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Trend Analysis of Long term Meteorological Variables of Mulshi Taluka, Pune, India

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Abstract: ***In today's developing world, the phenomenon of climate change and its impacts has drawn wide attention across India due to severe impacts on water resources, agriculture and food security. To predict the future climate change and its impacts on earth, it is very essential to know the basic trends of past climate variables. The present study analysed the monthly, seasonal, annual mean minimum and maximum temperature along with mean rainfall from the year 1980 to 2014 for the Velhe observatory (Indian Meteorological Station) of Pune district, Maharashtra, India to detect significant monotonic trends. These trends were analysed using non-parametric and seasonal Mann-Kendall test; and slope of the trend was assessed using linear regression method. It was found that there was no trend for mean annual minimum temperature and rainfall, but there was a statistically significant increasing trend at a 95 percent confidence interval for mean annual maximum temperature. The results indicated that the mean annual minimum temperature rose by 0.064°C/year and maximum temperature by 0.0198°C/year; however, mean annual rainfall was decreased by 0.0004 mm/year from 1980 to 2014.***

Keywords: Climate change, Mann-Kendall test, Linear Regression, Monotonic trend, Parametric and Non-Parametric test

1. Introduction

Over the last decades, human-caused emissions of greenhouse gases are at their peak, greatly influencing several aspects of the Earth's Climate System (Pachauri et al., IPCC 2014). In recent two to three decades, climate change phenomenon has drawn wide attention across the world from all possible angles. This climate change refers to any long-term trends or shifts in climate over many decades, around which climate variability is evident year to year. Climate is the average weather pattern at a place over at least 30 years (The Commonwealth Scientific and Industrial Research Organization, CSIRO, 2011). According to the Intergovernmental Panel on Climate Change (IPCC), climate change is defined as a ''change in the state of the climate that can be identified (for instance, by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer''. Climate change may be due to natural internal processes, external forcing, or persistent anthropogenic changes (especially due to land use) in the composition of the atmosphere (Lal, 2016)**.**

One of the most significant consequences of climate change are alterations in regional hydrological cycles and subsequent changes in river flow regimes, for instance, floods or low flows (Zhang et al., 2008). Climate change has already affected agriculture, increased the risk of hunger, water scarcity, and has lead to more rapid melting of glaciers (IPCC, 2007). Five billion people were affected by natural disasters in the past 25 years, resulting in approximately US $1 trillion of economic losses around the world (Stromberg, 2007). In India, freshwater availability in many river basins is likely to decrease due to climate change (Gosain et al., 2006). In the state of Maharashtra, India, it has observed uneven rains, hailstorms, unusual rise in land temperature and severe heat waves, mostly, in the summer season (March to May) along with droughts in the past decade, especially, in Pune, Marathwada and Vidarbha regions which have not only impacted inflation, but also affected the country's G.D.P and economy as agriculture is the backbone of India's economy. Droughts can destroy farmlands, pastures and watersheds; degrades the quality of land, declines the yield of crops, whereas, floods causes considerable damage to settlements and infrastructure (Mani et. al, 2018). While the IPCC (2007) has projected an increase in global precipitation due to the effects of climate change, both increase and decrease in precipitation have been observed at the regional level.

Much information is available on historical and long term changes in climate variables like rainfall and temperature. Nyeko-Ogiramoi et al. (2013) analysed the trend and variability of extreme temperature and rainfall in the Lake Victoria Basin of Africa through Areal Reduction Factor (ARF), Peak Over-Threshold (POT), and Quantile Perturbation approach and concluded that there is a positive change in the extreme climate. Daily rainfall trends in the Upper Nile River Basin were analysed by Mann-Kendall Tau and Trend-Free Pre-Whitening (TFPW) approach and found that there was a decreasing trend in daily rainfall index (Tabari et al., 2015). Daily rainfall extreme trend was analysed by Tabari et al. (2014) across Iran by Quantile Perturbation method and concluded that there was evidence of significant changes in extreme conditions. There was a slow and steady increase in daily maximum temperature in Pune district with the help of moving average method (Das et al., 2008). Trends of annual temperature and precipitation in Ethiopia were assessed by Mann-Kendall Tau test and reported an increasing trend in mean annual maximum temperature and a decreasing trend in mean annual minimum temperature (Hayelom et al., 2017). Long term trends were analysed in whole India with respect to mean monthly, seasonal, annual rainfall and concluded both increasing and decreasing trends in all the three climate variables (Kumar et.al, 2010). Statistical analysis of temperature and rainfall of Chhattisgarh state of India was studied by Khavase et al. (2015) with the help of both Mann-Kendall Tau test and regression analysis method and came to the conclusion that there was an increasing trend of total mean rainfall. Examination of mean maximum temperature over the Pune district revealed that there has been a significant cooling trend in the summer season (Gadgil and Dhorde, 2005).

India's monsoon is critical for drinking water, agricultural production, power generation, water resources management and the overall economy of the country (Das et al., 2012). Due to an increased number of natural disasters (rainstorms, drought, etc) and its high impacts on economic/human life, it is necessary for the regional administration to collect region-wise climatic data information about the temporal variability of various climate variables, especially, temperature and rainfall for better disaster management and water resources planning, so that the impacts of climate change can be mitigated. For this, it is very important to identify the historical changes in different climate variables to get a glimpse of that specific region's climate change/climate trends so that accurate climate prediction can be done for the future decades through various climate models and region-wise impact assessment can be done.

Long term trend analysis of rainfall and temperature provides information about its pattern and variability. The main objective of this research is to find and analyse the trends of various climate variables (monthly, seasonal and annual mean minimum and maximum temperature along with rainfall) for the Velhe Observatory of Mulshi Taluka, Pune district, Maharashtra State, India.

2. Study Area

Mulshi Taluka is located in the western part of Pune district, Maharashtra, India. The geographical location of this taluka is 18.50° North latitude and 73.51° East longitude with **Fig. 1** Study area map at an average elevation of 630 metres above mean sea level. Mulshi taluka is located in the Mulshi River valley of Western Ghat in Pune district and it is about 44 km far away from Pune city. The total area of the Mulshi taluka is 1029 sq km. Mula and Mutha are the main rivers in Mula valley and Panshet, Varasgaon are the major reservoirs built on these rivers. The taluka experiences tropical monsoon climate and average annual temperature is 24°C with an annual average rainfall of 2858 mm (Fig. 1).

