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Trends and Variability of Climatic Parameters in Vadodara District

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Abstract

Climate change may refer to a change in average weather conditions, or in the time variation of weather around longer-term average conditions. The impact of climate change on the various meteorological parameters has received a great deal of attention by scholars worldwide .The means for detecting climate trends and variability are time series analysis based on data sets e.g. Temperature, precipitation, wind speed and relative humidity. In this study the focus is on detecting trends in mean monthly maximum temperature, mean monthly minimum temperature, mean monthly precipitation, mean monthly wind speed and mean monthly relative humidity for the Vadodara district in the state of Gujarat. For this study, Mann-Kendall test was run at 5% significance level on time series data for Vadodara district for the period of thirty seven years strting from 1969 to 2005. Mann-Kendall test is carried out using software XLSTAT to analyze trend in given data. The resultant Mann- Kendall test statistic (Zs) indicates how strong the trend is and whether it is increasing or decreasing. A high positive value (Zs) statistic indicates an increasing trend while a low negative value indicates a decreasing trend in the time series of random variables. In this study maximum temperature shows highest increase in December while highest decrease in July .The minimum temperature has shown an increasing trend in all the months and a significant increase is observed in the month of March. The relative humidity is showing an increasing trend in all the months except the months of June, July and August. The wind speed is decreasing for all the months and a significant decrease is observed in June. Also, Sen's slope estimator has been used along with Mann Kendall test statistic (Zs). Pattern of trends as discussed in the results leads to a conclusion that climate in showing changes in all climatological parameters in vadodara district.

Keyword- Climate change, Mann-Kendal Test, Sen's Slope Estimator, Trend Analysis

I. INTRODUCTION

The physical conditions in the environment and atmosphere such as precipitation, temperature, wind, pressure and humidity, which have direct or indirect consequences upon the biosphere, are termed as weather while the pattern of weather in a region over a period of time is called climate (Cunningham et al., 2005). Climate is the long term regime of the atmospheric variables or the composite of the day to day to values of the weather elements for a given place or area for a given period. The period of averaging may be several months, seasons, years or even centuries. Drastic changes have taken place in the climate of the earth over the ages. Taken over a long period the trends of climate change are more pronounced and it shows variations according to the choice of period these changes are referred to as climate change. The Intergovernmental Panel on Climatic Change (IPCC) estimates that the global mean surface temperature has increased 0.6 ± 0.2 ºC since 1861 and predicts an increase of 2 to 4 ºC over the next 100 years (IPCC,2007).

Climate change and global warming are commonly detected throughout studies of variability of climatic parameters such as rainfall, temperature, runoff and groundwater .The changes in regional temperature and precipitation have important implications for all aspects of the hydrologic cycle. Variations in these parameters determine the amount of water that reaches the surface, evaporates or transpires back to the atmosphere, becomes stored as snow or ice, infiltrates into the groundwater system, runs off the land, and ultimately becomes base flow to streams and river.

One of the best ways of understanding how climate may change in future is to examine how it has changed in the past based upon long-term observational records. Changes in precipitation patterns affect water availability and runoff directly, while changes in temperature, radiation and humidity have an effect on evapotranspiration. Hence in this study an attempt has been made to detect the trends in various climatological factors like monthly maximum temperature, monthly minimum temperature, monthly relative humidity and monthly wind speed for Vadodara district from the year 1969 to 2005 using Mann-Kendal test and Sen's slope estimator.

Yadav et al. (2014) have indicated an increasing trend of annual rainfall in Almora, Bageshwar, Nainital, Pauri Gharwal, Pithoragarh, Udhamsingh Nagar and uttarkashi ;and a dcreasing trend of annual rainfall for Chamoli,Champawat , Rudraprayag and Tehri Garhwal district of Uttarakhand state, India in a study conducted from year 1971 to 2011.Shah et al.

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(2012) have observed that the rainfall is decreasing, minimum temperature, mean temperature and relative humidity are increasing and maximum temperature has no change for the Mann-Kendall test applied to Meteorological data of Peshawar (1981-2010)district, Pakistan. Babar et al have studied the rainfall data of 40 years from 1971 to 2001 in Nethravathi river basin and have indicated an increasing trend for month of September while decreasing trend for June, July and August months. Safari et al have conducted a study for fifty two years starting from 1958 to 2010 for the state of Rwanda, Africa on mean annual temperature and have indicated a significant change in temperature from year 1977.

