Research Paper

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Trend Assessment in Climatic Variables by Mann Kendall and t-test: A Case Study of Yavatmal District in Vidarbha, India

Statistics

KEYWORDS : Global Warming, Climatic variables, Trend, Regression, Mann-Kendall test

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ABSTRACT

There is a growing concern about global warming day by day as it affects climatic variables on planet earth. The main objective of the present research paper is to examine trends in rainfall and temperature of Yavatmal district in Vidarbha. The trends of maximum atmospheric temperature, rainfall and rainy days are analysed statistically for meteorological data of Yavatmal district in Vidarbha, over last three decades stretching between years 1975 to 2005. The long term change in temperature, rainfall and rainy days has been analysed by correlation and linear trend analysis. The decreasing trend is observed in mean of maximum (MMAX) temperature, rainy days (RD) and rainy days (RD J-S) during season June to September and is confirmed by Mann-Kendall trend test whereas very weak increasing trend is observed in total month rainfall (TMRF) and total month rainfall (TMRF J-S) during season June to September.

Summary: The Yavatmal district is one of the distressed districts due to farmer's suicides in Vidarbha, Maharashtra. Maximum temperature, rainfall and rainy days data during period 1975 to 2005 obtained from Indian Meteorological Department (IMD), Pune were analysed. It is observed that MMAX temperature, RD, RD (J-S) shows decreasing trend and TMRF and TMRF (J-S) observed weak increasing trend in Yavatmal district.

1. Introduction

Recently, Vidarbha region has become infamous for a large number of farmer suicides occurring day by day. Yavatmal district is one of the six distressed districts of Vidarbha for which the Government of India and Government of Maharashtra State have announced the package of relief for the farmers. Vidarbha's economy is primarily agricultural and it is less economically prosperous as compared to the rest of Maharashtra.

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. Studies indicate that if no corrective measures are taken, the atmospheric temperatures may increase by 1.4^{0}C to 5.8^{0}C by the year 2100 (IPCC 2001). Studies have demonstrated that global surface warming is occurring at a rate of 0.74$\pm$0.18 ^{0}C over 1906-2005. A number of scientific research study shown that surface air temperature increased about 0.2 till 0.6^{0}C during last century (Abaurrea and Cerian, 2001) and further it may increase about 1.5 to 4.5^{0}C until 2100 (IPCC,2004). This rate of increase may vary in different geographical regions (Colin et al., 1999). It is found that all India mean annual temperature is rising at the rate of 0.05^{0}C/decade over 1901-2003 which is mostly due to the rise of maximum temperature (0.07^{0}C/decade) rather than because of the rise of minimum temperature (0.02^{0}C/decade) (Kothawale and Rupa Kumar, 2005). Global warming and significant change in time series of temperature in different parts of the world could be considered as one of the most important factors of climate change in the 21st century (IPCC, 2007). Climate change is considered as one of the main environmental problems of the 21st century (Pytrik et al., 2010). The annual mean temperature of India as a whole has risen to 0.51^{0}C over the period 1901-2005 (M. H. Fulekar, R. K. Kale, 2010). Weather observations indicated that global average surface temperature has increased by 0.6^{0}C since 19th century (S.S. Chahal, 2010).

The main objective of present research is to analyse the 1975 to 2005 rainfall, rainy days and temperature data obtained from India Meteorological Department (IMD), Pune for, Yavatmal district of Vidarbha as a basis on sustainability of crop production. The analysis includes mean of maximum temperature, total month rainfall, total month rainfall from June to September, annual number of rainy days and number of rainy days in rainy season from the months of June to September using correlation analysis, regression analysis and Man-Kendall trend statistics.

