The SNHT easily detects breaks near the beginning and at the end of series, whereas to detect breaks in the middle of the series, PT and BR tests are more sensitive (Hawkins, 1977). Pettit's test is based on ranks of the elements in the series, which makes it less sensitive to outliers than other tests like SNHT and Buishand's test, which assume that Y_i values are normally distributed. The VNR test has sensitivity to departures of homogeneity having characteristics other than stepwise shifts. Annual rainfall amount and mean temperature are testing variables given that $Y_{i,}$ (i = 1,2 …. n) is the testing variable with $\bar{Y}$ is the mean and *s* is the standard deviation.

2.2.1. *Standard normal homogeneity test*

SNHT is the most referred homogeneity test in climate studies. A test statistic *T*(*d*) is used to compare the mean of the first *y* years with the last of ($n - y$) years can be written as,

$$T_d = d\,\bar{z}_1^2 + (n-d)\,\bar{z}_2^2,\ d = 1,2,...,n$$

where,

$$\bar{z}_1 = \frac{1}{d}\sum_{i=1}^{d}\frac{(Y_i - \bar{Y})}{s} \text{ and } \bar{z}_2 = \frac{1}{n-d}\sum_{i=d+1}^{d}\frac{(Y_i - \bar{Y})}{s}$$

TABLE 3

1% critical values for the statistic T_0 of the single shift SNHT as a function of *n* [calculated from simulations carried out by Jaruskova (1996) and the 5% critical value (Alexandersson and Moberg, 1997)

n	20	30	40	50	70	100
1%	9.56	10.45	11.01	11.38	11.89	12.32
5%	6.95	7.65	8.10	8.45	8.80	9.15

$\bar{z}_1$ and $\bar{z}_2$ are the mean values of z_i during the first *d* years and last (*n*-*d*) years, respectively. If a break is located at year D then *T*(*d*) reaches a maximum near the year $d = D$. The test statistic T_0 is defines as

$$T_0 = \max_{1 \le d \le n} T(d)$$

The probability of rejecting the null hypothesis when T_0 exceeds a certain critical value, which depends on sample size. Critical values for T_0 are given in Table 3 (Khaliq and Quarda, 2007).

2.2.2. *Buishand's range test*

The homogeneity test can be based on the cumulative deviations from the mean or adjusted partial sum which are define as,

$$S^* = 0 \text{ and } S_d^* = 2\sum_{i=1}^{d}(Y_i - \bar{Y}), d = 1,2,....,n$$

For a homogeneous series, there is no systematic deviations of the Y_i values with respect to their mean will appear, therefore the values of S_d^* will fluctuate around zero. Contrarily if a break is present at year *D*, then S_d^* reaches a maximum (negative shift) or minimum (positive shift) near the year $d = D$. Rescaled adjusted partial sums are obtained by dividing the values of S_d^* by the sample standard deviation *s*. The values are not influenced by any linear transformation; therefore, it is suitable to use the homogeneity test by Q statistics (Buishand, 1982).

$$Q = \max_{0 \le d \le n}\left|\frac{S_d^*}{s}\right|$$

In addition, the difference between the maximum and minimum value of the rescaled adjusted partial sums can also be computed by range statistics or R statistics.

$$R = \frac{\left(\max\limits_{0 \le d \le n} S_d^* - \min\limits_{0 \le d \le n} S_d^*\right)}{s}$$

TABLE 4

1% and 5% critical values for Q √n of the Buishand's range test as a function of n (Buishand, 1982); the value of *n* = 70 is simulated

n	20	30	40	50	70	100
1%	1.60	1.70	1.74	1.78	1.81	1.86
5%	1.43	1.50	1.53	1.55	1.59	1.62

TABLE 5

1% and 5% critical values for R √n of the Buishand's range test as a function of n (Buishand, 1982)

n	10	20	30	40	50	100
1%	1.29	1.42	1.46	1.50	1.52	1.55
5%	1.14	1.22	1.24	1.26	1.27	1.29

Critical values table by Buishand for both homogeneity tests Q√n and R√n are given in Tables 4&5 respectively.

2.2.3. *Pettit's test*

This test is non-parametric rank test, which does not require any assumption for normality. The test is based on the ranking order and the ranks r_1, r_2,… r_n of the Y_1, Y_2 … Y_n are used to calculate the statistics *(Pettit, 1979).*

$$X_d = 2\sum_{i=1}^{d} r_i - d(n+1) \quad d = 1,2,\ldots,n$$

If the break occurs in year m, then the statistics is maximal or minimal near the year *d* = *m*.

$$X_m = \max_{1 \le d \le n} |X_d|$$

Critical values for X_m are given in Table *2*.

2.2.4. *Von Neumann's ratio test*

The Von Neumann ratio is defined as the ratio of the mean square successive difference between the years to the variance (von Neumann 1941). The test statistic is given as,

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

TABLE 6

1% and 5% critical values of N of the Von Neumann ratio test as a function of n. For N ≤ 50 these values are taken from Owen (1962); for N=70 and N=100 the critical values are based on asymptotic normal distribution of N (Buishand, 1981)

n	20	30	40	50	70	100
1%	1.04	1.20	1.29	1.36	1.45	1.54
5%	1.30	1.42	1.49	1.54	1.61	1.67

This statistic is often used to test the independence of the random variables Y_i, which are assumed to be successive observations on a stationary Gaussian time series, and sometimes used to test that stationarity of the mean for uncorrelated time. However, this statistic can also be applied in detecting the inhomogeneous series. The series can be considered as homogeneous series if expected value, *N* = 2. However, for inhomogeneous series, the value of *N* tends to be lower than 2 (Buishand, 1982). Values greater than 2 implies that the series has rapid variations or oscillations in the mean (Suhaila *et al.*, 2008). This test gives no information about the location of the shift. Table 6 gives critical values for N.

2.3. *Critical values table*

The homogeneity tests are applied to the rainfall and temperature series at 5% level of significance. Critical values for all four tests (Wijngaard *et al.*, 2003) for rainfall, maximum temperature & minimum temperature are given in Tables 7, 8&9 respectively, followed by critical values after homogeneity correction in Tables 10, 11 & 12.

2.4. *Classification of homogeneity tests*

Classification is the second part of homogeneity tests where results from all these four tests are evaluated and combined together. Classification is made into three different categories based on how many tests rejected the null hypothesis (Schönwiese *Rapp*, 1997). These categories are Useful, Doubtful and Suspect and these can be interpreted as follows,

Class A: Useful - The series that rejects one or none null hypothesis under four tests at 5% level of significance are considered. The stations under this class can be considered as homogeneous and can be used for further analysis.

Class B: Doubtful - The series that rejects two null hypothesis under four tests at 5% level of significance are considered. The stations under this class have

