Meteorological Trend Analysis in Western Rajasthan (India) using Geographical Information System and Statistical Techniques

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Abstract
The present study focuses on the long term trends of meteorological parameters like precipitation, temperature, solar radiation, wind direction etc. of Udaipur district, Rajasthan which is mainly located in semi-arid zone in India. Meteorological parameters have been taken for this study to find out the annual variability using Mann-Kendall test and Sen's slope estimator. Yearly long term trend has been identified for thirty one years of data. There are both increasing and decreasing trends of meteorological parameters obtained by this MK test, suggesting overall significant changes in the study area.

Keywords*:* Trend analysis, Meteorological parameters, Mann-Kendall test, Sen's slope.

1. Introduction

Climate change generally refers to any change in climate over the time caused by naturally or anthropogenic response. The climate change and its extensive variability due to anthropogenic impact have got a special attention by IPCC (2001). In another sense, climate change means the shifting of climatic or meteorological parameters viz. precipitation, maximum temperature, minimum temperature, solar radiation, relative humidity, wind speed etc. and many other factors where as global warming or cooling which refer the changes of the surface temperature (Back and Bretherton 2005). The long term trends of all climatic parameters are necessary to assess the long term impact upon the environment of an area. Mann-Kendall (MK) is one of the most commonly used non-parametric tests for detecting climatic changes in time series and trend analysis (Mann 1945; Kendall 1955). MK trend test is a rank correlation test for two groups of observations proposed by Kendall (1955). Mann–Kendall (MK) test is able to suggest the significant trend in hydrological and climatological time-series data (Modarres and Silva 2007). Modarres and Sarhadi (2009) shown the spatial and temporal trend analysis using MK test in Iran in the last half of the twentieth century. Tabari et al. (2011) investigated the long-term trends of air temperatures and precipitation of Iran using MK test for the period of 1966 to 2005. Martinez et al. (2012) studied the long term trends of precipitation and temperature in Florida, USA using MK test. The annual and seasonal trends were analyzed in Serbia during 1980–2010 using Mann-Kendall and Sen's slope estimator (Gocic and Trajkovic 2013). Sayemuzzaman and Jha (2014) performed the spatial and temporal trend analysis using MK test for precipitation data across the state of North Carolina in United States in the period of 1950 to 2009. Lettenmaier, (1976) shown the trends in water quality using MK test from the records with dependent Observations. Hirsch et al. (1982) did an analysis using MK test for monotonic trends of water quality. The some other hydrological studies were carried out by (Van Belle and Hughes 1984; Hipel et al. 1988; Taylor and Loftis 1989; Zetterqvist 1991; Bouchard and Haemmerli 1992; Yu et al. 1993; Hamed 2008; Hamed 2009) etc.

For the Indian context there are several works regarding MK test. Jhajharia et al. (2009) showed the analyses of temporal characteristics of pan evaporation using Mann–Kendall test. Paul et al. (2011) did their study on climate change on a local basis and the hydrological trend in total annual precipitation rate on the basis of Mann-Kendall (MK) test analysis coupled with the wavelet transformation. Mondal et al. (2012) studied the changing pattern of long term trend of rainfall in Orissa coastal region, India. Patle et al. (2013) did their study on temporal variability in climatic parameters and potential evapotranspiration with the reference of crop from 1981 to 2011. Duhan et al. (2013) studied the spatial and temporal variability in the air temperatures at Madhya Pradesh of India based on monthly, annual and seasonal range from 1901 to 2002 using MK test. They also studied on seasonal and annual trends of rainfall for the Haryana and Madhya Pradesh, India (Duhan and Pandey

2013). Jain et al. (2013) did an analysis of rainfall and temperature trends using MK test for northeast India. Sonali and Kumar (2013) studied a spatio-temporal trend analysis using MK test with annual maximum and minimum temperatures of India. Trend analysis namely the Mann–Kendall test and Sen's slope estimator of the mean and extreme annual daily rainfall and temperature at the spatio-temporal level was done for all the 33 urban areas of Rajasthan state of India (Pingale et al. 2014). Kundu et al. (2014) showed the precipitation trend analysis using MK test over the eastern part of India. Suryavanshi et al. (2014) studied the trend analysis of historic past climatic variables using MK test for the Betwa river basin in India. Chaudhuri and Dutta (2014) described a trend of pollutants, temperature and humidity over Kolkata region of India using MK test and different ARIMA models. Bisai et al. (2014) used Mann-Kendall test for detection of surface air temperature for weather observation in Kolkata, India.