II. STUDY AREA AND DATA COLLECTION

The area selected for this study is Vadodara district in state of Gujarat, India. The district covers an area of 7794 km^2 and lies between 22.18º N Latitude and 73.12 ºE Longitude. The district has a sub-tropical climate with moderate to high summer, cold winter and medium rainfall and with moderate humidity. The climatological data required for the study was collected from Indian Meteorological Department (IMD), Pune for the years starting from 1969 to 2005.

III. METHODOLOGY

There are several approaches for detecting the trend in the time series. These approaches can be either parametric or non-parametric. Parametric methods assumed the data should normally distributed and free from outliers. On the other hand, non-parametric methods are free from such assumptions. The most popularly used non-parametric tests for detecting trend in the time series is the Mann-Kendall (MK) test .It is widely used for different climatic variables. For this study, the modified Mann-Kendall test was run at 5% significance level on time series data from the year 1969 to 2005 for various parameters like maximum temperature, minimum temperature, wind speed, relative humidity and sunshine hours. Also, Sen's slope estimator (Q) has been used along with Mann Kendall test statistic (Z_s).

A. Mann –Kendal Test

Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic and in hydrologic time series. There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend. The computational procedure for the Mann Kendall test considers the time series of n data points and Ti and Tj as two subsets of data where i = 1,2,3,…, n-1 and j = i+1, i+2, i+3, …, n. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1.On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S .The Mann-Kendall S Statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\,(T_j - T_i)$$

$$Sign\,(T_j - T_i) = \begin{cases} 1 \; if \; T_j - T_i > 0 \\ 0 \; if \; T_j - T_i = 0 \\ -1 \; if \; T_j - T_i < 0 \end{cases}$$

where T_j and T_i are the annual values in years j and i, j > i, respectively.

If n < 10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two tailed test is used. At certain probability level H_0 is rejected in favor of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$,where $S_{\alpha/2}$ is the smallest S which has the probability less than α/2 to appear in case of no trend. A positive value of S indicates an upward (downward) trend and negative value of S indicates a downward trend.

For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance. The variance (σ^2) for the S-statistic is defined by:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18}$$

In which ti denotes the number of ties to extent i. The summation term in the numerator is used only if the data series contains tied values. The standard test statistic Z_S is calculated as follows:

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$$Z_s = \begin{cases} \frac{S-1}{\sigma} for\ S > 0 \\ 0\ for\ S = 0 \\ \frac{S+1}{\sigma} for\ S < 0 \end{cases}$$

The test statistic Z_S is used a measure of significance of trend.

B. Sen's Slope Estimator

The method of calculating the Sen's slope estimator requires a time series of equally spaced data. The magnitude of trend is predicted by the Sen's estimator. Here, the slope (Ti) of all data pairs is computed as

$$T_i = \frac{Xj - Xk}{j-k}$$

Where:
Xj = data measurement at time j
Xk = data measurement at time k
j = time after time k,
Xj and Xk constitute the pairs of observations identified by place in the series. The median of these N values of Ti is represented as Sen's estimator of slope which is given as:

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N\ is\ even \end{cases}$$

IV. RESULTS AND DISCUSSIONS

The trends over the study period of 1969-2005 of all the meteorological parameters are observed in all months of the study period with the help of Mann- Kendall non parametric test and Sen's Slope estimator.

A. Mean Monthly Maximum Temperature

The Mann-Kendal test statistic (Z_s) and Sen's Slope estimator (Q) of monthly maximum temperature of all months are shown in Table-1 and Table-2 below. The increasing rates of maximum temperature are shown for the months of January, February, March, May, June, August, September, October, November and December. The decreasing trend is observed in April and July. However, December month shows higher increasing trend (Figure-1) amongst all the months and July month shows highest decreasing trend(Figure-2).