2. Literature Review

Moshrik R. Hamdi et al. analysed data from six meteorological stations distributed around Jordan using several parametric and nonparametric statistical tests and indicating that annual minimum temperature has increased in the last decade while annual temperature range has decreased. Modarres analyzed rainfall trend in the last half of the twentieth century in Iran and results revealed that the trends of annual rainfall began since 1070s for most of the stations. Kumar and Jain studied trend detection in seasonal and annual rainfall and rainy days using Mann Kendall test in Kashmir valley and result indicates the upward trend of rainfall and rainy days in one station whereas other stations indicates decreasing trend for both variables. Shafiqur Rehman et al. analysed extreme temperature trends for a meteorological data collection station in Jeddah, Saudi Arabia over four decades during 1970 and 2006 and observed significant increase in hot days per year and relatively smaller decrease in hot nights. Yazdani Mohammad Reza et al., studied trend of rainfall and temperature data in the Zayandehrud Basin during 40 years (1966-2005) and result indicates that there are not any linear and nonlinear significant trends among rainfall time series. Alkolibi examined impacts of climatic change in Saudi Arabia and obtained that temperature increase and rainfall decrease has major negative impact on agriculture and water supplies. Abhijit M. Zende et al. analysed time series of annual rainfall, number of rainy-days per year and monthly rainfall of 10 stations to assess climate variability in semi-arid region of Western Maharashtra and showed mixed trends of increasing and decreasing rainfall which are statistically significant for two stations by Mann Kendall test. Arun Mondal et al. studied rainfall trend by Mann-Kendall test of North-Eastern part of Cuttack district, Orissa for 40 years and concluded that there is evidence of some change in the trend of precipitation of the region in different months.

3. Study Area

The district of Yavatmal lies in Amravati division of Maharashtra State. It is located in the region of Vidarbha, in the east-central part of the State. The district is situated between 19^o 26' N and 20^o 42' N latitudes and 77^o 18' E and 79^o 9' E longitudes and has an area of 13,517 square kilometres with an average elevation of 445 metres (1459 feet). Jowar and cotton are the main produce of the district. The average rainfall of Yavatmal District is 911.34 mms. The climate of the district is in, general hot and dry with moderately cold winters. Most of the total annual rainfall is reserved during the south west monsoon season. The rainfall is not uniform in all parts of the district.

Volume : 2 | Issue : 5 | May 2013 • ISSN No 2277 - 8179

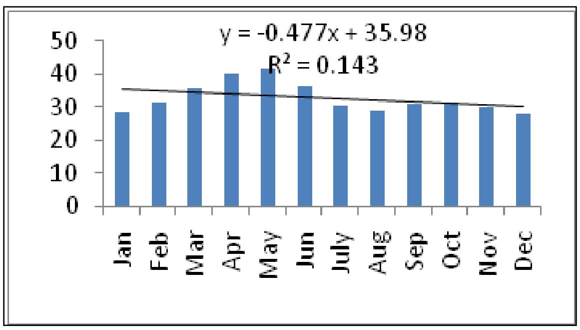
4. Data and Methodology

The data used in this paper are the monthly averages of total month rainfall, rainy days, and mean of maximum temperatures during 1975-2005 which are provided by the India Meteorological Department (IMD), Pune. Trend is defined as the general movement of a series over an extended period of time or it is the long term change in the dependent variable over a long period of time Trend is determined by the relationship between the two variables as temperature and time, rainfall and time, and rainy days and time. The statistical methods such as correlation analysis, regression analysis and coefficient of determination R^2 (Murray R. Spiegel, Larry J. Stephens, 2000) are used. The magnitudes of the trends of increasing or decreasing maximum temperatures, total month rainfall, and rainy days were derived and tested by the Mann-Kendall trend test and slope of the regression line by the least squares method using Microsoft Excel.

Table1. Statistical summary of monthly mean of MMAX temperatures during 1975-2005 for Yavatmal District

Month	Mean	S.D.	Mean Dev.	C.V. %
Jan	28.49032	1.252559	0.96358	4.396436
Feb	31.45806	1.308377	1.308377	4.159114
Mar	36.04643	1.325136	1.072533	3.676192
Apr	40.1037	1.024125	0.758848	2.553692
May	41.51154	1.590051	1.302071	3.830383
June	36.52069	2.156449	1.752438	5.904732
July	30.63333	1.297566	0.971111	4.235798
Aug	29.02	0.925277	0.669333	3.188412
Sep	30.90968	1.193693	0.953174	3.861875
Oct	31.73	1.435786	1.220667	4.525012
Nov	29.89333	1.108566	0.847111	3.708407
Dec	28.22667	0.982935	0.752	3.482292

Graph1. Shows month wise average amount of MMAX temperature of Yavatmal district during period 1975-2005.