TABLE 7

Homogeneity test statistics (*p* value approximation) for rainfall

Station	Pettitt's Test				SNHT				Buishand's Test				VNR			Class
	p	*K*	*Year*	*Trend*	*p*	T_0	*Year*	*Trend*	*p*	*Q*	*Year*	*Trend*	*p*	*N*	*Trend*	
Aurangabad	0.2243	421	1930	H0	0.2499	5.79	1925	H0	0.1066	10.29	1930	H0	**0.0167**	**1.54**	**Ha**	Useful
Ahmednagar	0.2754	583	1962	H0	0.6075	3.62	1962	H0	0.2715	9.63	1962	H0	**0.003**	**1.48**	**Ha**	Useful
Chikalthana	**0.0098**	**475**	**1986**	**Ha**	0.0701	9.18	1986	H0	**0.0099**	**12.38**	**1986**	**Ha**	0.2265	1.82	H0	Doubtful
Beed	0.7107	71	1986	H0	0.7472	2.47	1986	H0	0.5698	4.11	1986	H0	0.3899	1.91	H0	Useful
Dahanu	0.0779	393	1964	H0	0.0828	8.42	1964	H0	**0.0338**	**11.14**	**1964**	**Ha**	0.057	1.63	H0	Useful
Mormugao	0.6863	109	2000	H0	0.7403	2.77	2000	H0	0.7378	4.08	2000	H0	0.0803	1.59	H0	Useful
Panjim	0.4772	174	1993	H0	0.8637	2.14	1994	H0	0.5533	5.32	1993	H0	0.2246	1.80	H0	Useful
Jalgaon	0.4426	272	1970	H0	0.1965	5.93	2003	H0	0.459	6.61	1970	H0	0.2414	1.83	H0	Useful
Kolhapur	0.0933	386	1967	H0	0.207	6.27	1967	H0	0.0886	9.76	1967	H0	**0.0343**	**1.56**	**Ha**	Useful
Malegaon	0.8689	354	1926	H0	0.3798	4.87	2004	H0	0.8568	5.80	1926	H0	0.109	1.76	H0	Useful
Colaba	**0.0012**	**1390**	**1952**	**Ha**	**0.0013**	**15.83**	**1941**	**Ha**	**0.0003**	**21.23**	**1952**	**Ha**	0.1356	1.80	H0	Suspect
Santacruz	0.312	286	2004	H0	0.2423	5.77	1959	H0	0.2649	7.70	2004	H0	0.1496	1.75	H0	Useful
Nanded	0.7452	78	1963	H0	0.2832	4.92	1963	H0	0.5864	4.25	1963	H0	0.7545	2.22	H0	Useful
Nashik	0.8826	50	1964	H0	0.8083	2.15	1952	H0	0.7915	3.19	1957	H0	0.4861	1.98	H0	Useful
Ozar	**0.0153**	**222**	**1996**	**Ha**	**<0.0001**	**19.89**	**2002**	**Ha**	**0.0093**	**9.59**	**1997**	**Ha**	**0.0016**	**1.05**	**Ha**	Suspect
Osmanabad	0.4522	59	1997	H0	0.6879	2.55	1976	H0	0.4542	3.96	1997	H0	0.9491	2.62	H0	Useful
Pune	**0.0089**	**1170**	**1972**	**Ha**	**0.0075**	**13.49**	**2003**	**Ha**	**0.0077**	**17.59**	**1972**	**Ha**	**0.0006**	**1.44**	**Ha**	Suspect
Baramati	0.2152	143	1972	H0	0.5195	3.76	1972	H0	0.2113	6.20	1972	H0	0.1875	1.72	H0	Useful
Khandala	0.1263	58	1963	H0	**0.0448**	**7.16**	**1971**	**Ha**	0.0789	5.20	1963	H0	0.074	1.39	H0	Useful
Alibag	0.1427	452	1952	H0	0.3359	5.32	1952	H0	0.1982	8.99	1952	H0	0.5054	2.00	H0	Useful
Bhira	0.4498	128	1980	H0	0.7807	2.22	2003	H0	0.8286	3.73	1980	H0	**0.0064**	**1.32**	**Ha**	Useful
Ratnagiri	**0.0003**	**1426**	**1952**	**Ha**	**0.0004**	**19.15**	**1930**	**Ha**	**0.0004**	**21.94**	**1952**	**Ha**	**0.0198**	**1.61**	**Ha**	Suspect
Harnai	0.0751	402	1964	H0	0.12	6.92	1964	H0	0.0655	10.26	1964	H0	0.294	1.87	H0	Useful
Sangli	0.9006	171	1965	H0	0.2578	5.64	1932	H0	0.905	4.23	2004	H0	0.175	1.78	H0	Useful
Satara	0.3907	112	1981	H0	0.3851	4.30	1981	H0	0.4893	4.73	1981	H0	0.0591	1.51	H0	Useful
Mahabaleshwar	0.0562	516	1965	H0	0.1774	6.27	1963	H0	0.0643	11.04	1965	H0	0.0938	1.71	H0	Useful
Devgad	0.4894	152	1990	H0	0.4973	3.95	1947	H0	0.6049	4.87	1989	H0	0.0674	1.58	H0	Useful
Vengurla	**0.0209**	**298**	**1985**	**Ha**	0.0811	7.42	1985	H0	**0.0321**	**9.67**	**1985**	**Ha**	0.2993	1.85	H0	Doubtful
Solapur	0.1939	754	1947	H0	0.6258	3.63	1947	H0	0.2825	10.15	1947	H0	0.4089	1.96	H0	Useful
Jeur	0.1692	186	1976	H0	0.2138	5.74	2000	H0	0.2567	6.32	1976	H0	**0.012**	**1.34**	**Ha**	Useful

TABLE 8

Homogeneity test statistics (*p* value approximation) for maximum temperature

Station	Pettitt's Test				SNHT				Buishand's Test				VNR			Class
	p	*K*	*Year*	*Trend*	*p*	T_0	*Year*	*Trend*	*p*	*Q*	*Year*	*Trend*	*p*	*N*	*Trend*	
Aurangabad	**<0.0001**	**1090**	**1949**	**Ha**	**<0.0001**	**25.19**	**1963**	**Ha**	**<0.0001**	**22.12**	**1949**	**Ha**	**<0.0001**	**1.01**	**Ha**	Suspect
Ahmednagar	**<0.0001**	**1699**	**1957**	**Ha**	**<0.0001**	**26.03**	**1957**	**Ha**	**<0.0001**	**25.22**	**1957**	**Ha**	**<0.0001**	**0.74**	**Ha**	Suspect
Chikalthana	0.2534	297	2000	H0	0.3342	4.87	2000	H0	0.2286	7.90	2000	H0	**0.0063**	**1.42**	**Ha**	Useful
Beed	**0.0142**	**166**	**1981**	**Ha**	**0.0437**	**8.11**	**1982**	**Ha**	**0.0185**	**8.19**	**1981**	**Ha**	**0.0018**	**1.05**	**Ha**	Suspect
Dahanu	**<0.0001**	**914**	**1984**	**Ha**	**<0.0001**	**29.35**	**1984**	**Ha**	**<0.0001**	**22.04**	**1984**	**Ha**	**<0.0001**	**0.77**	**Ha**	Suspect
Mormugao	**0.0005**	**326**	**1976**	**Ha**	**<0.0001**	**28.25**	**1971**	**Ha**	**<0.0001**	**14.62**	**1975**	**Ha**	**<0.0001**	**0.39**	**Ha**	Suspect
Panjim	**<0.0001**	**558**	**2001**	**Ha**	**<0.0001**	**29.93**	**2001**	**Ha**	**<0.0001**	**18.11**	**2001**	**Ha**	**<0.0001**	**0.56**	**Ha**	Suspect
Jalgaon	**0.0295**	**470**	**1948**	**Ha**	**0.0496**	**11.49**	**1948**	**Ha**	**0.0451**	**10.76**	**1948**	**Ha**	**0.0008**	**1.24**	**Ha**	Suspect
Kolhapur	0.1315	357	1989	H0	**0.0314**	**9.65**	**1956**	**Ha**	0.1047	9.50	1956	H0	**0.0002**	**1.11**	**Ha**	Doubtful
Malegaon	0.4236	488	1950	H0	**0.0001**	**20.76**	**2002**	**Ha**	0.2213	9.98	2002	H0	**<0.0001**	**1.08**	**Ha**	Doubtful
Colaba	**<0.0001**	**3049**	**1950**	**Ha**	**<0.0001**	**68.01**	**1940**	**Ha**	**<0.0001**	**44.05**	**1950**	**Ha**	**<0.0001**	**0.41**	**Ha**	Suspect
Santacruz	**<0.0001**	**900**	**1985**	**Ha**	**<0.0001**	**30.05**	**1985**	**Ha**	**<0.0001**	**22.58**	**1985**	**Ha**	**<0.0001**	**0.96**	**Ha**	Suspect
Nanded	0.5785	92	1963	H0	**0.0034**	**16.53**	**2006**	**Ha**	0.6597	4.07	2006	H0	0.2122	1.75	H0	Useful
Nashik	**0.001**	**186**	**1964**	**Ha**	**0.0232**	**9.04**	**1964**	**Ha**	**0.0033**	**8.57**	**1964**	**Ha**	**0.0084**	**1.21**	**Ha**	Suspect
Ozar	0.3983	125	1984	H0	0.6484	2.85	1965	H0	0.3892	5.34	1984	H0	0.7254	2.19	H0	Useful
Osmanabad	**0.0001**	**153**	**1985**	**Ha**	**<0.0001**	**17.95**	**1985**	**Ha**	**<0.0001**	**10.48**	**1985**	**Ha**	**<0.0001**	**0.56**	**Ha**	Suspect
Pune	0.0958	855	1969	H0	0.1893	6.08	1904	H0	0.0755	13.25	1972	H0	**<0.0001**	**1.28**	**Ha**	Useful
Baramati	**0.0022**	**249**	**1974**	**Ha**	**0.0089**	**10.73**	**1975**	**Ha**	**0.0017**	**10.46**	**1974**	**Ha**	**<0.0001**	**0.86**	**H0**	Suspect
Alibag	**<0.0001**	**1484**	**1975**	**Ha**	**<0.0001**	**53.25**	**1985**	**Ha**	**<0.0001**	**31.87**	**1975**	**Ha**	**<0.0001**	**0.31**	**Ha**	Suspect
Bhira	0.0881	190	1973	H0	0.2273	5.49	1973	H0	0.1308	7.10	1991	H0	**<0.0001**	**0.58**	**Ha**	Useful
Ratnagiri	**<0.0001**	**2875**	**1964**	**Ha**	**<0.0001**	**65.42**	**1964**	**Ha**	**<0.0001**	**42.76**	**1964**	**Ha**	**<0.0001**	**0.38**	**Ha**	Suspect
Harnai	**<0.0001**	**962**	**1985**	**Ha**	**<0.0001**	**29.95**	**1986**	**Ha**	**<0.0001**	**22.17**	**1975**	**Ha**	**<0.0001**	**1.00**	**Ha**	Suspect
Sangli	**<0.0001**	**803**	**1971**	**Ha**	**<0.0001**	**21.13**	**1971**	**Ha**	**<0.0001**	**19.18**	**1971**	**Ha**	**<0.0001**	**0.94**	**Ha**	Suspect
Satara	**<0.0001**	**333**	**1990**	**Ha**	**<0.0001**	**26.91**	**1990**	**Ha**	**<0.0001**	**15.84**	**1990**	**Ha**	**<0.0001**	**0.35**	**Ha**	Suspect
Mahabaleshwar	**<0.0001**	**1342**	**1964**	**Ha**	**<0.0001**	**49.94**	**1963**	**Ha**	**<0.0001**	**30.76**	**1963**	**Ha**	**<0.0001**	**0.54**	**Ha**	Suspect
Devgad	**<0.0001**	**460**	**1975**	**Ha**	**<0.0001**	**20.91**	**1975**	**Ha**	**<0.0001**	**15.59**	**1975**	**Ha**	**<0.0001**	**0.81**	**Ha**	Suspect
Vengurla	**<0.0001**	**596**	**1970**	**Ha**	**<0.0001**	**26.83**	**1970**	**Ha**	**<0.0001**	**18.63**	**1970**	**Ha**	**<0.0001**	**0.82**	**Ha**	Suspect
Solapur	**<0.0001**	**2001**	**1964**	**Ha**	**<0.0001**	**27.55**	**2000**	**Ha**	**<0.0001**	**27.48**	**1964**	**Ha**	**<0.0001**	**0.93**	**Ha**	Suspect
Solapur Jeur	**<0.0001**	**491**	**1971**	**Ha**	**<0.0001**	**26.75**	**1971**	**Ha**	**<0.0001**	**17.67**	**1971**	**Ha**	**<0.0001**	**0.56**	**Ha**	Suspect