2. Study Area

Udaipur has a great historical importance in India. Generally it is called ‘Venice of the East’. It is also called the ‘city of lakes’. In 1568, Udaipur was founded by Rana Udai Singh after the fall of Chittor to Akbar. While, the Rajputs were thrown out of their capital and they never wanted to give up their lives for dignity, sense of freedom and honour instead. Tourists flock to this enchanting city in the heart of the Aravalli Hills which has three interconnected lakes viz. Fateh Sagar Lake, Lake Pichhola and the smaller Swaroop Sagar Lake. Geographically it is located between 23^{o}46' N and 25^{o}5' N and between 73^{o}9' E and 74^{o}35'E. The autumn or winter is the most appropriate season to visit. Tourists mainly arrive more in numbers between mid-September to late March or early April of the year. January is the coldest month of the year and while the days are dazzling, sunny and comparatively warmer than night with the maximum temperature around 28.3 ^{o}C. The summer temperature is 38.3°C (Max) and 28.8 °C (Min.) also in winters 28.3 °C (Max) and 11.6 °C (Min). Udaipur district is full of hard-rock structure surrounded by hilly terrains of Rajasthan. The district frequently experienced the drought hazard due to the belated monsoon, low rainfall and high summer temperature (Bhuiyan et al. 2006). Udaipur is also the centre for arts, crafts and cultures (Figure 1).

