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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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सार – कृषि, पर्यावरण और जल संसाधन परियोजनाओं के लिए वर्षा के लक्षणों में आ रहे बदलावों का अध्ययन आवश्यक है। सामान्यत:, प्रवृत्ति परीक्षण दिशा का आकलन और परिवर्तन के परिमाण का पता लगाते हैं परंतु समय श्रृंखला में यदि कोई असामान्य परिवर्तन होता है तो ये परीक्षण उसे सिद्ध नहीं कर पाते हैं। इस शोध में भारत के मध्य गुजरात के आणंद जिले के मौसम विज्ञानिक आँकड़ों में अधिकतम वायुमंडलीय तापमान और वर्षा का विश्लेषण किया गया है। सहसंबंध और रैखिक प्रवृत्ति विश्लेषण द्वारा तापमान और वर्षा (मौसमी और वार्षिक) में दीर्घ अवधि परिवर्तन का इसमें विश्लेषण किया गया है। MMAX तापमान में वृद्धि की प्रवृत्ति और TMRF, TMRF (J-S) में कमी की प्रवृत्ति का पता चला है और इसकी पुष्टि Mann kendall प्रवृत्ति परीक्षण द्वारा की गई है । यह देखा गया है कि मध्य गुजरात के आणंद में पिछले 41 वर्षों के दौरान वार्षिक MMAX तापमान में वृद्धि हुई है और वार्षिक TMRF में कमी आई है, TMRF (J-S) से पिछले 41 वर्षे के दौरान सांख्यिकीय रूप से असामान्य कमी की प्रवृत्ति का पता चला है और इसकी पुष्टि सार्थकता के 5% स्तर पर Mann kendall प्रवृत्ति द्वारा की गई है। कृषि मौसम विज्ञान विभाग, आणंद से प्राप्त 1970 से 2011 की अवधि के अधिकतम तापमान और वर्षा के आँकड़ों का विश्लेषण किया गया। यह पाया गया कि मध्य गुजरात के आणंद में अधिकतम तापमान का माध्य, वृद्धि की प्रवृत्ति दिखाता है और वर्षा के दिनों में पूरे महीने की वर्षा कमी की प्रवृत्ति दिखाती है।

ABSTRACT. The study of rainfall characteristics changes is critical for agricultural, environmental and water resources projects. Generally, trend test performs for evaluation of direction and magnitude of changes, but the test is not able to demonstrate abrupt change in time series if it occurs. The trends of maximum atmospheric temperature, rainfall are analysed for meteorological data of Anand district in Central Gujarat India. The long-term change in temperature, rainfall (Seasonal & Annual) has been analysed by correlation and linear trend analysis. 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. The Maximum temperature, rainfall during period 1970 to 2011 obtained from Department of Agricultural Meteorology, Anand were analysed. It is observed that Mean of maximum temperature shows increasing trend, total monthly rainfall and total monthly rainfall in the rainy season days shows decreasing trend in Anand of central Gujarat.

Key words – Global warming, Linear trend, Mann-Kendall test, Rainfall, Temperature.

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).

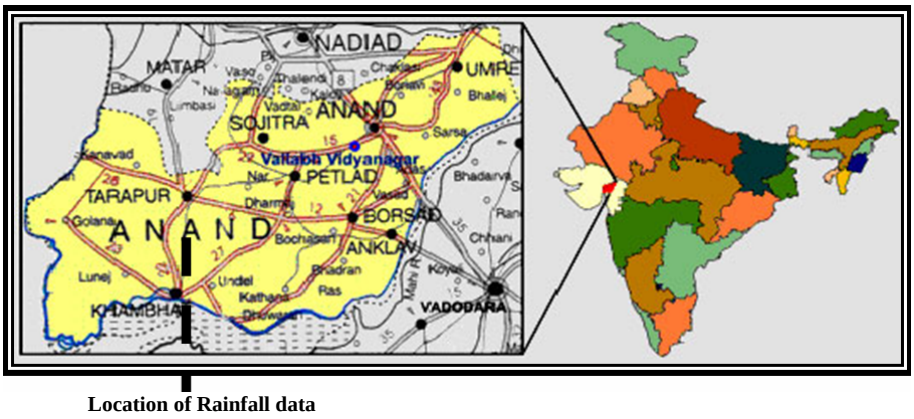

Fig. 1. Location of study area at Anand, Gujarat

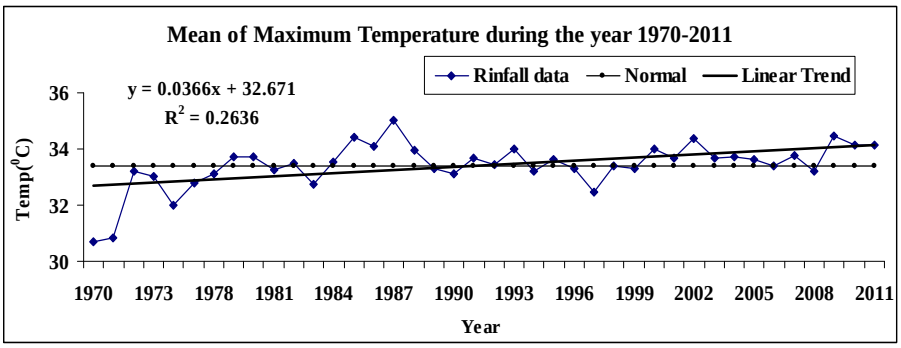

Fig. 2. Trend line of mean maximum temperature during the year 1970-2011 at Anand