TABLE 9

Homogeneity test statistics (*p* value approximation) for minimum temperature

Station	Pettitt's Test				SNHT				Buishand's Test				VNR			Class
	p	*K*	*Year*	*Trend*	*p*	T_0	*Year*	*Trend*	*p*	*Q*	*Year*	*Trend*	*p*	*N*	*Trend*	
Aurangabad	**0.0006**	**805**	**1917**	**Ha**	**<0.0001**	**34.79**	**1910**	**Ha**	**<0.0001**	**19.68**	**1917**	**Ha**	**<0.0001**	**1.03**	**Ha**	Suspect
Ahmednagar	**0.0001**	**1132**	**1930**	**Ha**	**0.0073**	**13.75**	**1930**	**Ha**	**0.0019**	**17.08**	**1930**	**Ha**	0.0839	1.73	H0	Suspect
Chikalthana	**<0.0001**	**922**	**1977**	**Ha**	**<0.0001**	**35.36**	**2001**	**Ha**	**<0.0001**	**22.36**	**1977**	**Ha**	**<0.0001**	**0.29**	**Ha**	Suspect
Beed	**0.0001**	**233**	**1975**	**Ha**	**<0.0001**	**15.98**	**1975**	**Ha**	**<0.0001**	**11.75**	**1975**	**Ha**	**0.0017**	**1.02**	**Ha**	Suspect
Dahanu	**<0.0001**	**988**	**1975**	**Ha**	**<0.0001**	**29.83**	**1975**	**Ha**	**<0.0001**	**22.40**	**1975**	**Ha**	**0.0011**	**1.25**	**Ha**	Suspect
Mormugao	**0.0111**	**260**	**1976**	**Ha**	**0.0052**	**13.94**	**1975**	**Ha**	**0.0031**	**11.16**	**1975**	**Ha**	**0.0143**	**1.34**	**Ha**	Suspect
Panjim	0.0608	278	1976	H0	**0.037**	**10.63**	**1964**	**Ha**	**0.0285**	**9.86**	**1976**	**Ha**	**0.0061**	**1.32**	**Ha**	Suspect
Jalgaon	0.1754	351	1992	H0	0.0521	8.66	1992	H0	0.0824	9.92	1992	H0	**0.0004**	**1.18**	**Ha**	Useful
Kolhapur	**<0.0001**	**858**	**1976**	**Ha**	**<0.0001**	**27.09**	**2008**	**Ha**	**<0.0001**	**17.20**	**1976**	**Ha**	**<0.0001**	**0.58**	**Ha**	Suspect
Malegaon	0.4704	514	1988	H0	0.0701	10.35	1989	H0	0.0693	12.58	1966	H0	**<0.0001**	**0.92**	**Ha**	Useful
Colaba	**0.0118**	**1134**	**1927**	**Ha**	**0.0003**	**17.98**	**2008**	**Ha**	**0.0161**	**16.06**	**1997**	**Ha**	**<0.0001**	**1.17**	**Ha**	Suspect
Santacruz	**<0.0001**	**901**	**1976**	**Ha**	**<0.0001**	**31.87**	**1975**	**Ha**	**<0.0001**	**22.57**	**1976**	**Ha**	**<0.0001**	**0.88**	**Ha**	Suspect
Nanded	**0.0173**	**193**	**1993**	**Ha**	0.0815	8.45	1993	H0	**0.0456**	**7.72**	**1993**	**Ha**	**0.0152**	**1.35**	**Ha**	Suspect
Nashik	0.158	88	1956	H0	0.2869	4.71	1956	H0	0.0872	5.28	1956	H0	0.1731	1.77	H0	Useful
Ozar	**0.0402**	**198**	**1999**	**Ha**	**0.0002**	**17.03**	**1999**	**Ha**	**0.0094**	**9.46**	**1999**	**Ha**	**0.0393**	**1.48**	**Ha**	Suspect
Osmanabad	**0.0058**	**106**	**2002**	**Ha**	0.2049	5.30	2002	H0	0.1398	4.99	2002	H0	**0.0041**	**0.93**	**Ha**	Doubtful
Pune	0.057	930	1962	H0	0.083	8.50	2005	H0	0.0674	13.44	1962	H0	**<0.0001**	**1.10**	**Ha**	Useful
Baramati	0.7612	84	1988	H0	0.5235	3.62	1991	H0	0.7023	3.93	1970	H0	0.1987	1.74	H0	Useful
Alibag	**0.0215**	**592**	**1994**	**Ha**	**0.002**	**14.22**	**2001**	**Ha**	**0.0161**	**13.25**	**1995**	**Ha**	**0.0008**	**1.29**	**Ha**	Suspect
Bhira	**0.0005**	**300**	**1978**	**Ha**	**0.03**	**13.84**	**2007**	**Ha**	**0.0039**	**10.25**	**1975**	**Ha**	**<0.0001**	**0.51**	**Ha**	Suspect
Ratnagiri	**0.0008**	**1271**	**1960**	**Ha**	**0.0007**	**26.32**	**2010**	**Ha**	**0.0003**	**19.86**	**1960**	**Ha**	**<0.0001**	**0.93**	**Ha**	Suspect
Harnai	0.2534	317	1974	H0	**0.0132**	**13.39**	**2008**	**Ha**	0.1558	8.82	1974	H0	**0.0021**	**1.29**	**Ha**	Doubtful
Sangli	**0.0494**	**428**	**1989**	**Ha**	**0.0022**	**17.69**	**2014**	**Ha**	0.0607	10.18	1990	H0	**<0.0001**	**0.95**	**Ha**	Suspect
Satara	**0.0116**	**200**	**1987**	**Ha**	**0.0017**	**13.27**	**1982**	**Ha**	**0.0075**	**9.20**	**1987**	**Ha**	**0.0055**	**1.21**	**Ha**	Suspect
Mahabaleshwar	0.4481	315	1997	H0	0.5813	3.51	1972	H0	0.2533	8.26	1972	H0	0.1549	1.78	H0	Useful
Devgad	**0.0136**	**293**	**1966**	**Ha**	**0.0037**	**14.09**	**1981**	**Ha**	**0.0028**	**11.48**	**1980**	**Ha**	**<0.0001**	**0.80**	**Ha**	Suspect
Vengurla	**<0.0001**	**487**	**1981**	**Ha**	**0.0001**	**19.00**	**1981**	**Ha**	**0.0001**	**15.55**	**1981**	**Ha**	**0.0023**	**1.23**	**Ha**	Suspect
Solapur	**<0.0001**	**1928**	**1956**	**Ha**	**0.0432**	**15.21**	**1996**	**Ha**	**0.0051**	**17.35**	**1956**	**Ha**	**<0.0001**	**0.99**	**Ha**	Suspect
Jeur	0.261	162	1987	H0	0.0543	11.70	1993	H0	**0.0108**	**9.48**	**1987**	**Ha**	**0.001**	**1.02**	**Ha**	Doubtful