3. Database and Methodology

3.1 Dataset

In this study, daily basis data of minimum and maximum temperature along with rainfall for thirty-four years (from the year 1980 to 2014) were taken from Indian Meteorological Department (IMD) for the Velhe observatory. There was no missing data in any of the variable. According to IMD, a year is divided into four seasons: winter (December to February), pre-monsoon/summer (March to May), monsoon (June to September), and post-monsoon (October to November). Analysis of climate variables-maximum and minimum temperature along with rainfall was carried out for all the seasons as well as for each separate month (from January to December) and eventually for the whole year separately. Basics statistics, such as mean, standard deviation, and coefficient of variation (CV) of all the three variables of different data sets are given in Table 1 to 6.

3.2 Methodology

This research was approached by examining and analysing the data of Velhe observatory of Mulshi town. Entirely a quantitative approach was adopted to carry out the data analysis using various statistical techniques. Monthly, seasonal and annual mean minimum and maximum temperature along with rainfall for all the thirty-four years were carried out which were then analysed to find whether there is any trend or not. The trend is defined as ‘‘the general movement of a series over an extended period of time or it is the long term change independent variable over a long period of time (Webber and Hawkins, 1980). This trend is determined by the relationship between two variables. In the present study, it was carried out for all monthly mean climate variables - minimum and maximum temperature along with rainfall with respect to time. This trend was derived and tested by Mann-Kendall 1945 trend test and Mann-Kendall Seasonal test for all the three variables. Linear Regression analysis was also done to find the slope of the regression line and to determine the yearly rate of change of climate variables. In addition, standard deviation (SD) and coefficient of variation (CV) of all the variables were calculated to find the percentage of variation in mean monthly, annual and seasonal data.

Mann-Kendall Test for Trend Detection

Mann-Kendall test is a non-parametric test used to identify the monotonic trend in a time series, even if there is seasonal component in the series. It is used to find whether dependent variable increases or decreases with respect to time. The biggest advantage of this test is that data is not required to fit a normal distribution. This test checks the null hypothesis of no trend versus the alternative hypothesis of increasing or decreasing trend. Let X1, X2, X3……Xn represents n data points where Xj represents the data point at time j. Then the Mann-Kendall statistic (S) is given by

$$\sum_{k=1}^{n-1} . \sum_{j=k+1}^{n} sign\,(Xj - Xk)$$

Where:

$$sign\,(Xj - Xk) = 1 \text{ if } Xj - Xk > 0$$
$$= 0 \text{ if } Xj - Xk = 0$$
$$= -1 \text{ if } Xj - Xk < 0$$

Here, Xj and Xk are the sequential data values and n is the length of the data set. 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 datasets with more than 10 values, normal approximations to Mann-Kendall test may be used. For this, the variance of S is obtained as, VAR (S) = $\frac{1}{18}\lfloor n(n-1)(2n+5)-\sum_{p=1}^{g} tp\ (tp -$ *12tp+5*

Where:
n is the number of data points,
g is the number of tied groups and
tp is the number of data points in the pth group

Finally, the Mann- Kendall statistic, Z, is given by:

$Z = \frac{S-1}{\sqrt{Var\ (S)}}$ if S > 0

= 0 if S = 0

$= \frac{S+1}{\sqrt{Var\ (S)}}$ if S < 0

Regression Test for Linear Trend

Linear regression is the most widely used statistical technique; it is a way to model a relationship between two sets of variables. It is a parametric test used to identify linear trends in time series. For this test, data should be normally distributed. This test gives us the best fit line for a dataset, providing a visual demonstration of the relationship between the data points. In fact, it determines the strength of the relationship between one dependent variable (usually denoted by Y) with respect to change in an independent variable (denoted by X). This is given by the equation

$$Y = A + Bx$$

Where:
A = Intercept of line on Y-axis
B = Rate of change of dependent variable with respect to one unit change in the independent variable

4. Results and Discussion

A) Trend analysis of monthly, annual and seasonal mean minimum temperature

For all the individual months, the trend of monthly mean minimum temperature was assessed by using the Mann-Kendall trend test. It is confirmed that there is no trend not only for individual months but also for mean annual minimum temperature. Results from Mann-Kendall seasonal test indicate that trends were altogether absent for all the four seasons. The trends, linear regression equation along with coefficient of determination for all individual months and annual year are represented in Figure 1; in addition, their statistical summary (mean, standard deviation and coefficient of variation) is shown in Table 1. The seasonal statistical summary is represented in Table 2. From all these figures, it is evident that monthly mean minimum temperature has been increased significantly in all the months except January, August and December.