B. Mean Monthly Minimum Temperature

The Mann-Kendal test statistic (Z_s) and Sen's Slope estimator (Q) of monthly minimum temperature of all months are shown in Table-1 and Table-2 below. The increasing rates of minimum temperature are shown for the months of January, February, March, April, May, June, July, August, September, October, November and December. The decreasing trend is observed in none of the months. However March month shows highest increasing trend (Figure-3) amongst all the months.

C. Mean Monthly Relative Humidity

The Mann-Kendal test statistic (Z_s) and Sen's Slope estimator (Q) of monthly relative humidity of all months are shown in Table-1 and Table-2 below. The increasing rates of relative humidity are shown for the months of January, February, March, April, May, September, October, November and December. The decreasing trend is observed in June, July and August months. However August month shows highest decreasing trend (Figure-4) amongst all the months and March month shows highest increasing trend (Figure-5)

D. Mean Monthly Wind Speed

The Mann-Kendal test statistic (Z_s) and Sen's Slope estimator (Q) of monthly wind speed of all months are shown in table below. The decreasing rates of wind speed are shown for the months of January, February, March, April, May, June, July, August, September, October, November and December. However June month shows highest decreasing trend (Figure-6) amongst all the months.

V. CONCLUSIONS

The analysis of various climatological factors like monthly maximum temperature, monthly minimum temperature, monthly relative humidity and monthly wind speed for Vadodara district from the year 1969 to 2005 using Mann-Kendal test and Sen's

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slope estimator have been carried out. Pattern of trends as discussed in the results leads to a conclusion that climate is showing some changes in Vadodara district which may affect water resources planning and management. The changes in climate are observed as follows:

- The mean monthly maximum temperature has also shown an increasing trend in all the months except April and July. The highest increase in temperature is observed in the month of December with the Mann-Kendall Statistic having value as high as Z_s= 235 and Sen's slope Estimator having value Q= 0.042. A significant decrease is observed in the month of July with the Mann-Kendall Statistic having value as low as Z_s= -42 and Sen's slope Estimator having value Q= -0.005.
- There is increasing trend for mean monthly minimum temperature in all the months. However, a significant increase in temperature is observed in the month of March with the Mann-Kendall Statistic having value as high as Z_s= 230 and Sen's slope Estimator having value Q= 0.045.
- The mean monthly relative humidity is showing an increasing trend in all the months except in the months of June, July and August . The highest increase in temperature is observed in the month of March with the Mann-Kendall Statistic having value as high as Z_s= 266 and Sen's slope Estimator having value Q= 0.295. The highest decrease is observed in the month of August with the Mann-Kendall Statistic having value as low as Z_s= -116 and Sen's slope Estimator having value Q= -0.155.
- The mean monthly wind speed is decreasing for all the months. However, a significant decrease in wind speed is observed in the month of June with the Mann-Kendall Statistic having value as low as Z_s= -441 and Sen's slope Estimator having value Q= -0.305

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	Mean Monthly Maximum Temperature		*Mean Monthly Minimum Temperature*		*Mean Monthly Relative humidity*		*Mean Monthly Wind Speed*	
Month	*Z_s*	*Remark*	*Z_s*	*Remark*	*Z_s*	*Remark*	*Z_s*	*Remark*
January	*114.0*	↑	*220.0*	↑	*264.0*	↑	*-246.0*	↓
February	*123.0*	↑	*146.0*	↑	*265.0*	↑	*-329.0*	↓
March	*39.0*	↑	*230.0*	↑	*266.0*	↑	*-254.0*	↓
April	*-23.0*	↓	*107.0*	↑	*219.0*	↑	*-315.0*	↓
May	*6.0*	↑	*111.0*	↑	*22.0*	↑	*-386.0*	↓
June	*36.000*	↑	*142.0*	↑	*-31.0*	↓	*-441.0*	↓
July	*-42.0*	↓	*149.0*	↑	*-50.0*	↓	*-426.0*	↓
August	*116.0*	↑	*165.0*	↑	*-116.0*	↓	*-418.0*	↓
Septembe r	*33.0*	↑	*224.0*	↑	*26.0*	↑	*-339.0*	↓
October	*39.0*	↑	*156.0*	↑	*121.0*	↑	*-232.0*	↓
November	*189.0*	↑	*7.0*	↑	*119.0*	↑	*-295.0*	↓
December	*235.0*	↑	*31.0*	↑	*193.0*	↑	*-228.0*	↓