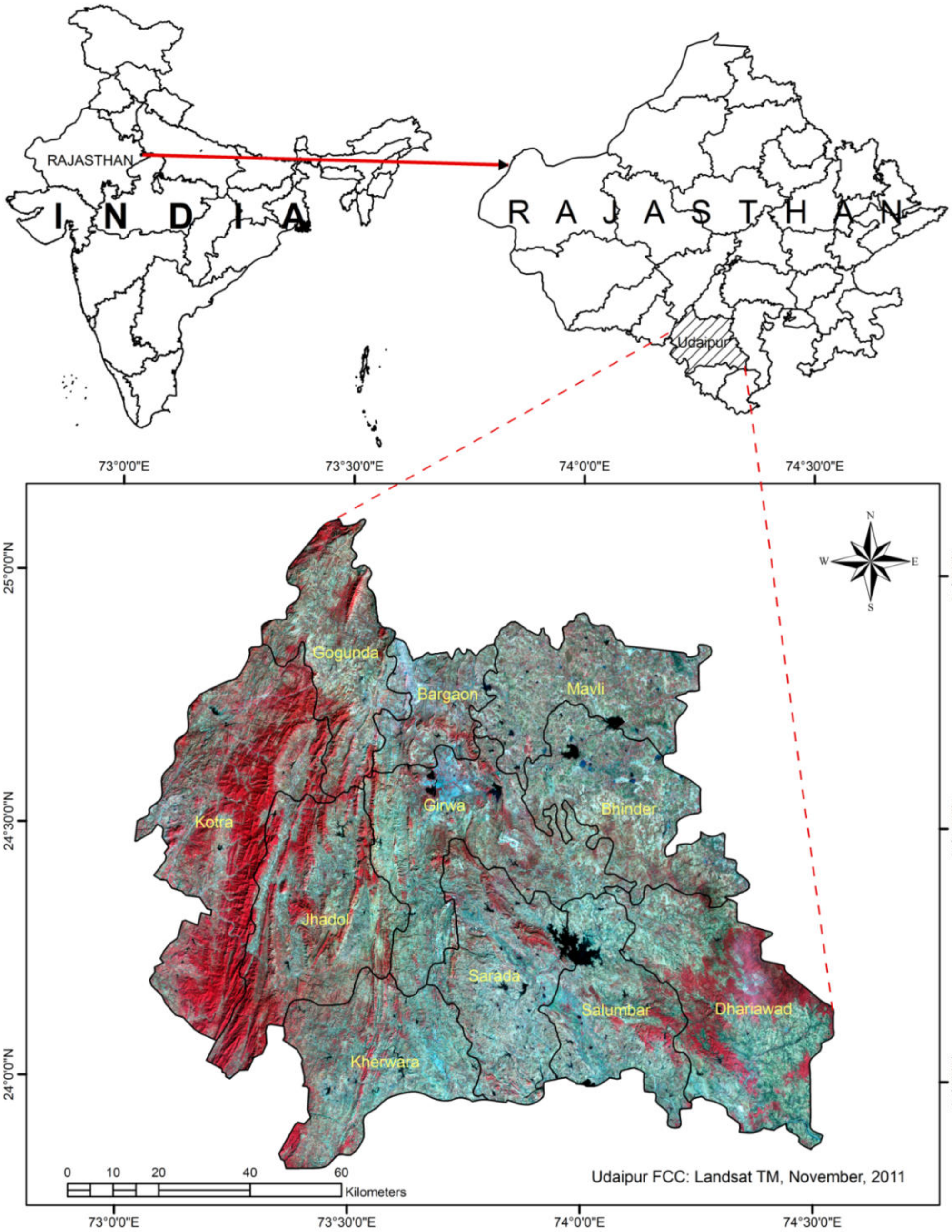

Figure 1: Location map of study area

3. Materials and Methods

For climatic parameters viz. maximum, minimum temperature, precipitation, relative humidity, wind speed and solar radiation have been used in this present study. The monthly data series from twelve stations covering period of thirty one years (1979–2010) were provided by the Climate Forecast System Reanalysis (CFSR) (Figure 2). The Climate Forecast System (CFS) is a model representing the global interaction between the Earth's oceans, land and atmosphere. It is produced by several dozen scientists under guidance from the National Centers for Environmental Prediction (NCEP) which offers hourly data with a horizontal resolution down to one-half a degree (approximately 56km) around the Earth for numerous variables. CFS makes use of the latest scientific approaches like surface observations, upper air balloon observations and satellite based observations etc. The Climate Forecast System Reanalysis (CFSR) is an effort to generate a continuous, standardized and best-estimate record of the state of the ocean and atmosphere field for use in climate monitoring and analytic. The technique keeps the model's software constant and runs the model retrospectively, from 1979 through the 2010. For long term Mann-Kendall test and Sen's slope analysis overall 12 meteorological stations were used to acquire the data. After collecting the data an interpolation technique has been done over the Udaipur district of Rajasthan state.

The Mann-Kendall statistic S is given as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn\,(xj - xi) \qquad (1)$$

Where, S is Mann-Kendall statistic and sgn is the signum function. The application of trend test is done to a time series xi that is ranked from i = 1, 2,.........n-1 and xj, which is ranked from j = i+1, 2,..........n. If n < 10, then value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall.

The variance statistic is given as

$$Var\,(S) = [n(n-1)(2n+5) - \sum_{i=1}^{m} t(i)(i-1)(2i+5)]/18 \qquad (2)$$

Where, t is considered as the number of ties up to sample i.
The Z test statistics is given by

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S-1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \qquad (3)$$

A positive value of Z indicates an increasing trend and negative value indicates decreasing trend. It is normally distributed.

True slope within the time series is estimated by the following formula laid by Sen (1968). Slope is given by

$$Q = \frac{xj - xi}{(j-k)} \quad i=1, 2,\ldots\ldots, N \qquad (4)$$

Where xj and xk are the data values at times j and k (j>k) respectively.

