Trend detection in annual maximum temperature and precipitation using the Mann Kendall test – A case study to assess climate change on Anand of central Gujarat

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1. Introduction

Rain is one of the nature's greatest gifts for countries. It is a major concern to identify any trends for rainfall to deviate from its periodicity, which would disrupt the economy of the country. In the present study rainfall is estimated based on the temperature, air pressure, humidity, cloudiness, precipitation, wind direction, wind speed, etc., consolidated from meteorological experts. The available literature suggests a wide range of impacts of climate change in Asia in general and in India in specific. Studies indicate an increase in the temperatures to the tune of 0.57 degree centigrade per 100 years (Rupakumar et al., 1994). However, the analyses of past rainfall events suggest no clear trend. The decadal departures found are above and below the long time averages alternatively for three consecutive decades (Kothyari and Singh, 1996).
2. Data and methodology

2.1. Study area

The study area is located in the Anand, Gujarat state of India shown in Fig. 1. Geographically, it is situated at the Anand (latitude - 22° 35' N, longitude- 72° 58' E) station is located in Middle Gujarat Agro-Climatic Zone-3. The annual rainfall at Anand is ranged between 286.9 mm to 1693.4 mm.

The data used in this paper are the monthly averages of total monthly rainfall and mean of maximum temperatures during 1975-2005. The yearly averages were calculated from the monthly readings which are provided by the Department of Agricultural Meteorology, BACA, Anand Agricultural University, Anand. Trend is determined by the relationship between the two variables as temperature and time, rainfall and time. The statistical methods such as correlation analysis, regression analysis and coefficient of determination $R^2$ (Murray & Larry, 2000) are used. The magnitudes of the trends of increasing or decreasing maximum temp, total monthly rainfall, were derived and tested by the Mann-Kendall (M-K) trend test.
### TABLE 1

Statistical summary of monthly mean of maximum temperatures during the years 1975-2005 at Anand

| Month   | Mean   | S.D. (%) | Mean Deviation | C.V. (%) |
|---------|--------|----------|----------------|----------|
| January | 27.870 | 1.040    | 0.69742        | 3.732    |
| February| 30.153 | 1.536    | 1.48844        | 5.095    |
| March   | 34.947 | 1.866    | 0.97625        | 5.341    |
| April   | 38.336 | 1.315    | 0.34423        | 3.429    |
| May     | 39.056 | 2.060    | 0.81775        | 5.275    |
| June    | 36.551 | 1.703    | 1.24045        | 4.658    |
| July    | 32.346 | 1.072    | 0.46023        | 3.315    |
| August  | 31.197 | 1.354    | 0.61436        | 4.349    |
| September| 33.138| 1.758    | 0.70040        | 5.306    |
| October | 35.257 | 1.523    | 0.80005        | 4.319    |
| November| 32.625 | 1.152    | 0.98331        | 3.531    |
| December| 29.290 | 1.036    | 0.57176        | 3.537    |

The coefficient of variation for MMAX temperature is highest in the month of March and it is observed as 5.341% whereas it is lowest in the month of July and it is 3.315% for the Anand district in Table 1. This means maximum temperature is most stable in the month of May and least stable in the month of July for the Anand district.

The coefficient of variation for TMRF observed highest in the month of April and it is 556.77% whereas coefficient of variation is minimum for the month of August and it is 37.237% for the Anand district in Table 2. This shows that rainfall is more stable in the month of April and is more variable in the month of August for the Anand district.

### TABLE 2

Statistical summary of monthly mean of total monthly rainfall during the years 1975-2005 at Anand

| Month   | Mean   | S.D. (%) | Mean Deviation | C.V. (%) |
|---------|--------|----------|----------------|----------|
| January | 1.216  | 4.223    | 0.524756       | 347.285  |
| February| 1.319  | 4.560    | 0.453438       | 345.612  |
| March   | 0.168  | 0.537    | 0.128264       | 320.073  |
| April   | 0.500  | 2.784    | 1.191482       | 556.776  |
| May     | 4.987  | 15.552   | 31.60764       | 311.851  |
| June    | 157.177| 187.008  | 89.35304       | 118.979  |
| July    | 340.290| 167.204  | 169.8967       | 49.136   |
| August  | 575.813| 214.413  | 201.4204       | 37.237   |
| September| 100.435| 108.656  | 31.84704       | 108.185  |
| October | 23.448 | 48.803   | 9.384111       | 208.129  |
| November| 25.713 | 63.323   | 8.692981       | 246.269  |
| December| 0.929  | 3.266    | 0.392255       | 351.538  |