Table 1: Mann-Kendal Trend Statistic (Z_s) for mean monthly maximum and minimum temperature, mean monthly relative humidity and mean monthly wind speed from years 1969-2005

Where Z_s is the Mann-Kendal Test Statistic. ↑ indicates an increasing trend. ↓ indicates a decreasing trend

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	Mean Monthly Maximum Temperature		*Mean Monthly Minimum Temperature*		*Mean Monthly Relative humidity*		*Mean Monthly Wind Speed*	
Month	*Q*	*Remark*	*Q*	*Remark*	*Q*	*Remark*	*Q*	*Remark*
January	*0.025*	↑	*0.051*	↑	*0.264*	↑	*-0.08*	↓
February	*0.029*	↑	*0.042*	↑	*0.275*	↑	*-0.106*	↓
March	*0.01*	↑	*0.045*	↑	*0.295*	↑	*-0.057*	↓
April	*-0.004*	↓	*0.022*	↑	*0.203*	↑	*-0.083*	↓
May	*0.002*	↑	*0.014*	↑	*0.03*	↑	*-0.194*	↓
June	*0.011*	↑	*0.019*	↑	*-0.049*	↓	*-0.305*	↓
July	*-0.005*	↓	*0.014*	↑	*-0.097*	↓	*-0.221*	↓
August	*0.025*	↑	*0.021*	↑	*-0.155*	↓	*-0.167*	↓
September	*0.009*	↑	*0.037*	↑	*0.043*	↑	*-0.1*	↓
October	*0.012*	↑	*0.031*	↑	*0.254*	↑	*-0.044*	↓
November	*0.05*	↑	*0.001*	↑	*0.189*	↑	*-0.072*	↓
December	*0.042*	↑	*0.011*	↑	*0.185*	↑	*-0.078*	↓

Table 2: Sen's Slope Estimator (Q) for mean monthly maximum and minimum temperature, mean monthly relative humidity and mean monthly wind speed from years 1969-2005.

Where Q_s is the Mann-Kendal Test Statistic. ↑ indicates an increasing trend. ↓ indicates a decreasing trend.

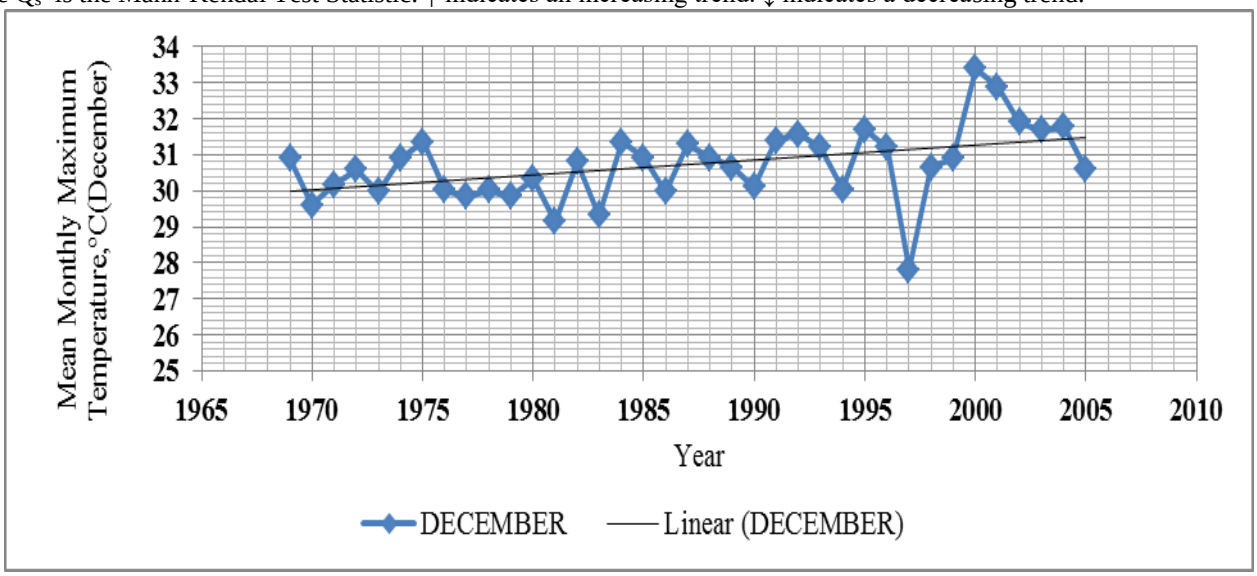

Fig. 1: Trends for Mean Monthly Maximum Temperature, ºC (December 1969-2005)