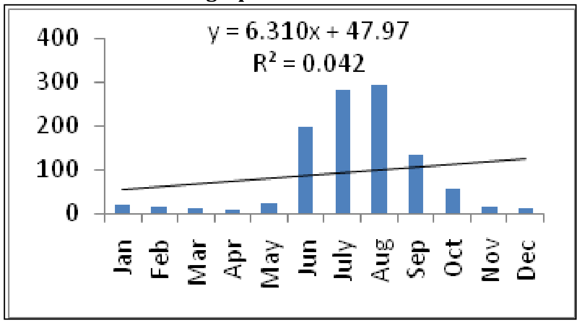
The coefficient of determination R2=0.143 indicating only 14.3% of the variation in MMAX temperature can be explained by the regression model.

Table2. Statistical summary of monthly data of TMRF during 1975-2005 of Yavatmal district

Month	Mean	S.D.	Mean Dev.	C.V. %
Jan	17.38387	24.12248	17.28137	138.7636
Feb	13.22258	19.62865	19.62865	148.4479
Mar	12.4069	19.82235	13.85111	159.7688
Apr	6.72069	9.877586	7.496076	146.9728
May	22.44074	25.72992	18.85734	114.6572
Jun	198.4533	115.5816	92.06978	58.24121
July	283.23	117.7196	95.75467	41.56326
Aug	296.5533	118.2819	99.34311	39.88553
Sep	135.4	123.5836	88.25161	91.27299
Oct	54.67667	52.63719	41.83867	96.26994
Nov	16.46	29.38287	21.92133	178.5107
Dec	10.95667	19.56966	13.45556	178.6096

The coefficient of variation for TMRF observed highest in the month of December and it is 178.60% whereas coefficient of variation is minimum for the month of August and it is 39.88% for the Akola district. This shows that rainfall is more stable in the month of August and is more variable in the month of December for the Yavatmal district.

Graph 2. Shows month wise average amount of TMRF of Yavatmal district during a period 1975-2005.



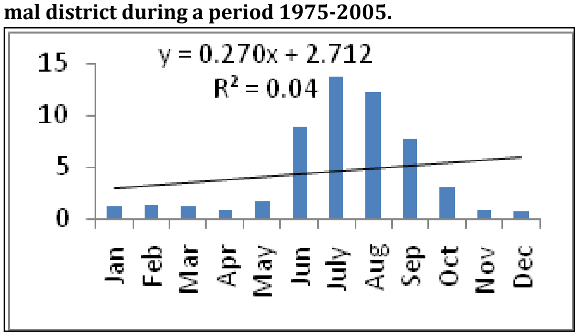
The coefficient of determination R2=0.042 indicating only 4.2% of the variation in TMRF can be explained by the regression model.

Table3. Statistical summary of monthly data of RD during 1975 -2005 of Yavatmal district

Month	Mean	S.D.	Mean Dev.	C.V. %
Jan	1.129032	1.408118	1.021852	124.719
Feb	1.290323	1.71646	1.71646	133.0257
Mar	1.103448	1.620629	1.177778	146.8695
Apr	0.896552	1.234759	0.989298	137.7232
May	1.62963	1.596827	1.218107	97.98713
Jun	9	2.840592	2.133333	31.56214
July	13.76667	3.757139	2.864444	27.29157
Aug	12.3	3.505169	2.92	28.49731
Sep	7.774194	4.883371	3.995838	62.81514
Oct	3.1	2.249138	1.9	72.55283
Nov	0.9	1.561388	1.2	173.4875
Dec	0.733333	1.201532	0.88	163.8452

The coefficient of variation for number of rainy days observed highest in the month of November and it is 173.48% whereas coefficient of variation is minimum for the month of July and it is 27.29% for the Yavatmal district. This shows that number of rainy days is more stable in the month of July and is more variable in the month of November for the Yavatmal district.

Graph 3. Shows month wise average amount of RD of Yavatmal district during a period 1975-2005.



The coefficient of determination R2=0.04 indicating only 4.0% of the variation in rainy days can be explained by the regression model.