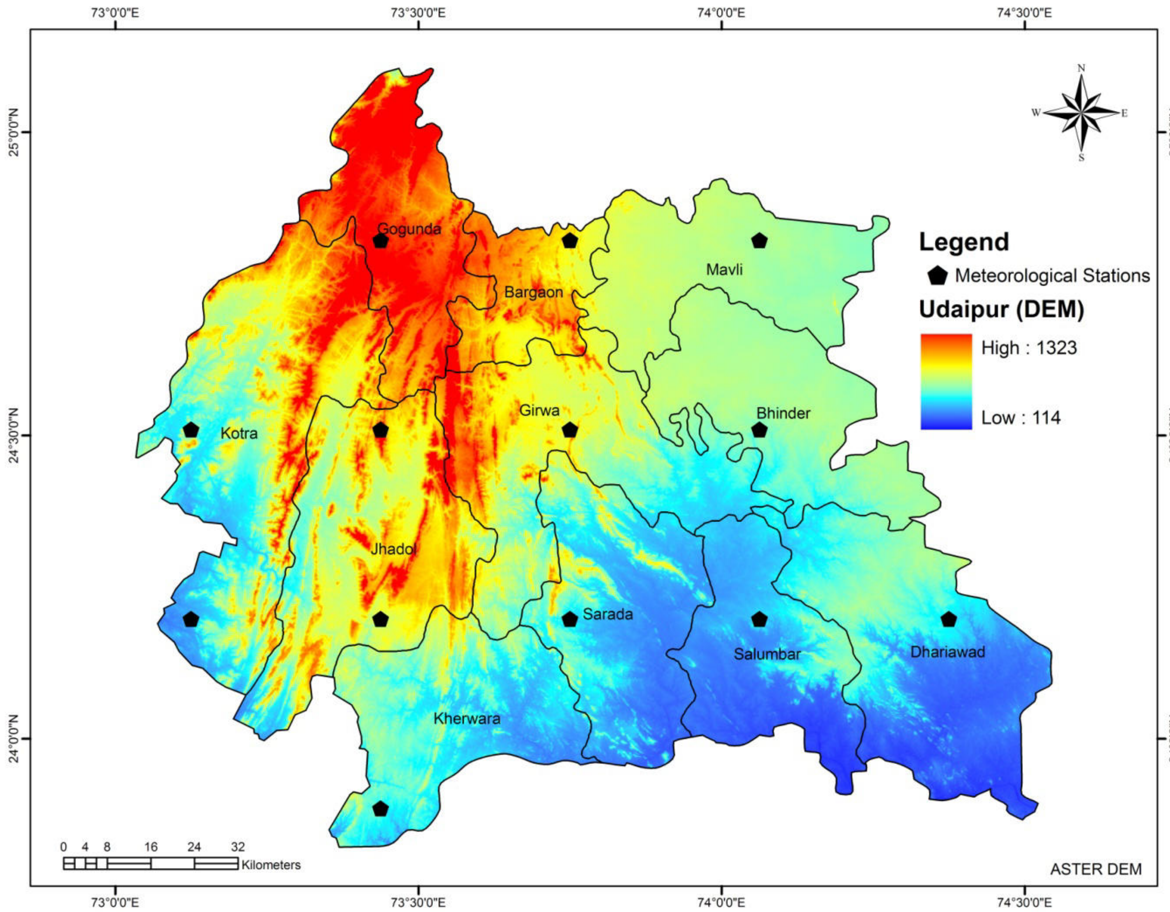

Figure 2: Locations of meteorological stations

4. Results and Discussions

Annual mean of daily time series data of climatic parameters, viz. temperature (maximum and minimum), precipitation, wind speed, relative humidity and solar radiation were analyzed using Mann- Kendall test for Udaipur district of Rajasthan India. MATLAB 7.10.0 (R 2010a) package was used for the analysis of data. Table 1 shows Mann-Kendall statistics and p-values derived at 95% confidence level. In the Mann-Kendall test, parameters like Kendall's tau, S statistic and the Z statistic were considered to identify the increasing or decreasing trend in the time series of climatic parameters. The test results are discussed in detail separately for each parameter. The spatial variation of climatic parameters showed the very low to very high zones in different part of the study site. In the western part of the study site (Kotra block) the maximum temperature is very high and towards eastern side it is gradually decreasing . On the other hand, minimum temperature is in the south and south western part of the area. However, north western part and southern part added very high concentration of precipitation due to Aravalli hills in Gogunda and Jhadol block in the Udaipur district. Wind speed is very high in the western part of the area. Relative humidity is very high in Girwa, Bhinder and some part of the Kotra block in study site. Solar radiation is very high in some dispersed block in the southern part of the area namely Sarada, Salubar, Kherwara, Kotra and Girwa block (Figure 3).