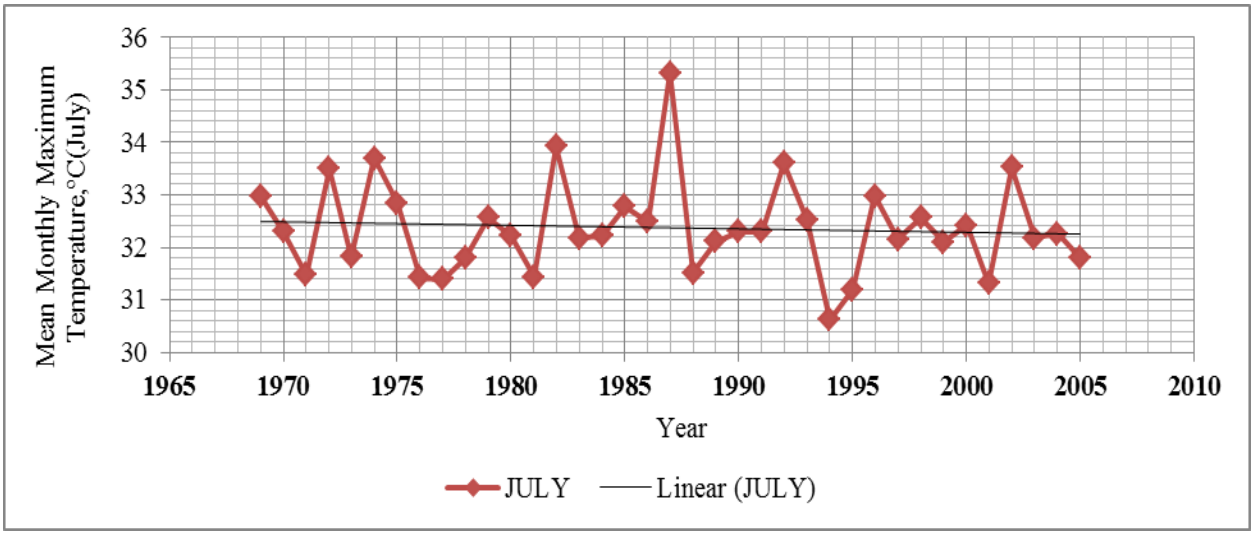

Fig. 2: Trends for Mean Monthly Maximum Temperature, ºC (July 1969-2005)

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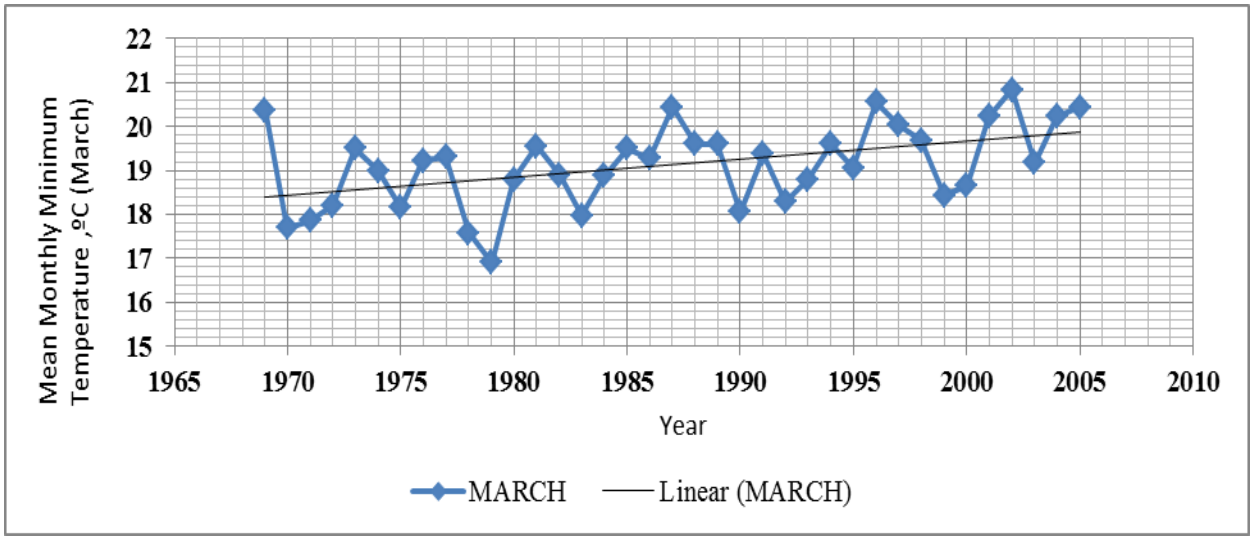