Volume : 2 | Issue : 5 | May 2013 • ISSN No 2277 - 8179

4.1 Linear Regression

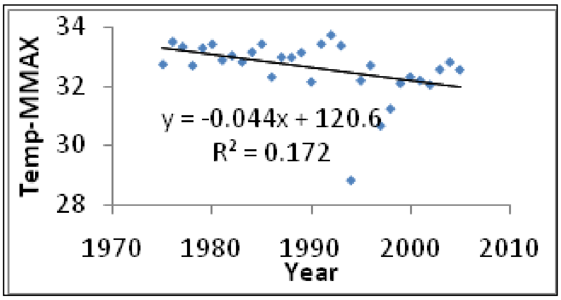
The linear regression line was fitted using the most common method of principle of least squares. The equation of a linear regression line is given as:

Y = a + b X,

Where, Y is the observation on the dependent variable, X is the observation on the independent variable, **a** is an intercept of the line on the vertical axis, and **b** is the slope of the regression line. In order to fit regression lines, scatter diagrams of the annual mean of maximum temperature, total month rainfall and rainy days (dependent variables) against time (independent variable) were plotted. The drawing of the scattered diagrams and the fitting of the regression lines were done in Microsoft Excel.

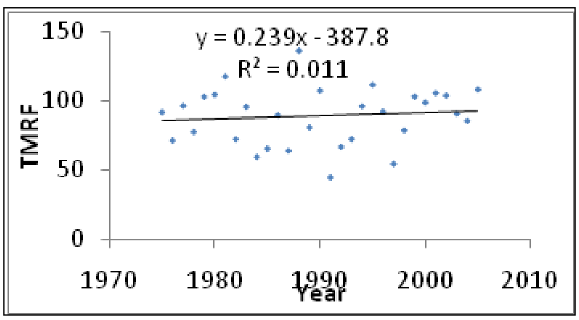
4.2 Trend Analysis

In the present study, trend analysis has been done by using regression analysis.



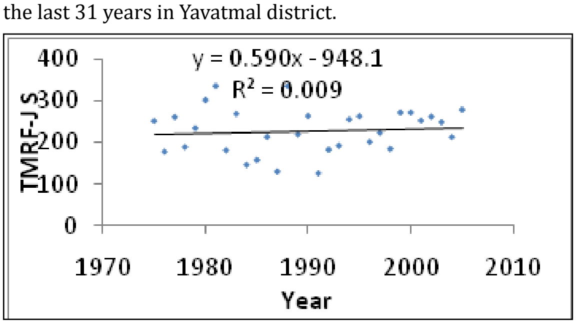
(a)

The diagram(a) indicate the trend line for annual mean of maximum temperature against time is decreasing, which implies there is a negative linear relationship between annual mean of maximum temperature and time. Annual MMAX temperature has decreased by 1.364^{0}C during the last 31 years in Yavatmal district.



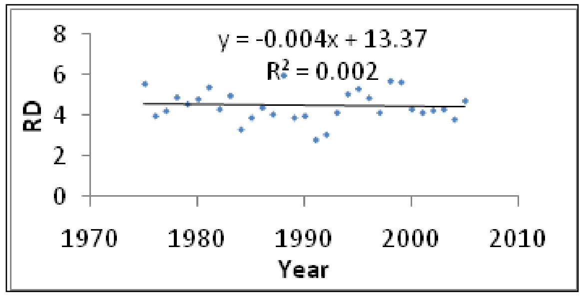
(b)

The diagram (b) indicate the trend line for annual total month rainfall against time is increasing, which implies there is a positive linear relationship between annual total month rainfall and time. Annual total month rainfall increased by 7.409 mm during the last 31 years in Yavatmal district.



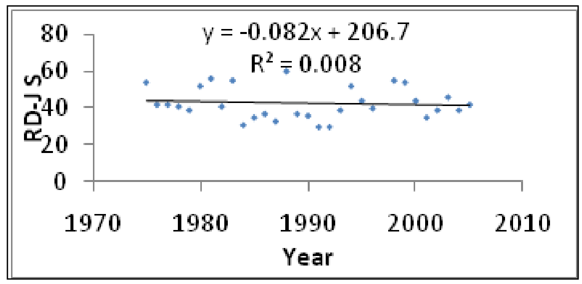
(c)

The diagram (c) indicate the trend line for average total month rainfall in the rainy season during June to September against time is increasing, which implies there is a positive linear relationship between average total month rainfall during June to September and time.Average total month rainfall during June to September increased by 18.29 mm during the last 31 years in Yavatmal district.



(d)

The diagram (d) indicate the trend line for average rainy days against time is weakly decreasing, which implies there is a very small negative linear relationship between average rainy days and time. Average rainy days are decreased by 0.124 days during the last 31 years in Yavatmal district.