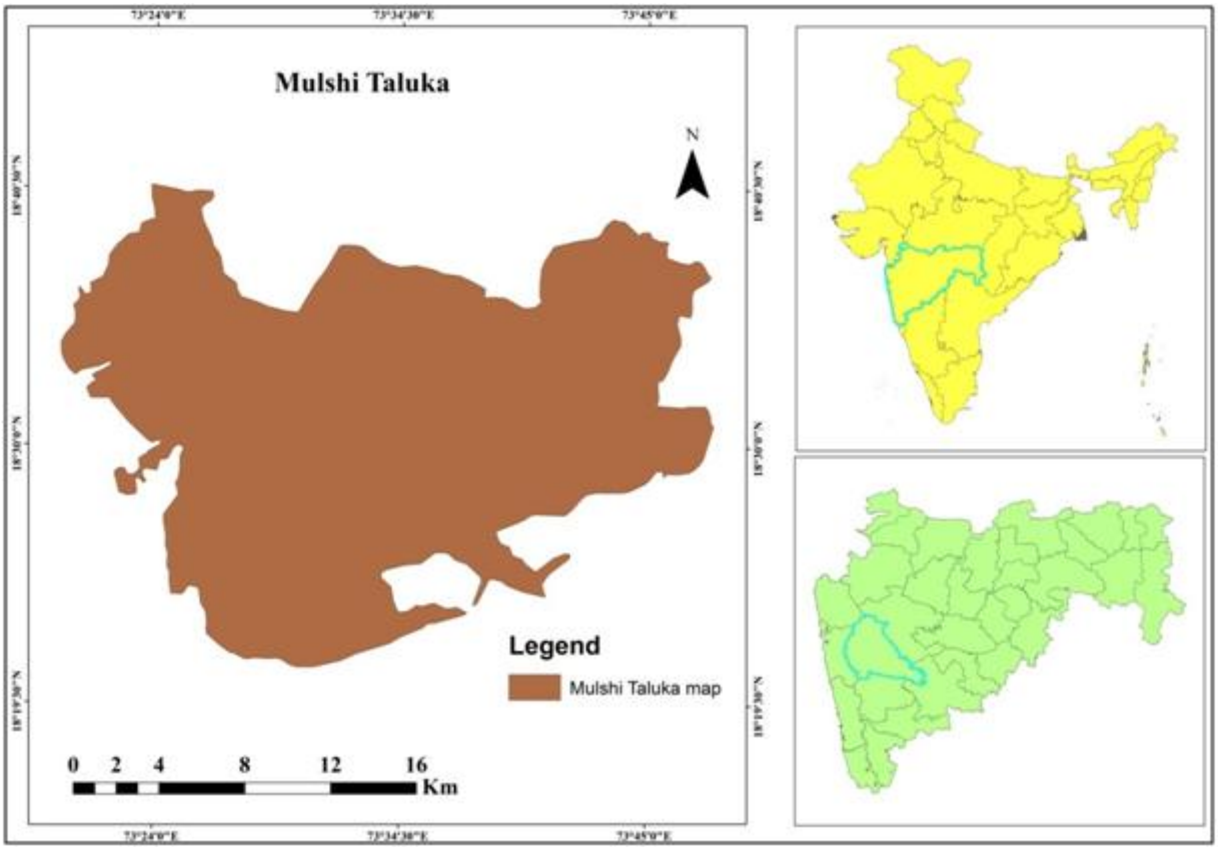
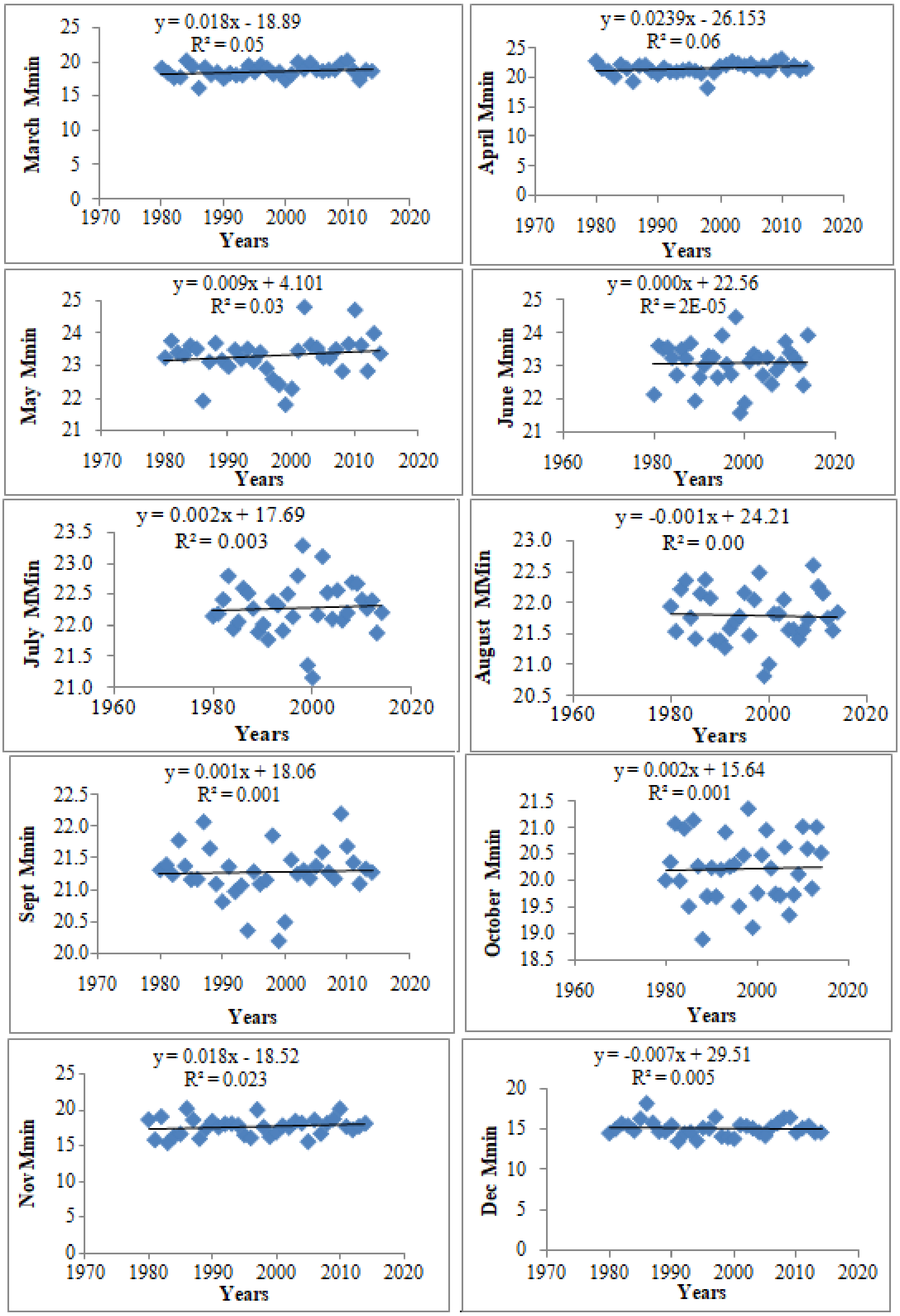


Figure 1: Study Area Map

From the years 1980 to 2014, it was found that the highest mean monthly minimum temperature was increased in the month of April (0.0239°C) followed by February, March and November (0.0180°C), but the temperature in January month was decreased by 0.0095°C. November month showed the highest variation in mean minimum temperature of 6.89%; however, the month of August showed the steadiest state of minimum temperature with coefficient of variation of only 1.87%. In terms of season-wise, mean minimum temperature was high throughout the summer season as it has risen by 0.0174°C from the years 1980 to 2014. But in monsoon season, from 1980 to 2014 years, the minimum temperature was almost stable as the coefficient of variation was hovering between 1.87 to 1.92 %.