TABLE 10

Homogeneity Test Statistics (*p* value approximation) for Rainfall after Correction

Station	Pettitt's Test				SNHT				Buishand's Test				VNR			Class
	p	*K*	*Year*	*Trend*	*p*	T_0	*Year*	*Trend*	*p*	*Q*	*Year*	*Trend*	*p*	*N*	*Trend*	
Chikalthana	0.2048	312	1993	H0	0.6473	3.13	1993	H0	0.3612	6.96	1993	H0	0.7406	2.16	H0	Useful
Colaba	0.2556	710	1929	H0	0.1941	6.64	1925	H0	0.1474	11.83	1941	H0	0.542	2.02	H0	Useful
Ozar	0.7036	96	2002	H0	0.2763	4.97	2004	H0	0.6841	4.15	2002	H0	0.3929	1.91	H0	Useful
Pune	0.8446	418	2003	H0	0.3894	4.79	2003	H0	0.6045	7.72	2003	H0	0.0172	1.61	H0	Useful
Ratnagiri	**0.0397**	**906**	**1972**	**Ha**	0.1854	6.57	1972	H0	0.0603	13.32	1972	H0	0.2482	1.87	H0	Useful
Vengurla	0.48	162	1964	H0	0.7046	2.65	1963	H0	0.5409	5.24	1963	H0	0.5695	2.05	H0	Useful

TABLE 11

Homogeneity test statistics (*p* value approximation) for maximum temperature after correction

Station	Pettitt's Test				SNHT				Buishand's Test				VNR			Class
	p	*K*	*Year*	*Trend*	*p*	T_0	*Year*	*Trend*	*p*	*Q*	*Year*	*Trend*	*p*	*N*	*Trend*	
Aurangabad	0.3184	389	1963	H0	0.3191	5.37	1971	H0	0.3886	7.73	1963	H0	**0.0055**	**1.45**	**Ha**	Useful
Ahmednagar	0.1703	607	1940	H0	0.2393	6.25	1981	H0	0.2427	9.64	1981	H0	**<0.0001**	**1.02**	**Ha**	Useful
Beed	0.487	86	1990	H0	0.0868	7.15	1961	H0	0.5114	4.30	1990	H0	0.0358	1.41	H0	Useful
Dahanu	0.1444	346	1964	H0	0.2227	6.17	1961	H0	0.1158	9.27	1964	H0	**0.005**	**1.40**	**Ha**	Useful
Mormugao	0.0923	196	1969	H0	**0.0047**	**11.68**	**1968**	**Ha**	0.0771	7.87	1969	H0	**<0.0001**	**0.85**	**Ha**	Doubtful
Panjim	**<0.0001**	**570**	**2001**	**Ha**	**<0.0001**	**47.20**	**2001**	**Ha**	**<0.0001**	**22.75**	**2001**	**Ha**	**<0.0001**	**0.17**	**Ha**	Suspect
Jalgaon	0.1481	366	1988	H0	0.124	7.85	1989	H0	0.0664	10.20	1988	H0	**0.0099**	**1.46**	**Ha**	Useful
Kolhapur	**0.0054**	**521**	**1989**	**Ha**	**0.0267**	**9.88**	**1989**	**Ha**	**0.0102**	**12.59**	**1989**	**Ha**	**0.0008**	**1.21**	**Ha**	Suspect
Colaba	**0.0008**	**1434**	**1985**	**Ha**	**0.0002**	**19.28**	**1986**	**Ha**	**0.0009**	**21.05**	**1986**	**Ha**	**<0.0001**	**0.97**	**Ha**	Suspect
Santacruz	0.2332	309	1999	H0	0.5241	3.84	2001	H0	0.3883	6.89	2001	H0	0.1546	1.75	H0	Useful
Nashik	0.0573	122	1958	H0	0.11	7.53	1982	H0	0.3719	4.57	1958	H0	**0.0427**	**1.43**	**Ha**	Useful
Osmanabad	0.443	59	1981	H0	0.1782	5.12	1978	H0	0.4096	4.06	1981	H0	0.1731	1.64	H0	Useful
Baramati	0.1527	154	1963	H0	0.0686	7.54	1990	H0	0.153	6.60	1963	H0	**0.0041**	**1.19**	**Ha**	Useful
Alibag	**0.0101**	**646**	**1994**	**Ha**	**0.0018**	**14.75**	**1997**	**Ha**	**0.0091**	**14.12**	**1994**	**Ha**	**<0.0001**	**0.85**	**Ha**	Suspect
Ratnagiri	**0.0019**	**1244**	**2000**	**Ha**	**<0.0001**	**32.63**	**2001**	**Ha**	**0.0006**	**21.30**	**2000**	**Ha**	**<0.0001**	**0.92**	**Ha**	Suspect
Harnai	0.1782	347	1959	H0	0.13	7.55	1957	H0	0.0859	9.81	1959	H0	0.1567	1.76	H0	Useful
Sangli	0.1704	346	1939	H0	**0.0155**	**11.05**	**1939**	**Ha**	0.1477	8.90	1939	H0	**0.0008**	**1.27**	**Ha**	Doubtful
Satara	0.0775	161	1999	H0	0.1514	5.86	2008	H0	0.2592	5.68	2006	H0	**0.0004**	**0.99**	**Ha**	Useful
Mahabaleshwar	**0.0324**	**530**	**1948**	**Ha**	**0.0159**	**11.10**	**1940**	**Ha**	0.0525	11.14	1948	H0	**0.0296**	**1.58**	**Ha**	Suspect
Devgad	0.3327	174	1993	H0	**0.0155**	**10.00**	**1993**	**Ha**	0.3388	6.13	1993	H0	**0.0129**	**1.39**	**Ha**	Doubtful
Vengurla	0.0877	254	2000	H0	**0.0155**	**10.10**	**2001**	**Ha**	0.1183	7.99	2000	H0	0.0527	1.56	H0	Useful
Solapur	0.0632	918	2000	H0	**0.0109**	**12.09**	**2001**	**Ha**	0.0734	13.20	2000	H0	**<0.0001**	**1.19**	**Ha**	Doubtful
Jeur	0.1731	185	1981	H0	0.2896	5.13	1981	H0	0.1385	7.28	1981	H0	**0.0053**	**1.27**	**Ha**	Useful

TABLE 12

Homogeneity Test Statistics (*p* value approximation) for Minimum Temperature after Correction