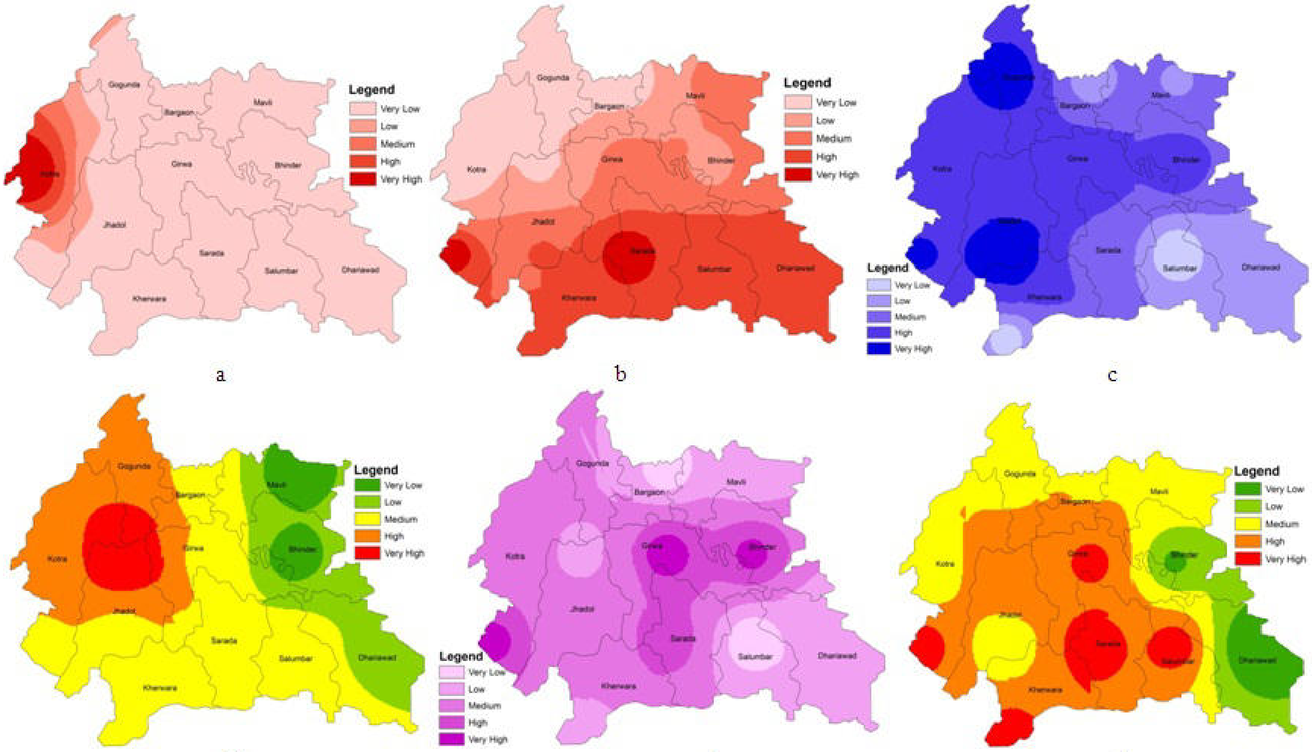

Figure 3: Maximum (a) and minimum temperature (b), precipitation (c), wind speed (d), relative humidity (e) and solar radiation (f)

Maximum temperature

In case of annual mean of daily maximum temperature, S statistic, Zc statistic and Kendall's tau for maximum temperature were -36, -0.5676 and -0.072581, respectively at below 95% confidence level. Negative Kendall's tau and S statistics show the decreasing trend in time series of maximum temperature but the Zc statistics does not reveal the statistically significant trend (Table 1).