The graph depicts that the annual mean minimum temperature has increased by 0.0640°C/ year from 1980 to 2014 with a coefficient of variation of 1.95%. Monthly, annual, and seasonal graphs for a mean minimum temperature of Velhe Observatory (Fig. 2)



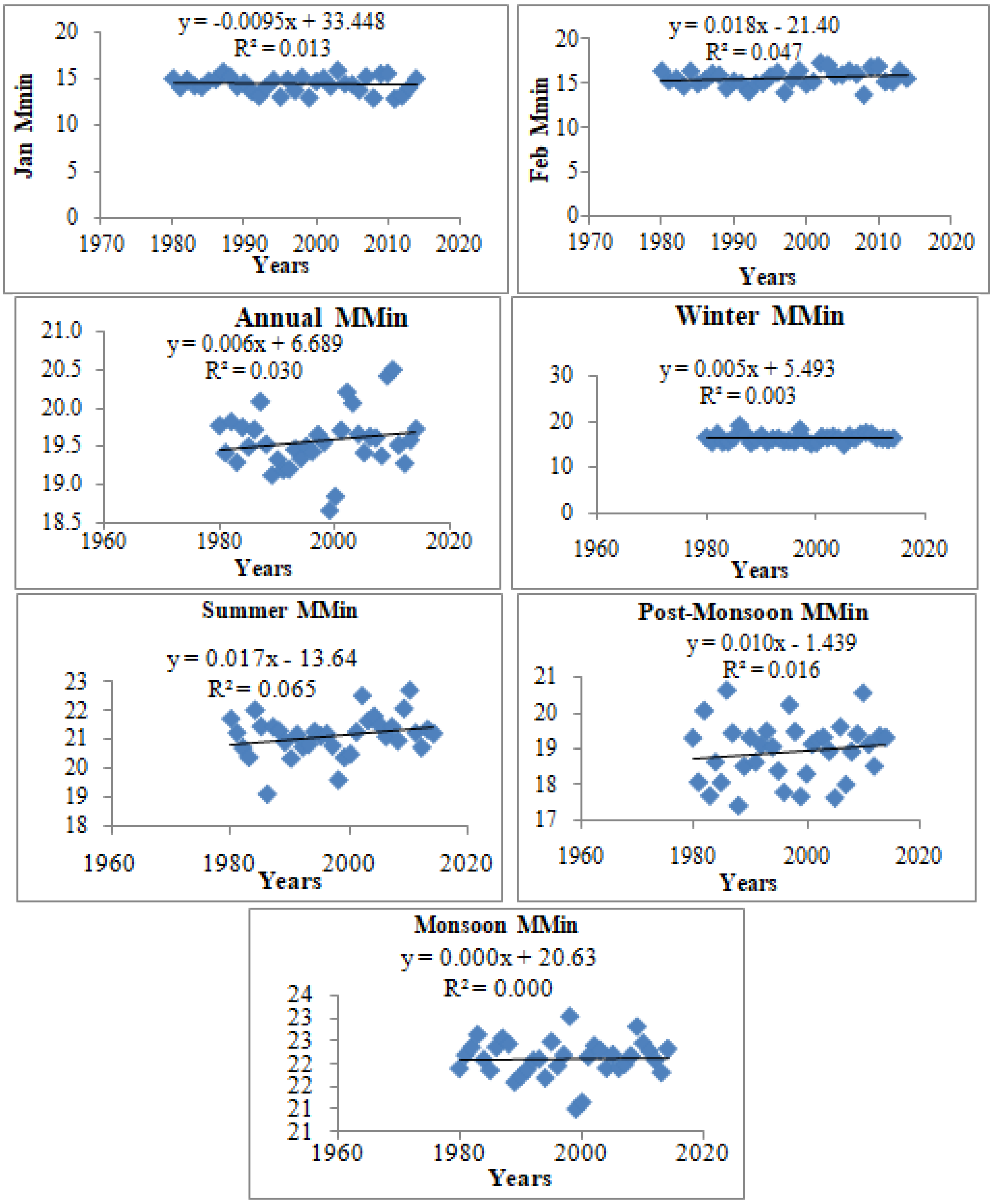


Figure 2: Monthly, annual, and seasonal graphs for a mean minimum temperature of Velhe Observatory

Table 1: Monthly and Annual Statistical Summary of Minimum Temperature

Months	Mean (Ẍ)	Standard Deviation (∂)	Coefficient of Variation (CV% = ∂/Ẍ)
January	14.42	0.84	5.86
February	15.53	0.87	5.63
March	18.58	0.88	4.73
April	21.50	0.97	4.51
May	23.29	0.62	2.67
June	23.09	0.62	2.68
July	22.28	0.42	1.90
August	21.78	0.41	1.87
September	21.27	0.41	1.92
October	20.23	0.61	3.03
November	17.61	1.21	6.89
December	15.11	0.96	6.35
Annual	19.56	0.38	1.95

Table 2: Seasonal Statistical Summary of Minimum Temperature

Seasonal	Mean (Ẍ)	Standard Deviation (∂)	Coefficient of Variation (CV% = ∂/Ẍ)
Winter	15.02	0.58	3.87
Summer	21.12	0.69	3.31
Monsoon	22.10	0.40	1.84
Post-Monsoon	18.92	0.81	4.28

B) Trend analysis of monthly, annual and seasonal mean maximum temperature

For all the individual months, trends of monthly mean maximum temperature were assessed by using Mann-Kendall trend test and it is confirmed that there is a statistically significant increasing trend at 95% confidence interval not only for March, April, November and December months but also for an overall annual mean. Results from Mann-Kendall seasonal test indicate that there is an increasing trend in winter, summer and post-monsoon season. The trends, linear regression equation and coefficient of determination for all individual months and annual year are represented in Figure 2; in addition, their statistical summary (mean, standard deviation and coefficient of variation) is shown in Table 3. The seasonal statistical summary is represented in Table 4. From these figures, it is evident that monthly mean maximum temperature has been increased significantly for all the months (Fig. 3).