Station	Pettitt's Test				SNHT				Buishand's Test				VNR			Class
	p	*K*	*Year*	*Trend*	*p*	T_0	*Year*	*Trend*	*p*	*Q*	*Year*	*Trend*	*p*	*N*	*Trend*	
Aurangabad	0.4013	357	1973	H0	0.0437	8.72	1980	Ha	0.4195	7.45	1973	H0	**0.0192**	**1.55**	**Ha**	Useful
Ahmednagar	0.1493	632	1981	H0	0.0293	13.34	2003	Ha	0.4511	8.00	2003	H0	0.4619	1.98	H0	Useful
Chikalthana	**0.0001**	**616**	**2001**	**Ha**	**<0.0001**	**29.65**	**2006**	**H0**	**0.0001**	**16.97**	**2005**	**Ha**	**<0.0001**	**0.58**	**Ha**	Suspect
Beed	0.9289	54	1994	H0	0.3463	4.17	1961	H0	0.9766	2.38	1994	H0	0.3164	1.83	H0	Useful
Dahanu	0.3288	281	1968	H0	0.4173	4.22	2005	H0	0.6569	5.51	1968	H0	0.8619	2.25	H0	Useful
Mormugao	0.7359	104	1989	H0	0.1675	5.63	1964	H0	0.9249	3.19	1987	H0	0.3711	1.90	H0	Useful
Panjim	0.8276	125	2003	H0	**0.0322**	**9.41**	**1964**	**Ha**	0.7295	4.53	1976	H0	**0.0395**	**1.53**	**Ha**	Doubtful
Kolhapur	0.0532	418	2007	H0	**0.0009**	**22.16**	**2008**	**Ha**	**0.0189**	**11.59**	**2007**	**Ha**	**<0.0001**	**0.76**	**Ha**	Suspect
Colaba	**0.0012**	**1354**	**1995**	**Ha**	**<0.0001**	**26.87**	**2000**	**Ha**	**0.0004**	**21.48**	**1995**	**Ha**	**<0.0001**	**1.30**	**Ha**	Suspect
Santacruz	0.5856	227	2010	H0	0.1898	6.15	1954	H0	0.6102	5.74	2010	H0	0.0513	1.62	H0	Useful
Nanded	0.3324	117	1993	H0	0.2123	5.70	2006	H0	0.6209	4.16	1993	H0	0.1056	1.60	H0	Useful
Ozar	0.4618	118	1975	H0	0.2064	5.68	1968	H0	0.2325	6.07	1975	H0	0.5784	2.06	H0	Useful
Osmanabad	0.2867	60	2002	H0	0.4379	3.30	1997	H0	0.2385	4.53	1997	H0	**<0.0001**	**8.18**	**Ha**	Useful
Alibag	0.7735	251	1982	H0	0.5231	3.98	2014	H0	0.6567	6.02	1982	H0	**0.0205**	**1.55**	**Ha**	Useful
Bhira	0.6026	109	1975	H0	**0.0083**	**21.55**	**2007**	**Ha**	0.1231	6.89	2005	H0	**<0.0001**	**0.60**	**Ha**	Doubtful
Ratnagiri	0.3593	594	2010	H0	**0.0013**	**21.74**	**2010**	**Ha**	0.112	12.00	2010	H0	**<0.0001**	**1.06**	**Ha**	Doubtful
Harnai	0.5106	251	1974	H0	0.607	3.48	1950	H0	0.4699	6.50	1974	H0	**0.0494**	**1.61**	**Ha**	Useful
Sangli	0.4666	263	1969	H0	**0.0191**	**15.98**	**2014**	**Ha**	0.5527	6.08	1969	H0	**<0.0001**	**1.04**	**Ha**	Doubtful
Satara	0.3116	120	2000	H0	0.1522	6.54	1980	H0	0.1979	6.10	1982	H0	0.069	1.53	H0	Useful
Devgad	0.3609	168	1985	H0	0.3742	4.37	2003	H0	0.4739	5.41	1985	H0	**0.0004**	**1.08**	**Ha**	Useful
Vengurla	0.6855	132	1978	H0	0.9053	1.82	1950	H0	0.8124	4.04	1978	H0	0.2017	1.77	H0	Useful
Solapur	**0.0081**	**1178**	**1975**	**Ha**	0.2681	6.14	2000	H0	0.2526	10.24	1996	H0	**<0.0001**	**1.08**	**Ha**	Doubtful

inhomogeneities and can be used for further analysis after critical inspection.

Class C : Suspect - The series that rejects three or all null hypothesis under four tests at 5% level of significance are considered. The stations under this class have significant inhomogeneities and cannot be used for further analysis.

In this study stations with class 'doubtful' and 'suspect' are excluded from further climate trend analysis until they are thoroughly inspected for inhomogeneities and necessary corrections are made to adjust the data for homogeneity.

2.5. *Homogeneity correction*

The results from homogeneity tests are analysed and based on categorisation, stations with class 'doubtful' and 'suspect' are selected for correction procedure. Stations with category 'useful' are used as reference station. Adjustment factor is calculated for both rainfall and temperature, which is needed to correct the original data series.

2.5.1. *Selection of reference station*

For selection of reference station, influence of spatial variation and eventual inhomogeneities in the reference

TABLE 13

Homogeneity tests before and after correction summary

Index	District	Station	Class of Homogeneity (Before)			Class of Homogeneity (After)		
			Rainfall	Maximum Temperature	Minimum Temperature	Rainfall	Maximum Temperature	Minimum Temperature
42851	Ahmednagar	Ahmednagar	A	C	C	--	A	A
43013	Aurangabad	Aurangabad	A	C	C	--	A	A
42921	Aurangabad	Chikalthana	B	A	C	A	--	C
42925	Beed	Beed	A	C	C	--	A	A
43075	Dahanu	Dahanu	A	C	C	--	A	A
43001	Goa	Mormugao	A	C	C	--	B	A
43003	Goa	Panjim	A	C	C	--	C	B
43009	Jalgaon	Jalgaon	A	C	A	--	A	--
43011	Kolhapur	Kolhapur	A	B	C	--	C	C
43014	Malegaon	Malegaon	A	B	A	--	--	--
43021	Mumbai	Colaba	C	C	C	A	C	C
43057	Mumbai	Santacruz	A	C	C	--	A	A
43058	Nanded	Nanded	A	A	C	--	--	A
43060	Nashik	Nashik	A	C	A	--	A	--
42920	Nashik	Ozar	C	A	C	A	--	A
43062	Osmanabad	Osmanabad	A	C	B	--	A	A
43063	Pune	Pune	C	A	A	A	--	--
43069	Pune	Baramati	A	C	A	--	A	--
43061	Pune	Khandala	A	--	--	--	--	--
43071	Raigad	Alibag	A	C	C	--	C	A
43109	Raigad	Bhira	A	A	C	--	--	B
43111	Ratnagiri	Ratnagiri	C	C	C	A	C	B
43113	Ratnagiri	Harnai	A	C	B	--	A	A
43117	Sangli	Sangli	A	C	C	--	B	B
43153	Satara	Satara	A	C	C	--	A	A
43157	Satara	Mahabaleshwar	A	C	A	--	C	--
43158	Sindhudurg	Devgad	A	C	C	--	B	A
43192	Sindhudurg	Vengurla	B	C	C	A	A	A
43193	Solapur	Solapur	A	C	C	--	B	B
43196	Solapur	Jeur	A	C	B	--	A	--

TABLE 14

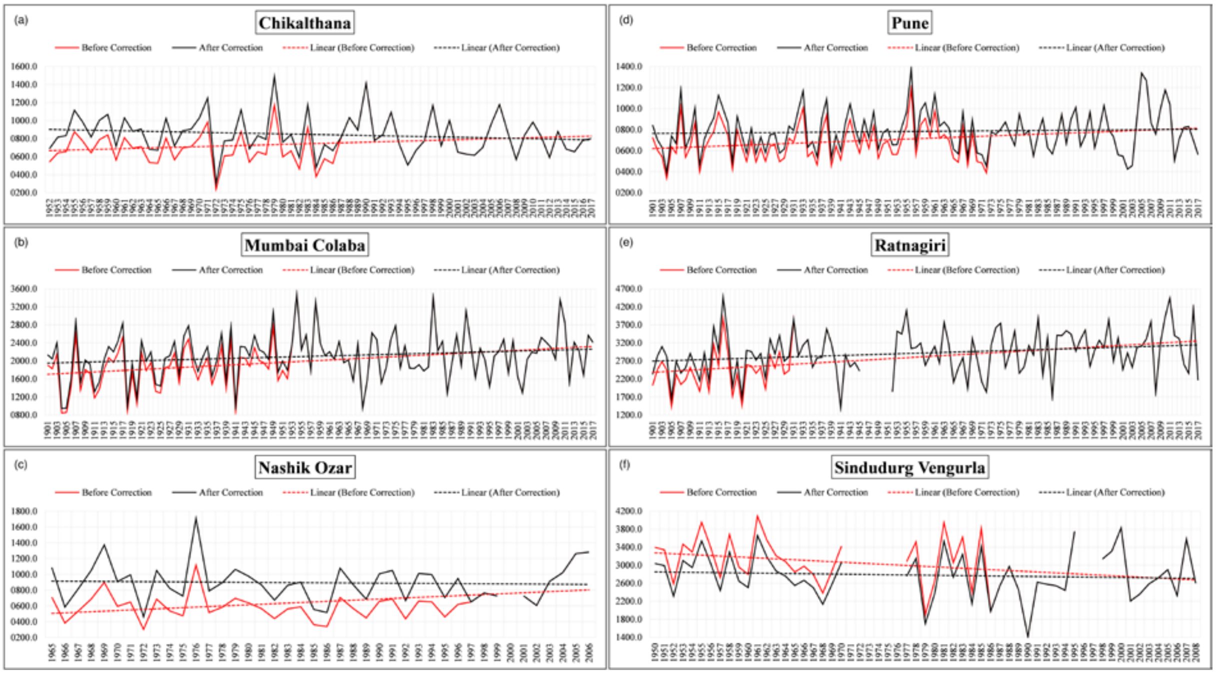
Homogeneity test results

Parameter	Total Stations	Station Class (Before Correction)			Station Class (After Correction)		
		Class A:Useful	Class B:Doubtful	Class C:Suspect	Class A:Useful	Class B:Doubtful	Class C:Suspect
Precipitation	30	24 (80%)	2 (7%)	4 (13%)	30 (100%)	0 (0%)	0 (0%)
Maximum Temperature	29	5 (17%)	2 (7%)	22 (76%)	18 (62%)	5 (17%)	6 (21%)
Minimum Temperature	29	6 (21%)	3 (10%)	20 (69%)	20 (69%)	6 (21%)	3 (10%)