2.2. Linear regression

The equation of a linear regression line is given as:

$$ y = a + bx $$

where, $y$ is the observation on the dependent variable, $x$ is the observation on the independent variable,
TABLE 3
Year wise rainfall data during the years 1975-2005 at Anand

| Years | MMAX  | TMRF  | TMRF (J-S) |
|-------|-------|-------|------------|
| 1975  | 32.03 | 1633.4| 1530.5     |
| 1976  | 32.83 | 1633.1| 1530.3     |
| 1977  | 33.12 | 1285.8| 1277.2     |
| 1978  | 33.73 | 824.3 | 735.7      |
| 1979  | 33.72 | 894.2 | 640.6      |
| 1980  | 32.25 | 643.7 | 643.1      |
| 1981  | 33.49 | 1026.8| 921.6      |
| 1982  | 32.78 | 876.7 | 558.1      |
| 1983  | 33.56 | 1119.6| 1093.1     |
| 1984  | 33.44 | 726.5 | 726.5      |
| 1985  | 34.10 | 574.5 | 332.7      |
| 1986  | 35.04 | 286.9 | 285.1      |
| 1987  | 33.39 | 434.0 | 419.5      |
| 1988  | 33.33 | 1000.4| 1000.4     |
| 1989  | 33.14 | 706.0 | 702.0      |
| 1990  | 33.69 | 1232.1| 1094.2     |
| 1991  | 33.45 | 643.7 | 643.1      |
| 1992  | 34.01 | 672.0 | 666.4      |
| 1993  | 33.24 | 775.5 | 700.0      |
| 1994  | 33.64 | 1236.7| 1214.9     |
| 1995  | 33.33 | 557.4 | 545.5      |
| 1996  | 32.48 | 897.9 | 870.5      |
| 1997  | 33.41 | 1111.3| 1018.6     |
| 1998  | 33.33 | 1111.3| 1018.6     |
| 1999  | 34.02 | 425.2 | 384.2      |
| 2000  | 33.69 | 431.7 | 361.6      |
| 2001  | 34.39 | 709.4 | 666.8      |
| 2002  | 33.68 | 478.0 | 478.0      |
| 2003  | 33.75 | 1135.4| 1112.2     |
| 2004  | 33.54 | 866.0 | 857.8      |
| 2005  | 33.73 | 1693.4| 1688.0     |

(Source: Department of Agricultural Meteorology, Anand).
Note: (i) MMAX = Mean of maximum temperature,
(ii) TMRF = Total month rainfall and
(iii) TMRF (J-S) = Total month rainfall during June to September.

The total mean rainfall (dependent variables) against time (independent variable) in years were plotted. Linear regression lines were then fitted to determine the trends of temperature, rainfall. The drawing of the scattered diagrams and the fitting of the regression lines were done in Microsoft Excel in Table 3.

The Fig. 2 indicates the trend line for annual MMAX temperature against time is increasing, which implies there is a positive linear relationship between annual MMAX temperature and time. MMAX temperature has increased by 0.2636 °C during the last 41 years (1970-2011).

The Fig. 3 indicates the trend line for annual TMRF against time is decreasing, which implies there is a negative linear relationship between annual TMRF and time annual TMRF decreased by 245 mm during the last 41 years in Anand of Central Gujarat. The lowest rainfall was received 385 mm in the year 1986 whereas the highest rainfall was 2271.0 in 2006.

The Fig. 4 indicates the trend line for annual TMRF (J-S) against time is decreasing, which implies there is a negative linear relationship between annual TMRF(J-S) and time during decreased by 195 mm during the last 41 years in Anand of Central Gujarat. The lowest rainfall was received 383 mm in the year 1986 whereas the highest rainfall was 2214.6 in 2006.

2.3. Correlation coefficient

The correlation coefficients between temperature, rainfall, agriculture production and time were calculated as shown in Table 4.

Given the pairs of values \((x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)\), the Karl Pearson’s formula for calculating the correlation coefficient ‘r’ is given by:

\[
r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}
\]

where, \(i = 1, 2, \ldots, n\)

2.3.1. Testing the significance of the correlation coefficient

In testing the significance of the correlation coefficient, the following null \((H_0)\) and alternative \((H_1)\) hypothesis were considered.

Hypothesis: \(H_0: \rho = 0\) against \(H_1: \rho \neq 0\)

where, \(\rho\) is the population correlation coefficient.
The appropriate test statistics for testing the above hypothesis is:

\[ t = r \sqrt{(n - 2) / \sqrt{(1 - r^2)}} \], d. f. = \(n - 2 = 29\)

Significant value for \(t\) at 5\% level = 1.746

2.4. The Mann-Kendall test for trend

The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test was suggested by Mann (1945) and has been extensively used with environmental time series (Hipel and McLeod, 2005).