(e)

The diagram (e) indicate the trend line for number of rainy days in the rainy season during June to September against time is decreasing, which implies there is a negative linear relationship between number of rainy days and time. The number of rainy days during June to September is decreased by 2.542 days during the last 31 years in Yavatmal district.

4.2 Correlation Coefficient

The correlation coefficient determines the magnitude and strength of linear relationship between the two variables under study. The correlation coefficients between temperature, rainfall, agriculture production and time were calculated as follows.

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=∑ (xi-x) (yi–y) / √∑ (xi-x)^2 ∑ (yi-y)^2 ,
i=1,2,..........n.

4.2.1Testing 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: ρ=0 against H_1: ρ≠0

Where, ρ is the population correlation coefficient.

The appropriate test statistics for testing the above hypothesis is

t = r √ (n-2) / √ (1-r^2), d. f. = n-2 = 29

Significant value for t at 5% level = 1.746

The following table represents the values of the correlation coefficients and the test statistics represented within the bracket.

4.3 Calculating p-value:
The p-value for a test of hypothesis is defined to be the smallest level of significance at which the null hypothesis is rejected.

The p-values were calculated in the following manner.

p-value= P(t>Observed value of the test statistic)
= 1- P(t≤ Observed value of the test statistic)

Table5. The correlation coefficient between TMRF and RD, coefficient of determination, t- value and p-value for Yavatmal district

Month	r	r2	t-value	p-value	Result
June	0.4441	0.1972	2.669	0.0123	Significant
July	0.6898	0.4758	5.131	0.0001	Extremely significant
August	0.3979	0.1583	2.335	0.02	Significant
Sept.	0.8902	0.7924	10.52	0.0001	Extremely significant

As p-value is less than 0.05, the null hypothesis is rejected at 5% level of significance and conclude that the correlation coefficient between total month rainfall and rainy days are statistically significant for the month of June and August whereas it is extremely statistically significant for July and September.

5. 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 in environmental time series (Hipel and McLeod, 2005). The test compares the relative magnitudes of sample data rather than the data values themselves.

Let X_1, X_2........ Xn represents n data points where Xj represents the data point at time j. Then the Mann-Kendall statistic (S) is given by

$S=\Sigma\,\Sigma$ sign $(Xj- X_k)$, for j>k and j=2, 3……n, k=1, 2…….j-1
Where: sign (Xj-Xk) = 1 if Xj-Xk>0
= 0 if Xj-Xk =0
= -1 if Xj-Xk <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.

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

For this, variance of S is obtained as,
$V(S) = [n (n-1) (2n+5) - \sum t_p(t_p-1)(2t_p+5)] /18$, p=1,2…..q

Where t_p 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:

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

The presence of a statistically significant trend is evaluated using Z value.

Table6. Table shows result of Mann Kendall test for climatic variables of Yavatmal district

Variable	S value	z-value	p- value	Result
MMAX	-159	-2.6854	0.0072	Significant
TMRF	53	0.5098	0.6101	Not significant
TMRF(J-S)	0	0	1	Not significant
RD	-62	-1.0383	0.2991	Not significant
RD(J-S)	-40	-0.6641	0.5066	Not significant

For MMAX temperature, the value of S obtained as -159, a very high negative value indicating decreasing trend and is statistically significant that there is enough evidence to determine downward trend as shown in figure (a) which 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 53, 0, indicating statistically not significant increasing trend where as RD, RD (J-S) obtained as -62, and -40; a negative value of S indicating decreasing trend but statistically not significant.

6. Conclusions
It is observed that monthly mean of maximum (MMAX) temperature shows statistically significant decreasing trend, number of rainy days (RD) and number of rainy days (RD J-S) during June to September shows statistically insignificant decreasing trend during 1975 to 2005 and is confirmed by Mann Kendall test at 5% level of significance. The annual MMAX temperature has decreased at a rate of 0.044^{0}C per year during the same period in Yavatmal district. The mean of total month of rainfall (TMRF) shows statistically insignificant increasing trend, mean of total month rainfall (TMRF J-S) during rainy season from June to September shows statistically insignificant increasing trend, during 1975 to 2005 and is confirmed by Mann Kendall trend at 5% level of significance.

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