TABLE 15

Homogeneity Test Regression Statistics Results

Station	Rainfall				Maximum Temperature				Minimum Temperature			
	Before		After		Before		After		Before		After	
	R Square	Slope	R Square	Slope	R Square	Slope	R Square	Slope	R Square	Slope	R Square	Slope
Aurangabad	--	--	--	--	0.245	0.011	0.001	0.001	0.163	0.008	0.001	0.000
Ahmednagar	--	--	--	--	0.187	0.013	0.000	0.000	0.038	0.004	0.002	-0.001
Chikalthana	0.054	2.472	0.026	-1.786	--	--	--	--	0.594	0.041	0.074	0.010
Beed	--	--	--	--	0.090	-0.026	0.015	0.009	0.386	0.034	0.007	0.003
Dahanu	--	--	--	--	0.507	0.020	0.023	0.003	0.391	0.019	0.005	0.002
Mormugao	--	--	--	--	0.548	0.030	0.064	0.007	0.173	0.011	0.001	-0.001
Panjim	--	--	--	--	0.619	0.023	0.696	0.052	0.064	0.005	0.005	0.001
Jalgaon	--	--	--	--	0.007	0.002	0.034	-0.005	--	--	--	--
Kolhapur	--	--	--	--	0.003	0.001	0.040	-0.004	0.253	0.015	0.009	0.002
Colaba	0.119	5.310	0.031	2.674	0.714	0.015	0.089	0.004	0.002	0.000	0.105	0.004
Santacruz	--	--	--	--	0.412	0.014	0.006	0.001	0.349	0.017	0.000	0.000
Nanded	--	--	--	--	--	--	--	--	0.088	0.021	0.012	0.007
Nashik	--	--	--	--	0.155	0.035	0.007	-0.006	--	--	--	--
Ozar	0.162	7.277	0.003	-1.035	--	--	--	--	0.211	0.022	0.022	0.005
Osmanabad	--	--	--	--	0.617	0.053	0.051	0.008	0.002	-0.005	0.025	-0.017
Pune	0.087	1.655	0.004	0.353	--	--	--	--	--	--	--	--
Baramati	--	--	--	--	0.048	-0.012	0.084	0.014	--	--	--	--
Alibag	--	--	--	--	0.788	0.024	0.110	0.005	0.074	0.004	0.001	0.000
Bhira	--	--	--	--	--	--	--	--	0.078	0.028	0.018	-0.012
Ratnagiri	0.169	7.536	0.050	3.892	0.654	0.014	0.050	0.002	0.114	-0.005	0.009	-0.001
Harnai	--	--	--	--	0.500	0.018	0.035	0.004	0.041	-0.006	0.002	-0.001
Sangli	--	--	--	--	0.313	0.014	0.001	0.001	0.041	0.006	0.001	-0.001
Satara	--	--	--	--	0.714	0.066	0.044	0.009	0.085	-0.016	0.001	-0.001
Mahabaleshwar	--	--	--	--	0.664	0.032	0.066	0.006	--	--	--	--
Devgad	--	--	--	--	0.419	0.018	0.035	0.004	0.248	-0.018	0.001	-0.001
Vengurla	0.103	-10.379	0.008	-2.500	0.551	0.015	0.013	0.002	0.252	-0.012	0.004	0.001
Solapur	--	--	--	--	0.180	0.007	0.001	0.001	0.082	0.006	0.000	0.000
Jeur	--	--	--	--	0.521	0.047	0.020	0.006	--	--	--	--



Figs. 1(a-f). Rainfall series before and after homogeneity correction

series will be reduced by using more than one reference series. The criteria for selecting reference series stations must satisfy conditions such as, it must be at minimum distance from test station, it should have same climate properties as test station, the availability of data must be of same or more period as test station and it the data of reference series should highly correlate with test series data. Based on our testing results, we have decided to use only single reference station because the aforementioned selection criteria was difficult to achieve for multiple reference station as stations with ‘useful’ categories were at far distance from each other having different data availability period and difference in climate patterns.

2.5.2. *Adjustment factor*

After identifying the break dates in test series, an adjustment for homogeneity is made by calculating adjustment factor. This adjustment factor is then used to correct the data before the break date by multiplying original rainfall data or by adding in original temperature data. As mentioned earlier, rainfall and temperature series have different correction procedure; the details of which are given below.

2.5.3. *Rainfall series correction*

Generally, ratio in test and reference series q in a specific year i is given as,

$$q_i = \frac{f(P_i)}{g(Q_{ij}, j = 1, K_i)}$$

Here, i is the function of precipitation P_i at the test station, Q_{ij} is the precipitation at the j^{th} reference station, and g is the function of precipitation at all the $k_i k_i$ reference stations. Functions of f and g are defined as,

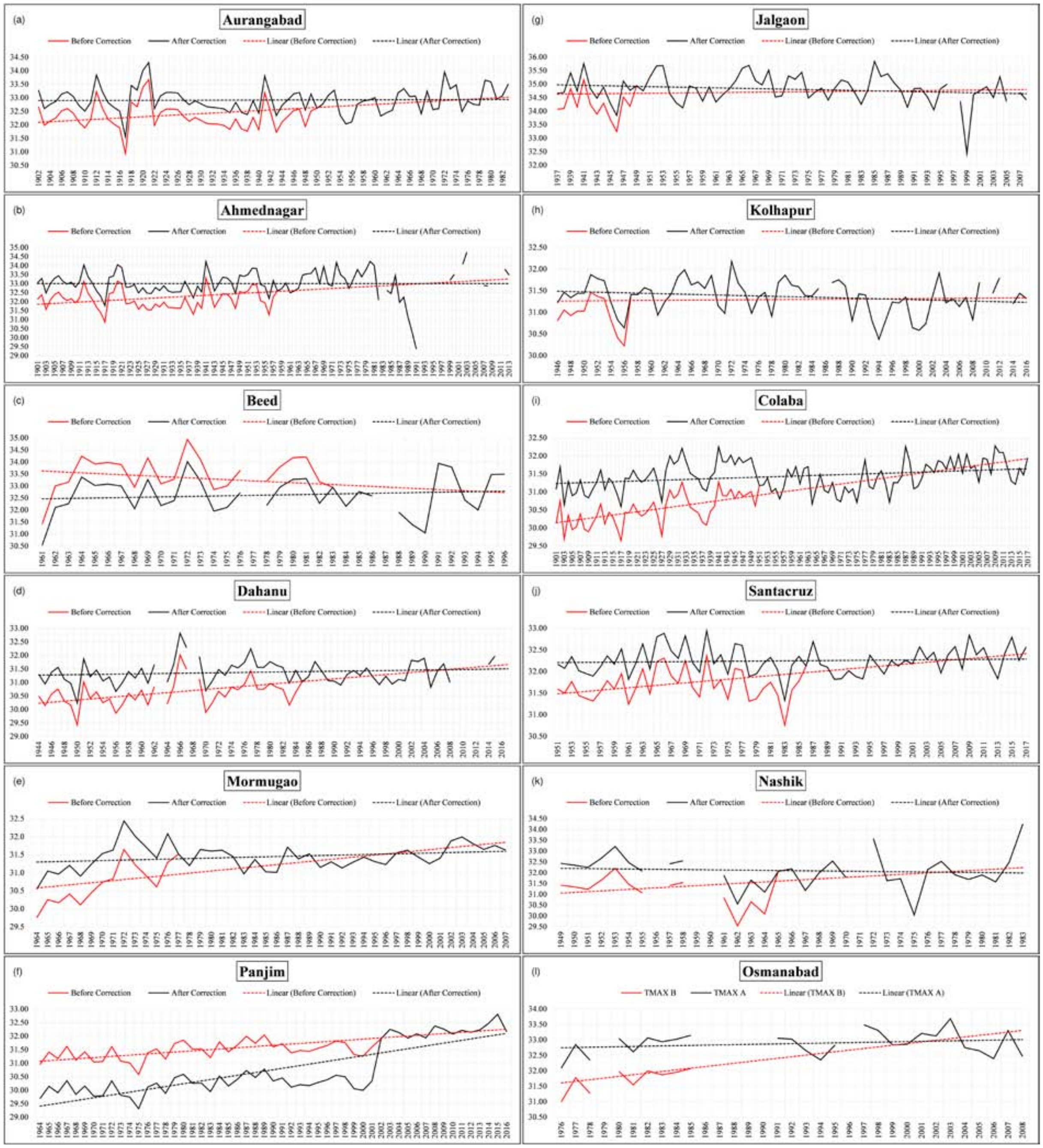
$$f(P_i) = \frac{P_i}{\bar{P}} \text{ and } g(Q_{ij}, j = 1, K_i) = \frac{\sum_{j=1}^{k_i} V_j (Q_{ij} / \bar{Q}_j)}{\sum_{j=1}^{k_i} V_j}$$