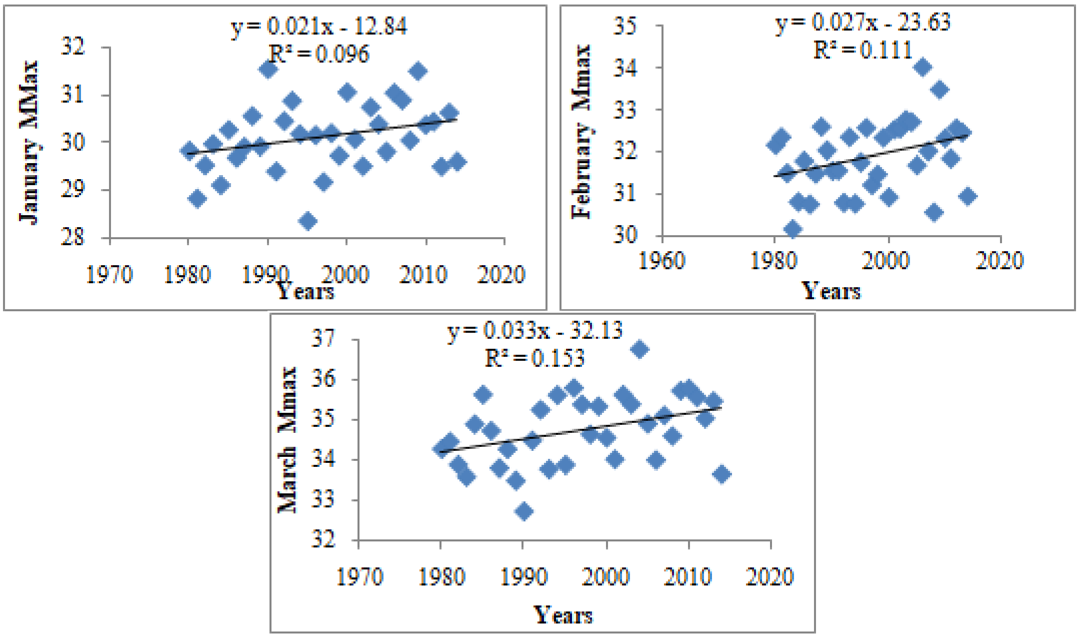
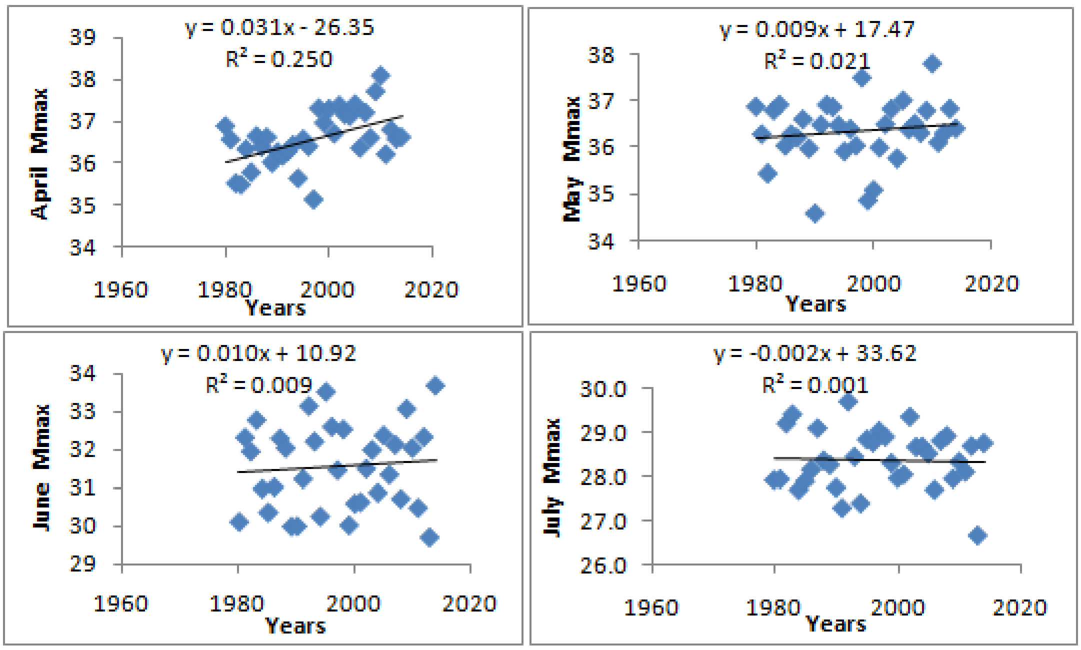


Figure 3: Monthly mean maximum temperature

For all thirty-four years (1980 to 2014), the highest mean maximum temperature was increased in the month of March by 0.0335°C and November by 0.0340°C. June month showed the highest coefficient of variation in mean monthly maximum temperature of 3.51% followed by February at 2.67%. However, April showed the lowest coefficient of variation of only 1.77%. This implies that the highest fluctuation in mean monthly maximum temperature was in June and February months, whereas, in the month of April, it was mostly stable. In terms of season-wise, winter showed the highest increase in mean maximum temperature (0.0268°C) but in the summer season, it was highly stable as the coefficient of variation was only 1.48%. In contrast, temperatures in the post-monsoon season fluctuated as the coefficient of variation was the highest (2.08%).