Let \(X_1, X_2, \ldots, X_n\) represents \(n\) data points where \(X_j\) represents the data point at time \(j\). Then the Mann-Kendall statistic \((S)\) is given by:

\[ S = \sum \Sigma \text{Sign} (X_j - X_k), j = 2, 3, \ldots, n \text{ and } k=1, 2, \ldots, j-1 \]

where: \(\text{Sign} (X_j - X_k) = 1\) if, \(X_j - X_k > 0\)

\(= 0\) if \(X_j - X_k = 0\)

\(= -1\) if \(X_j - X_k < 0\)

A very high positive value of \(S\) is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with \(S\) and the sample size, \(n\), to statistically quantify the significance of the trend in Table 5.

For a sample size > 10, a normal approximations to the Mann-Kendall test may be used.

For this, variance of \(S\) is obtained as,

\[ V(S) = \left[ n (n - 1) (2n + 5) - \Sigma tp (tp - 1)(2tp + 5) \right] / 18, \]

\[ P = 1, 2, \ldots, q \]

where \(tp\) is the number of ties for the \(p\)th value and \(q\) is the number of tied values.

Then, standardized statistical test is computed by:

\[ Z = S - 1 / \sqrt{V(S)} \text{ if } S > 0, \]

\[ = S + 1 / \sqrt{V(S)} \text{ if } S < 0 \]
### TABLE 4

The correlation coefficient between TMRF, coefficient of determination-value and p-value

| Month   | r     | $r^2$   | t-value | p-value   | Result     |
|---------|-------|---------|---------|-----------|------------|
| June    | 0.133 | 0.017   | 5.256   | 0.000001  | Significant|
| July    | 0.511 | 0.261   | 12.491  | 0.00162   | Significant|
| August  | 0.496 | 0.246   | 9.348   | 0.000001  | Significant|
| September | 0.537 | 0.288   | 6.9211  | 0.000001  | Significant|

### TABLE 5

Result of Mann Kendall test for climatic variables in Anand district

| Variable | S-value | Z-value | Result     |
|----------|---------|---------|------------|
| MMAX     | 146.00  | 0.000   | Insignificant|
| TMRF     | 38.00   | 0.41563 | Significant|
| TMRF (J-S) | 48.00   | 0.5279  | Significant|

For MMAX temperature, the value of S obtained as 146 a very high positive value indicating increasing trend and is statistically significant that there is enough evidence to determine an upward trend as shown in Table 5 and is confirmed by the M-K trend test at 5% level of significance. For TMRF, TMRF (J-S), the respective value of S obtained as 38 and 48 value indicating decreasing trend.

### 3. Conclusions

It is observed that MMAX temperature shows significant increasing trend during 1975 to 2005 and is confirmed by Mann Kendall test. The increasing trend in MMAX temperature and decreasing trends in TMRF, TMRF (J-S), is observed and is confirmed by Mann-Kendall trend test. It is observed that annual MMAX temperature has increased and annual TMRF decreased during the last 41 years in Anand of Central Gujarat., the TMRF (J-S) shows statistically significant decreasing trend shows statistically insignificant decreasing trend during the last 41 years and is confirmed by Mann Kendall trend at 5% level of significance.

### References

Abaurrea, J. and Cerian, A. C., 2001, “Trend and variability analysis of rainfall series and their extreme events”, [http://metodostadisticos.unizar.es/personales/acebrian/publicaciones/AbCeSPRIN.pdf](http://metodostadisticos.unizar.es/personales/acebrian/publicaciones/AbCeSPRIN.pdf).

Chahal, S. S, 2010, “Climate Change: Challenges and Researchable Issues for Agricultural Sustainability”, University News, 48, 24, June 14-20, 73-79.

Colin, P., Silas, M., Stylianos, P. and Pinhas, A., 1999, “Long term changes in diurnal temperature range in Cyprus”, *Atmos. Res.*, 51, 85-98.

Hipel, K. W. and McLeod, A. I., 2005, “Time Series Modelling of Water Resources and Environmental Systems. Electronic reprint of our book originally published in 1994”, [http://www.stats.uwo.ca/faculty/aim/1994Book](http://www.stats.uwo.ca/faculty/aim/1994Book).

IPCC, Climate Change, 2001, “Impacts, adaptation and vulnerability”, IPCC, Cambridge University Press, UK, 2001.

Kothyari, U. C. and Singh, V. P., 1996, “Rainfall and temperature trends in India”, *Hydrological processes*, 10, 357-372.

Murray, R. Spigel and Larry, J. Stephens, 2000, “SCHAUM’S outlines statistics”, Third Edition, TATA McGraw-Hill Edition.

Mann, H. B., 1945, “Nonparametric tests against trend”, *Econometrica*, 13, 245-259.

Rupakumar, Krishna, Kumar, K. K. and Pant, G. B., 1994, “Diurnal asymmetry of surface temperature trends over India”, *Geophysical Research Letters*, 21, 677-680.

Singh, N. and Sontakke, 2001, “Natural and anthropogenic environmental changes of the Indo-Gangetic Plains, India”, *Climate Change*, 52, 287-313.