where, $\bar{P}$ and $\bar{Q}_j$ are mean precipitation throughout the observation period for the test station and the j^{th} reference station, respectively, and k_i is the number of reference stations in the ith year of observation. V_j is a weight factor for reference station j which is defined by the correlation coefficients between the test series and j^{th} reference series (Peterson *et al*., 1998).

Inhomogeneous series is adjusted by multiplying the precipitation values for the period before the break date with an adjustment factor,

$$\text{AF} = \frac{q_a}{q_b}$$

Here, q_a and q_b are mean values of q_i after and before break year, respectively.

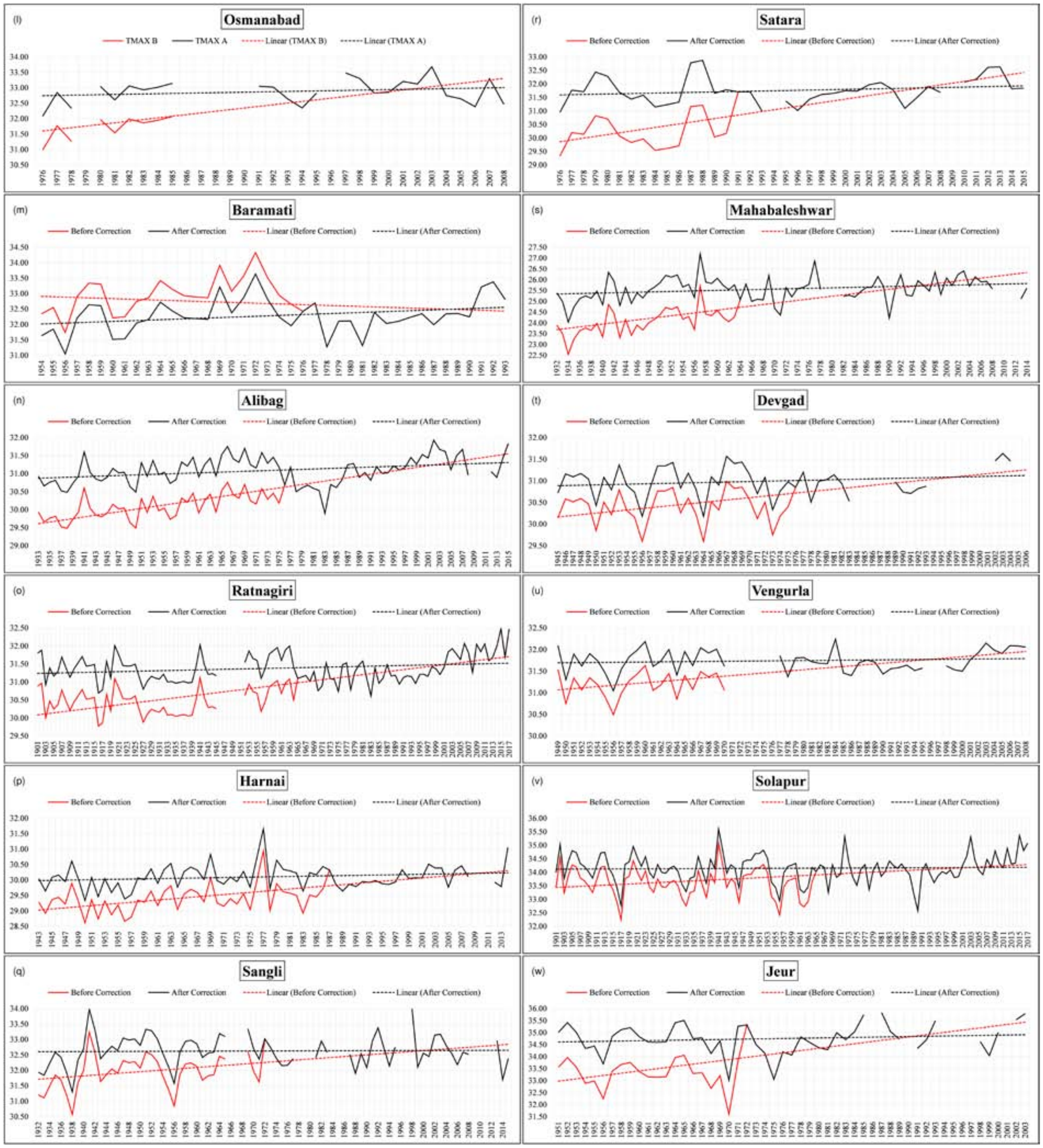


Figs. 2(a-l). Maximum temperature series before and after homogeneity correction

2.5.4. *Temperature series correction*

First, select a time interval Δt before and after break year t_{break}. Next, for each interval Δt, take average of each individual month separately and let us call it t_{break} and t_{after} Now, calculate the correction dT for each month separately by taking difference of these averages t_{before} and t_{after}.

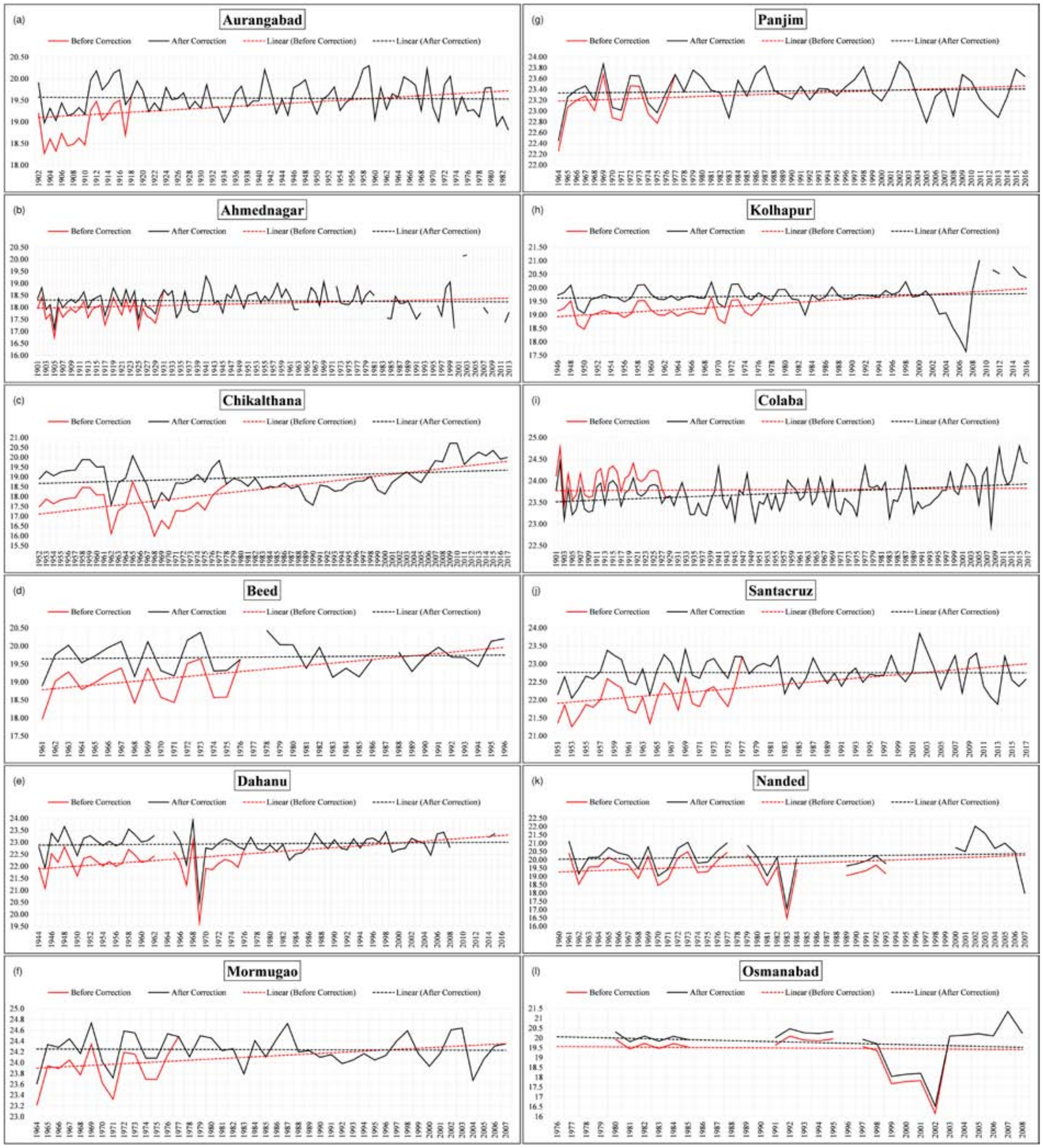
After calculating dT, make smoothing 12 monthly dT by taking 3-month adjacent running average to achieve reasonable variation of dT throughout the year. By doing this for each of 12 months individually, we will get our adjustments factor AF for each month. Corrected series can be achieved by adding this adjustment factor in original temperature series for the period before the break year.