Fig. 3: Trends for Mean Monthly Minimum Temperature, ºC (March 1969-2005)

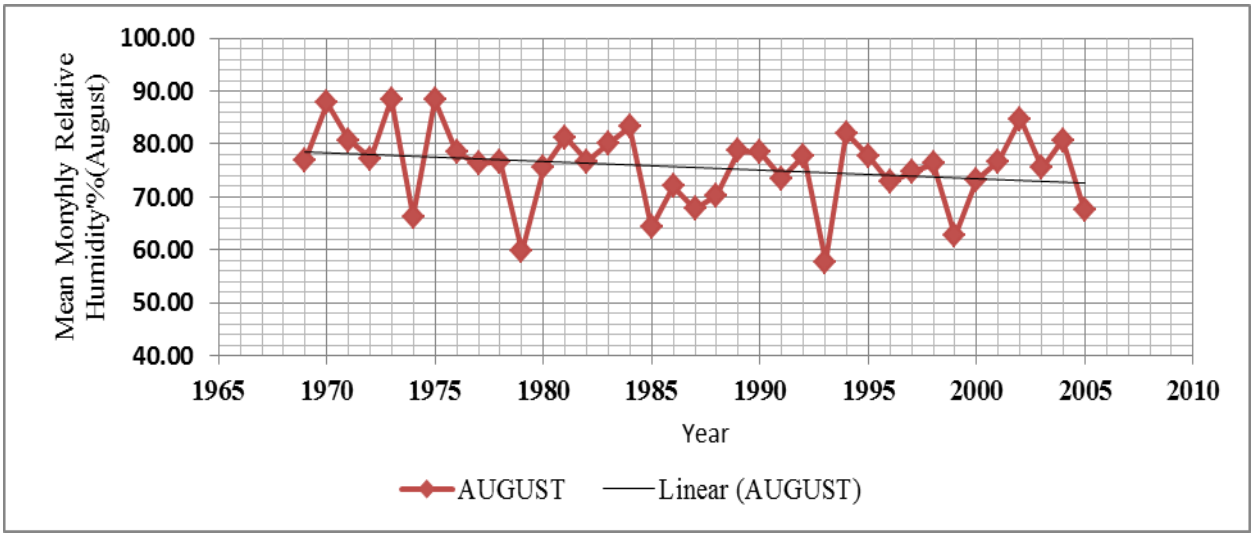

Fig. 4: Trends for Mean Monthly Relative Humidity, % (August, 1969-2005)