Minimum temperature

In case of annual means of daily minimum temperature, S statistics, Zc statistics and Kendall's tau for minimum temperature were 174, 2.805692 and 0.350806, respectively at 95% confidence level. The positive value of Kendall's tau and S statistics shown increasing trend in the time series data of minimum temperature. From Zc statistic, it was revealed that trend was statistically significant over the period of 1979-2010 (Table 1).

Precipitation

In case of annual means of daily precipitation, S statistics, Zc statistics and Kendall's tau for precipitation were 28, 0.437883 and 0.056452, respectively at 95% confidence level. The positive value of Kendall's tau and S statistics showed increasing trend in the time series data of precipitation. From Zc statistic, it was revealed that trend was statistically significant over the period of 1979-2010 (Table 1).

Wind speed

S statistics, Zc statistics and Kendall's tau for annual mean of daily wind speed were -18, -0.275704 and -0.03629 respectively at below 95% confidence level. Test results of S statistic and Kendall's tau showed decreasing trend in the time series data of wind speed. Since, $Zc<Z1-\alpha/2$, the test result did not reveal the statistically significant trend (Table 1).

Relative humidity

S statistic, Zc statistic and Kendall's tau for annual mean of daily relative humidity were -4, -0.048654 and -0.008065, respectively at below 95% confidence level. Test results of S statistic and Kendall's tau showed the

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decreasing trend in the time series data of relative humidity but the Zc statistics does not reveal the statistically significant trend (Table 1).

Solar radiation

In case of annual mean of daily Solar radiation, S statistics, Zc statistics and Kendall's tau for Solar radiation were 88, 1.410955 and 0.177419, respectively at 95% confidence level. The positive value of Kendall's tau and S statistics showed increasing trend in the time series data of Solar radiation. From Zc statistic, it was revealed that trend was statistically significant over the period of 1979-2010 (Table 1).

Table 1: Mann-Kendall's Statistic for climatic parameters

Parameters	S Statistic	Zc Statistic	Kendall's tau	Confidence level (95%)	Tests results
Max. Temp.	-36	-0.5676	-0.072581	0.95	Decreasing
Min. Temp.	174	2.80569	0.350806	0.95	Increasing
Precipitation	28	0.43788	0.056452	0.95	Increasing
Wind Speed	-18	-0.2757	-0.03629	0.95	Decreasing
Relative Humidity	-4	-0.0487	-0.008065	0.95	Decreasing
Solar Radiation	88	1.41096	0.177419	0.95	Increasing