Figs. 3(l-w). Maximum temperature series before and after homogeneity correction

3. Results and discussions

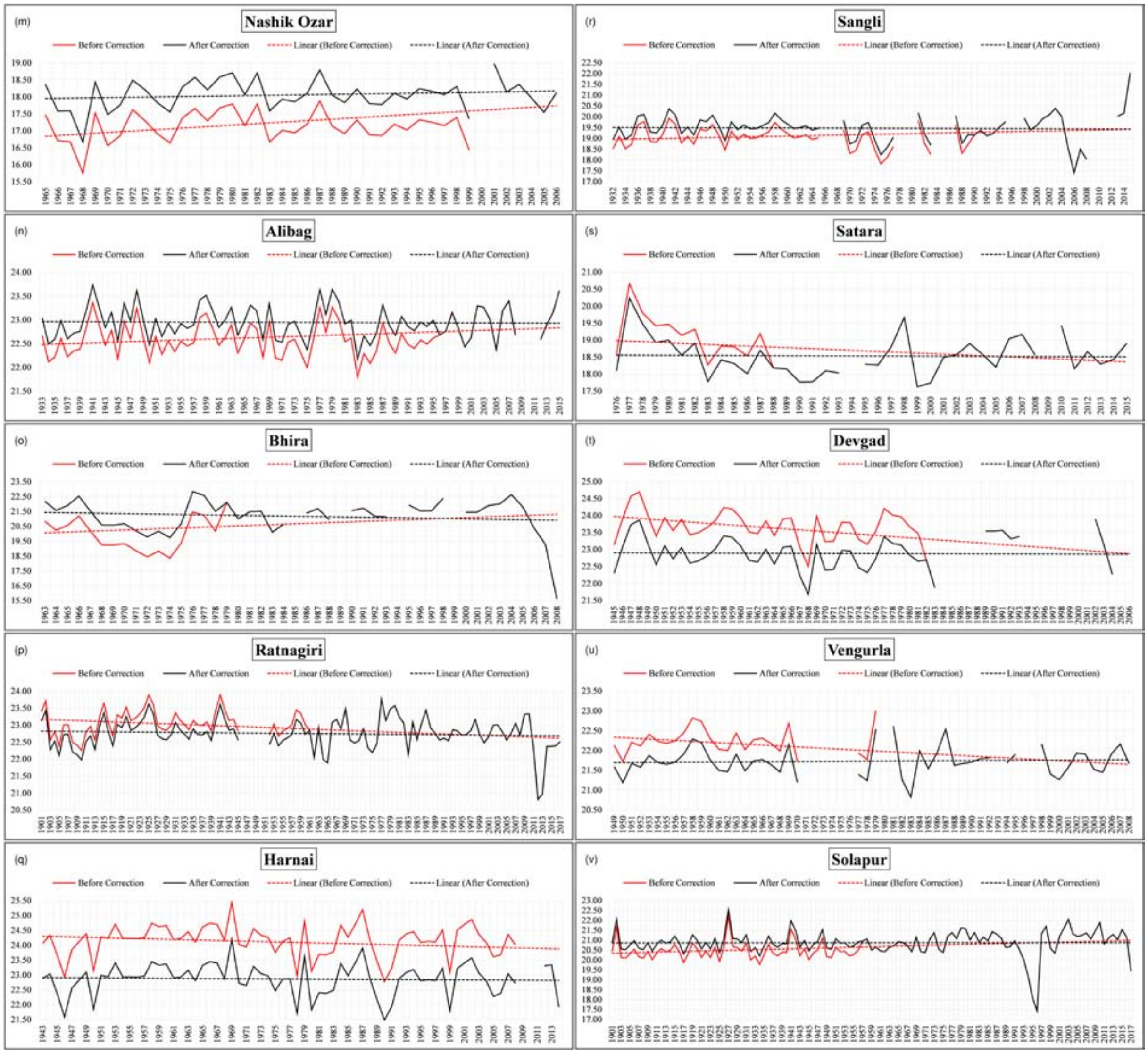
Total 30 rainfall and temperature stations were tested for data homogeneity. For rainfall series, homogeneity test results show 80% as useful, 7% as doubtful and 13% as suspect (Table 7), For maximum temperature series, homogeneity test result shows 17% useful, 7% doubtful and 76% suspect stations (Table 8) and for minimum temperature series, homogeneity test result shows 21% useful, 10% doubtful and 69% suspect stations (Table 9). Use of various test found to be useful in detecting break year because of their characteristics as parametric, non-parametric, rank, *etc*. It is also observed that, break year detected by most tests were same for a respective station. The stations with doubtful and suspect category were taken up for correction by using useful category stations as reference series for rainfall. After applying correction procedures, the results show all 100% rainfall stations as



Figs. 4(a-l). Minimum temperature series before and after homogeneity correction

'useful' (Table 10), for maximum temperature series the results are 62% as 'useful', 17% as 'doubtful' and 21% as 'suspect (Table 11), while for minimum temperature series these results are 69% as 'useful', 21% as 'suspect' and 10% as 'doubtful' (Table 12). The 'useful' category stations may be used further in climate and trend analysis studies. Table 13 shows the summary of homogeneity tests before & after correction for all three parameters, whereas Table 14 shows the consolidated homogeneity test results.

Table 15 shows the linear regression statistics (change in trend) for all three parameters before and after applying the homogeneity correction. Fig. 1 shows the linear trend line for rainfall and it shows that 33% stations show-decreasing trend after applying homogeneity



Figs 5(m-v). Minimum temperature series before and after homogeneity correction

correction. Figs. 2&3 shows the linear trend line for maximum temperature and it shows that 9% of the stations show the increasing trend whereas 13% of the total stations show the decreasing trend after applying homogeneity correction. Figs. 4&5 shows the linear trend line for minimum temperature, which shows that 5% of the stations show the increasing trend whereas 18% of total stations show the decreasing Trend. For majority of stations, it has been seen then there is an overall reduction in magnitude of a trained to applying the homogeneity correction for all the rainfall and temperature series.

One of the biggest consequences of biased trends are reflected in the climate change studies. Several climate studies show the increasing trend in temperature and decreasing trend in rainfall over last century, concluding as an effect of global warming. Such studies have failed to incorporate effects of non-climatic jumps in data and the inhomogeneities arrived due to various external factors are also not considered. Here, the trends in series before and after correction will also help to determine if there is an effect of climate change or not.

4. Conclusions

In the present study, homogeneity tests are proven most important part of climate and trend analysis studies. Different characteristics of these tests not only helped in identifying significant non-climatic jump in a time series but also location of a break period. The correction methods used are proved to be very effective in removing non-climatic jump from time series and making it homogeneous.

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