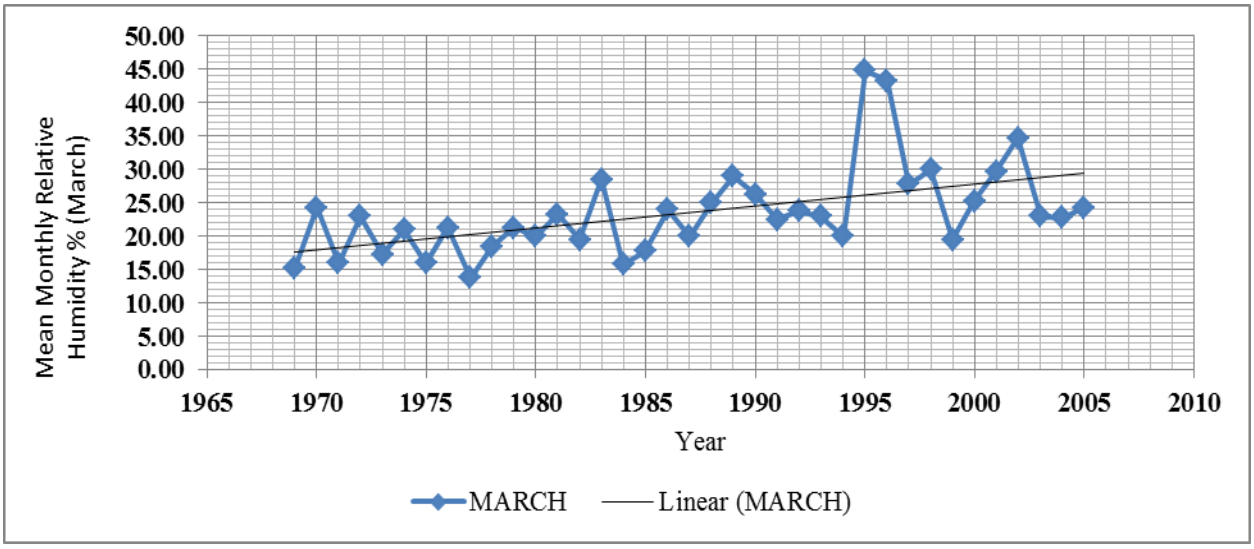

Fig. 5: Trends for Mean Monthly Relative Humidity, % (March, 1969-2005)

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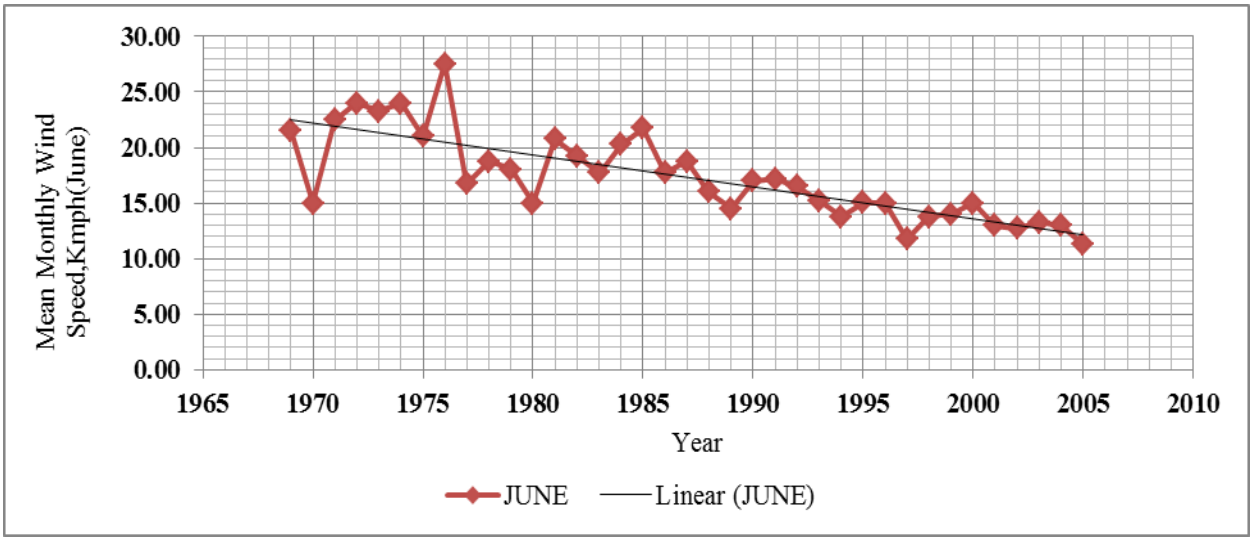

Fig. 6: Trends for Mean Monthly Wind Speed, Kmph (June, 1969-2005)

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