The graph depicts that the annual mean maximum temperature was increased by 0.0198°C/year from 1980 to 2014 with a coefficient of variation of 1.95%. Monthly, annual, and seasonal graphs for a mean maximum temperature of Velhe Observatory (Fig. 4) are shown.



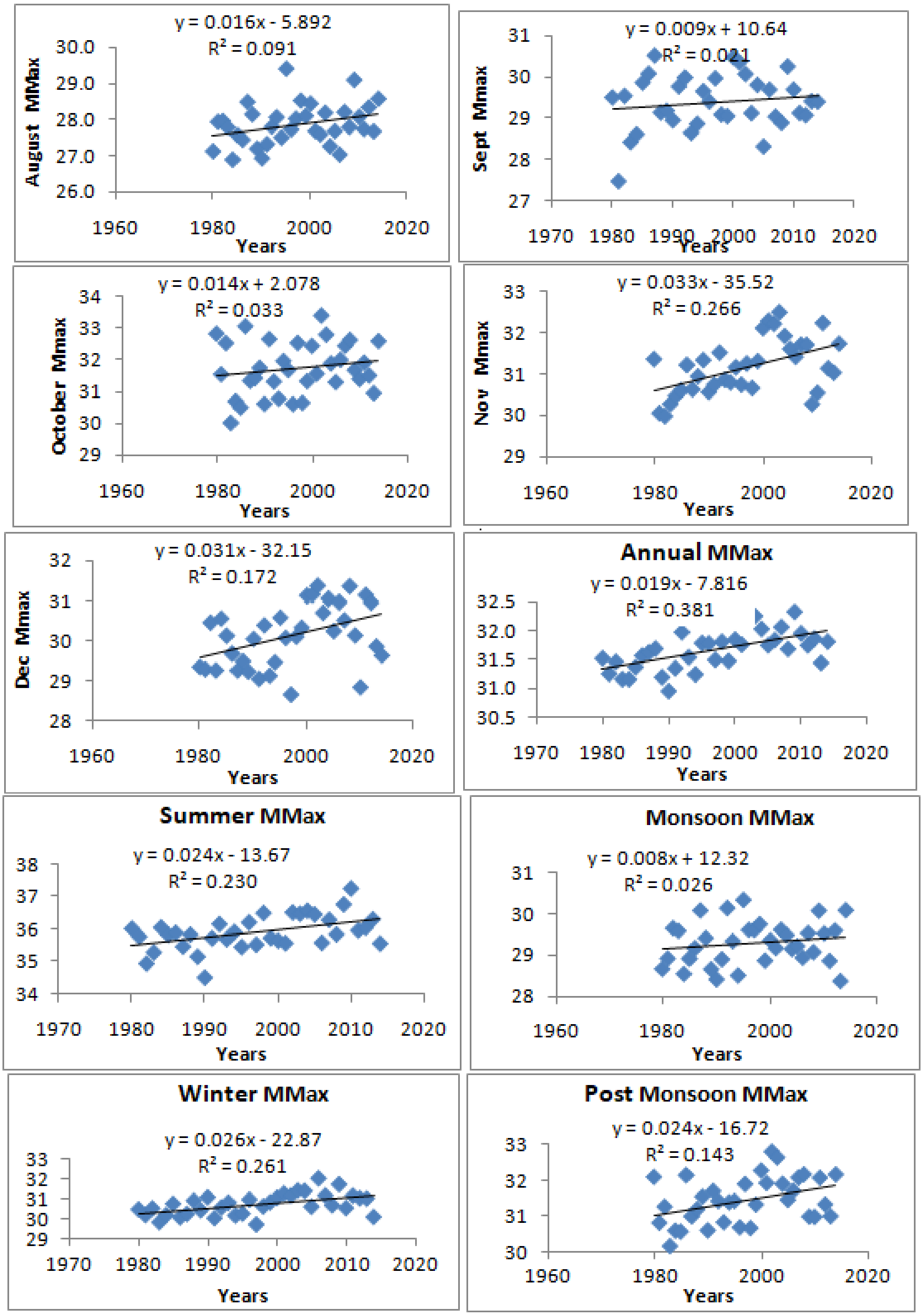


Figure 4: Monthly, annual, and seasonal Graphs for a mean maximum temperature of Velhe Observatory

Table 3: Monthly and Annual Statistical Summary of Maximum Temperature

Months	Mean (Ẍ)	Standard Deviation (∂)	Coefficient of Variation (CV% = ∂/Ẍ)
January	30.10	0.71	2.36
February	31.90	0.85	2.6
March	34.75	0.87	2.52
April	36.85	0.65	1.77
May	36.65	0.66	1.83
June	31.56	1.11	3.51
July	28.37	0.66	2.31
August	27.85	0.57	2.06
September	29.37	0.66	2.25
October	31.74	0.83	2.63
November	31.17	0.66	2.13
December	31.65	0.77	2.55
Annual	3.65	0.32	1.02