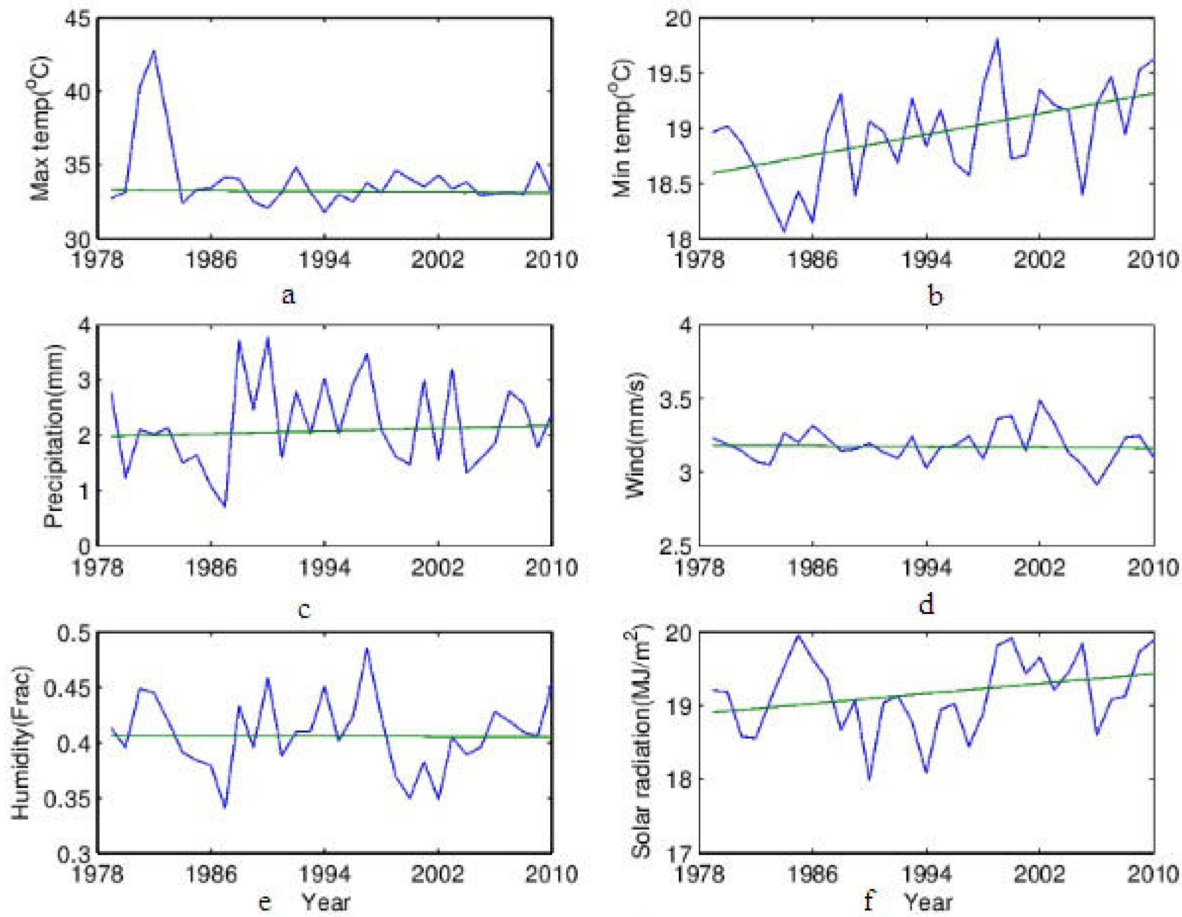

Figure 4: Sen's linear estimates of annual mean for maximum temperature (a), minimum temperature (b), precipitation (c), wind speed (d), relative humidity (e) and solar radiation (f)

Time series data of annual mean of daily climatic parameters, viz. temperature (maximum and minimum), precipitation, wind speed, relative humidity and solar radiation were analyzed using Sen's slope estimator, following the Mann-Kendall test. Sen's slope estimators were used to find out the changes per unit time. The results of Sen's slope estimator and graphical representation of the Sen's linear estimates for the observed time series of annual mean of daily maximum temperature, minimum temperature, precipitation, relative humidity, wind speed and solar radiation are shown in Table 2 and Figure 4 (a-f) respectively.

Table 2: Summary of test statistics of Sen's slope estimator at 95% confidence level

Parameters	Years	Mean	Standard Deviation	Sen's Slope (Q)
Max. Temp	1979-2010	34.0065	0.16335	-0.006189
Min. Temp	1979-2010	18.9349	0.124406	0.023369
Precipitation	1979-2010	2.19331	0.032548	0.006186
Wind Speed	1979-2010	3.18258	0.014777	-0.000673
Relative Humidity	1979-2010	0.40788	0.00809	-0.000028
Solar Radiation	1979-2010	19.1555	0.131781	0.016834

5. Conclusion

In the present study, the spatial and temporal variability of climatic parameters have been investigated at the Udaipur district of the Rajasthan. The application of this trend analysis supports an overall upward and downward trend even though not statistically significant. The Mann-Kendall test represents both positive and negative long term meteorological trends in the area although not so much more significant. All climatic parameters vary in different months for different years which are evident in the graphs. Sen's Slope is also indicating increasing and decreasing magnitude of the slope in correspondence with the Mann-Kendall Test values. The significant decreasing trend has found only for maximum temperature, wind speed and relative humidity parameters since 1979 to 2010. Minimum temperature, precipitation and solar radiation analysis showed that significant increasing trend over the region. The spatial map layout has also supported the variation according to the Mann-Kendall test and Sen's slope.

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