Extreme summer rainfall events were observed in northwest India during the recent decades (Singh and Sontakke, 2001). In addition, the number of rainy days during monsoons along the east coast has gone down during the last decade indicating more intense rainfall events. The rainfall and temperature is the most fundamental physical parameter among the climate as it determines the environmental factors of the particular region which affects the agricultural productivity. Global warming/Climate change is one of the most important worldwide issue talked among the scientists and researchers. The annual mean temperature of India as a whole has risen to 0.51 °C over the period 1901-2005. A number of scientific research study shown that surface air temperature increased about 0.2 till 0.6 °C during last century (Abaurrea and Cerian, 2001) and further it may increase about 1.5 to 4.5 °C until 2100 (IPCC, 2004). This rate of increase may vary in different geographical regions (Colin *et al*., 1999). Weather observations indicated that global average surface temperature has increased by 0.6 °C since 19th century (Chahal, 2010). Studies indicate that if no corrective measures are taken, the atmospheric temperatures may increase by 1.4 °C to 5.8 °C by the year 2100 (IPCC, 2001).

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	27.87040	1.040	0.69742	3.732
February	30.15393	1.536	1.48844	5.095
March	34.94694	1.866	0.97625	**5.341**
April	38.33558	1.315	0.34423	3.429
May	39.05581	2.060	0.81775	5.275
June	36.55008	1.703	1.24045	4.658
July	32.34629	1.072	0.46023	**3.315**
August	31.11966	1.354	0.61436	4.349
September	33.13821	1.758	0.70040	5.306
October	35.25691	1.523	0.80005	4.319
November	32.62496	1.152	0.98331	3.531
December	29.28933	1.036	0.57176	3.537

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	31.60766	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	201.4023	**37.237**
September	100.435	108.656	31.84704	108.185
October	23.448	48.803	9.383411	208.129
November	25.713	63.323	8.692981	246.269
December	0.929	3.266	0.392255	351.538

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.

2.2. *Linear regression*

The equation of a linear regression line is given as:

$$y = a + b\,x$$

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.

a is an intercept of the line on the vertical axis and b is the slope of the line. In order to fit regression lines, scatter diagrams of the annual mean of maximum temperature, 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 indicate 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), … (x_n, y_n), the Karl Pearson's formula for calculating the correlation coefficient 'r' is given by:

$$r = \sum(\overline{x_i - x})(\overline{y_i - y}) / \sqrt{\sum(\overline{x_i - x})^2 \sum(\overline{y_i - y})^2}$$

$i = 1, 2, \ldots, n$

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, ρ is the population correlation coefficient.

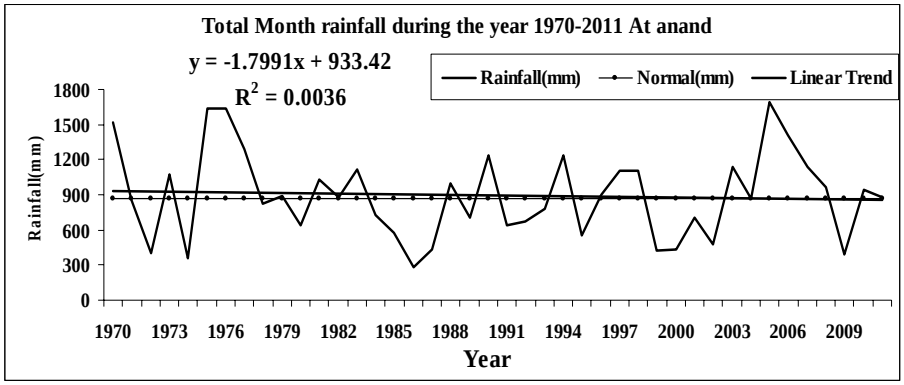

Fig. 3. Trend line of TMRF during the year 1970-2011 at Anand

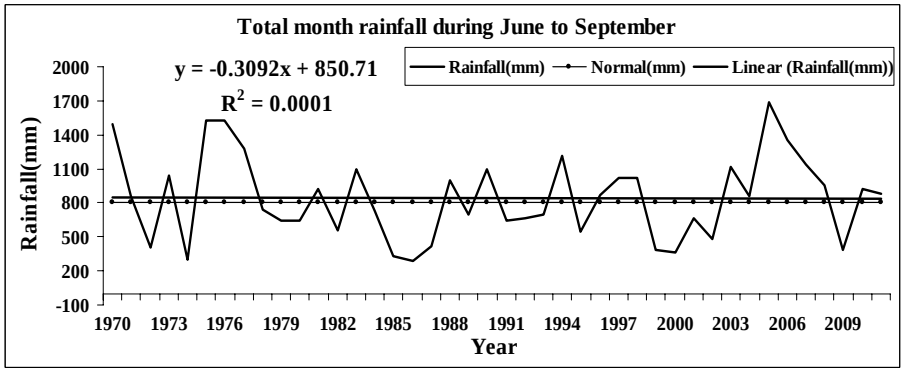

Fig. 4. Total monthly rainfall during June to September at Anand

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, … 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:

$S = \Sigma \Sigma$ Sign $(X_j - X_k)$, j = 2, 3,…n and k=1, 2,.., j-1

where: 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,

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

$P = 1, 2,\ldots, q$

where tp is the number of ties for the pth value and q is the number of tied values.

Then, standardized statistical test is computed by:

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

$= S + 1 / \sqrt{V(S)}$ 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.

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