Table 4: Seasonal Statistical Summary of Maximum Temperature

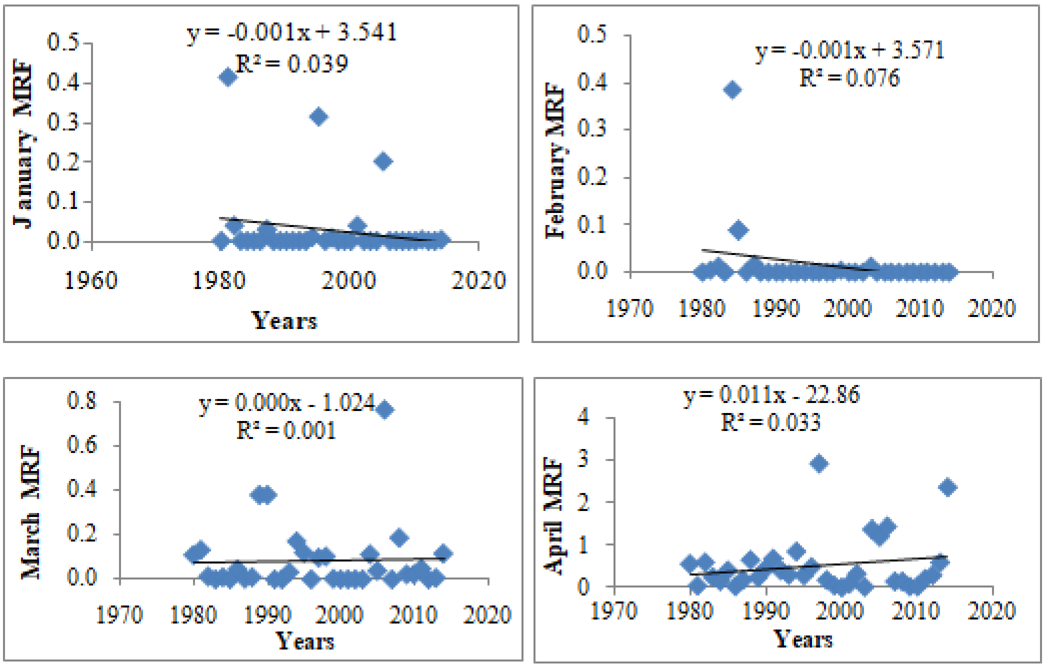
Seasonal	Mean (Ẍ)	Standard Deviation (∂)	Coefficient of Variation (CV% = ∂/Ẍ)
Winter	30.71	0.54	1.75
Summer	35.89	0.53	1.48
Monsoon	29.29	0.53	1.81
Post-Monsoon	31.46	0.65	2.08

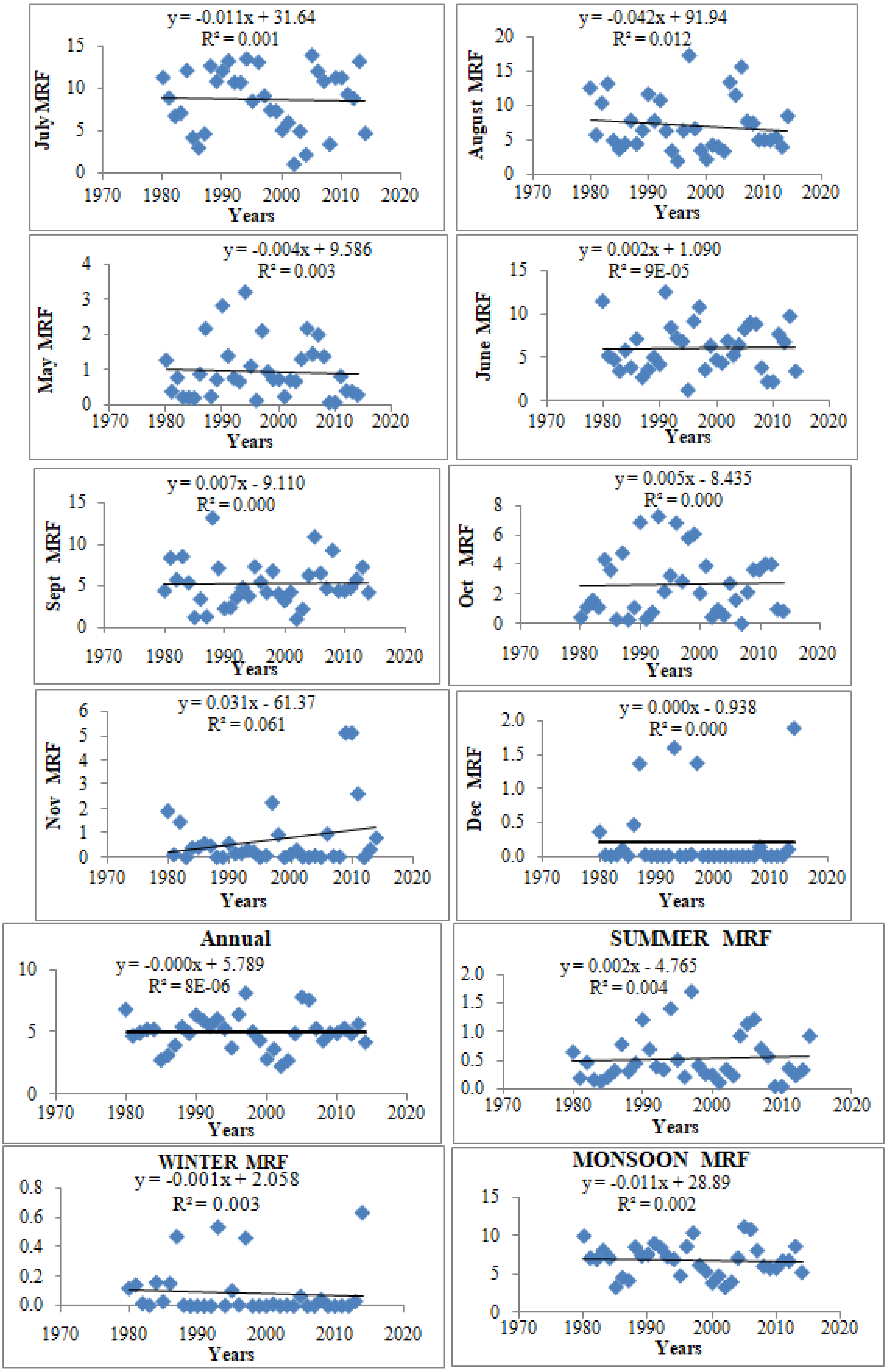
C) Trend analysis of monthly, annual and seasonal mean rainfall (MRF)

For all the individual months, mean monthly rainfall trends were assessed by using a Mann-Kendall trend test. It is confirmed that there is no trend except for February month. There is no trend either for any season and it is too absent for annual mean rainfall. The trends, linear regression equation along with the coefficient of determination for all individual months and annual year are represented in Figure 3; in addition, their statistical summary (mean, standard deviation and coefficient of variation) is shown in Table 5. The seasonal statistical summary is represented in Table 6. From these figures, it is evident that monthly mean rainfall has been increased significantly for March, April, June and September to December, whereas, for the months of January, February, May, July and August, rainfall has been decreased significantly. Moreover, there has been a significant increase in the incidence of prolonged monsoon breaks in India during the months of July and August in recent decades (Ramesh Kumar et al., 2009).

From the years 1980 to 2014, the highest mean monthly rainfall was increased in the month of November by 0.0311 mm but in August month, rainfall was decreased by 0.0425 mm. February month showed the highest coefficient of variation in mean monthly rainfall (444.4%) followed by January (301%). In contrast, July showed the lowest coefficient of variation (41.69%). This implies that the highest fluctuation in monthly mean rainfall was in February and January months, while, in the month of June, it was quite stable. In terms of seasonal basis from 1980 to 2014 years, mean rainfall has been decreased by 0.001 mm and 0.11 mm in winter and monsoon respectively; however, it has risen by 0.0183 mm and 0.003 mm in post-monsoon and summer season respectively. The mean rainfall was most stable in monsoon season with the variation of only 30.5%, but it highly fluctuated in winter as the coefficient of variation was the highest (196.5%).

The graph depicts that the annual mean rainfall was decreased by 0.0004 mm/ year from 1980 to 2014 years with a coefficient of variation of 1.95%. Monthly, seasonal and annual graphs for a maximum temperature of Velhe Observatory (Fig. 5)




y = -0.011x + 31.64
R² = 0.001
July MRF
Years
y = -0.042x + 91.94
R² = 0.012
August MRF
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y = -0.004x + 9.586
R² = 0.003
May MRF
Years
y = 0.002x + 1.090
R² = 9E-05
June MRF
Years
y = 0.007x - 9.110
R² = 0.000
Sept MRF
Years
y = 0.005x - 8.435
R² = 0.000
Oct MRF
Years
y = 0.031x - 61.37
R² = 0.061
Nov MRF
Years
y = 0.000x - 0.938
R² = 0.000
Dec MRF
Years
Annual
y = -0.000x + 5.789
R² = 8E-06
Years
SUMMER MRF
y = 0.002x - 4.765
R² = 0.004
Years
WINTER MRF
y = -0.001x + 2.058
R² = 0.003
Years
MONSOON MRF
y = -0.011x + 28.89
R² = 0.002
Years

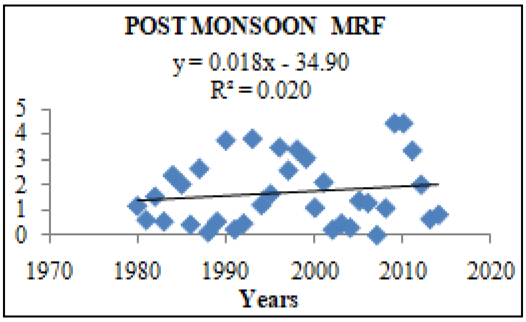

Figure 5: Monthly, Seasonal and Annual Graphs for Maximum Temperature of Velhe Observatory (Figure 4)

Table 5: Monthly and Annual Statistical Summary of Rainfall

Months	Mean (Ẍ)	Standard Deviation (∂)	Coefficient of Variation (CV% = ∂/Ẍ)
January	0.03	0.09	301.05
February	0.01	0.07	444.40
March	0.08	0.15	181.96
April	0.51	0.65	127.36
May	0.97	0.79	81.59
June	6.14	0.77	45.11
July	8.76	3.65	45.69
August	7.15	3.86	54.04
September	5.28	2.69	50.91
October	2.65	2.13	80.38
November	0.74	1.28	174.22
December	0.21	0.51	237.37
Annual	2.71	0.764	28.1

Table 6: Seasonal Statistical Summary of Rainfall

Seasonal	Mean (Ẍ)	Standard Deviation (∂)	Coefficient of Variation (CV% = ∂/Ẍ)
Winter	0.08	0.16	196.51
Summer	0.52	0.41	79.22
Monsoon	6.83	2.08	30.56
Post-Monsoon	1.69	1.31	77.69

5. Conclusion

The present study has examined the trends of monthly annual and the seasonal mean of three climate variables - minimum and maximum temperature along with rainfall from 1980 to 2014 years. The trends were assessed by using Mann-Kendall 1945 and Seasonal Mann-Kendall test. The slope of the trend was assessed by linear regression.

The analysis of minimum temperature indicated that there are no trends for monthly, annual and seasonal basis. However, it has found that the annual mean minimum temperature rose at a very slow rate (0.064°C/year) but steadily. From 1980 to 2014 years, it has found that April month was the second hottest after May as the minimum temperature rose by 0.0239°C; however, January month was the coldest as temperature fall by 0.095°C. From 1980 to 2000 years, the average annual mean minimum temperature was 19.42°C but it was increased to 19.75°C from 2001 to 2014, that is, by 0.33°C.

The analysis of mean maximum temperature indicated that there is an increasing trend for March, April, November and December months. Even though IMD considers May as the hottest month, it was found that April was the hottest among all as the mean maximum temperature rose by 0.032°C from 1980 to 2014 years. Results indicated that there is an increasing trend for winter, summer and post-monsoon season and also at an annual basis as the mean maximum temperature rose steadily by 0.0198°C/year from 1980 to 2014 years. From this, it can be concluded that summers have become hotter and there are high fortunes that it will continue in the future too. From 1980 to 2000 years, the annual average maximum temperature was 31.489°C but it increased to 31.858°C from 2001 to 2014 years, that is, by 0.369°C.

The analysis of rainfall indicated that there are no trends for monthly (except February), annual and seasonal basis. But the annual mean rainfall decreased by 0.0004 mm/ year but steadily. From 1980 to 2014 years, monthly mean rainfall increased in the month of November by 0.0311 mm and it decreased in August month by 0.0425 mm. The mean rainfall has increased in summer and post-monsoon season, whereas, it has decreased in winter and monsoon. From this, it can be inferred that the normal mean rainfall has decreased, while, unusual rainfall has increased.

6. Acknowledgement

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7. Funding

Financial assistance, fund or research grant have not been taken from any institution.

8. Conflict of interest

The authors declare that they have no conflict of interest.

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