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Temporal variability of climatic parameters and potential evapotranspiration

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ABSTRACT

A study was undertaken to evaluate the temporal variability in climatic parameters and potential evapotranspiration (PET) of reference crop. Time series data (1981-2011) of mean daily minimum and maximum temperature, mean daily temperature, relative humidity, wind speed and sunshine hours were analysed using Mann-Kendall test and Sen's slope estimator to establish the trend. The CROPWAT model was used to estimate the PET. Minimum temperature, mean daily temperature, relative humidity and wind showed increasing trend, whereas sunshine hour and ET_o had decreasing trend. Results revealed that mean daily minimum and mean daily temperature increased by 0.02°C/year and 0.01°C/year, respectively. Mean daily maximum temperature remained constant over the period as indicated by the Sen's slope. Mean daily relative humidity and wind speed increased by 0.11% per year and 0.57 km/year during 1981–2011. Mean daily sunshine hours and reference evapotranspiration decreased by 0.06 hour/year and 0.01 mm/year, respectively during 1981–2011.

Key words: Climate change, Evapotranspiration, Mann-Kendall test, Sen's estimator, Trend analysis

Climate change and its possible impact on crop water requirement are the matter of great concern for countries like India where the spatial and temporal variability in rainfall often influences the water supply. Water requirement of a crop is normally estimated from potential evapotranspiration of reference crop and crop factor. Potential evapotranspiration depends largely on climatic factors. Climate of a region is normally described in terms of climatic parameters such as temperature, wind speed, solar radiation, duration of sunshine hours and relative humidity. Besides the use of climate models, temporal variability of climatic parameters can also be studied through the analysis of long term climatic data. Studies are being conducted throughout the world to assess the climatic variability and to evaluate its impact on crop water requirement. Increased concentration of greenhouse gases (GHGs) is considered to be responsible for global warming and climate change. IPCC (2007) reported that global surface temperature increased at a rate of 0.74 ± 0.18°C during 1906–2005. Minimum and maximum temperature, relative humidity, wind speed and sunshine duration are important climatic parameters which control reference evapotranspiration (ET_o) and crop water requirement. Crop water requirement in a region varies with the variation in these parameters. Studies suggest that crop water requirement would change in future as a result of global warming and climate change. By now it has been established that global warming and climate change is a reality. However, degree of spatial and temporal variation is still a matter of investigation. There have been several attempts to evaluate the spatial and temporal variations in climatic parameters using various climate models. Climatic variability can also be investigated using parametric and non-parametric statistical methods for time series. The parametric method considers that data is normally distributed and is free from outliers but non-parametric methods are free from any such assumption (Hamed and Rao 1998). The most commonly used non-parametric method for analysing the trend in the time series is the Mann-Kendall (MK) test (Mann 1945, Kendall 1975). Researchers have extensively used this method for different hydro-meteorological parameters (Hirsch 1984, Aziz and Burn 2006, Mondal *et al.* 2012). Mann-Kendall test is an important tool for analysing the trend of climatic parameters, evaporation, reference evapotranspiration, stream flows and groundwater fluctuations (Bandyopadhyay *et al.* 2009, Ramazanipour and Roshani 2011). Kampata *et al.* (2008) carried out the trend analysis of long term rainfall using the

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cumulative summation test and Mann-Kendall test in Zambia. Xu *et al*. (2010) detected the trend in precipitation and runoff (1951-2000) of major Chinese rivers to find out the impact of human interventions using the Mann-Kendall statistics. Dodangeh (2012) did time series analysis of important climatic parameters such as radiation, temperature, precipitation and evaporation which were required for water resource management using nonparametric Mann-Kendall test. Partal *et al*. (2006) analysed precipitation data of across the Turkey and determined the trends of the long-term annual mean and monthly total precipitation series using Mann-Kendall and Sen's tests. Yue and Hashino (2003) studied long term trends of monthly precipitation using Mann-Kendall test in Japan and found significant negative trends. Rai *et al*. (2010) emphasized on the need to identify the specific nature and attributes of the time series of climatic data which is very essential for planning and management of water resources. Mondal *et al*. (2012) analysed daily rainfall data of 40 years (1971–2010) using Mann-Kendall test, modified Mann-Kendall test and the Sen's slope estimator to identify the trend and slope magnitude in a time series of precipitation. Chen *et al.* (2007) used Mann–Kendall and the linear regression methods to study the temporal trends of annual and seasonal precipitation and temperature from 1951 to 2003 in the Hanjiang basin. Tabari *et al*. (2011) carried out the trend analysis of reference evapotranspiration in the western half of Iran using the Mann-Kendall test, the Sen's slope estimator and the linear regression. They reported that significant increasing trend in ET_o was mainly due to the significant increase in air temperature. Zang *et al*. (2011) studied the spatio-temporal trends of potential evapotranspiration (1961-2003) in Songnen plain of China using Mann-Kendall test, accumulative departure curve, and climatic change rate. The spatial analysis of evapotranspiration was carried out using GIS tool. Sabziparvar *et al.* (2012) analysed the 50 year (1957–2006) meteorological data and studied the long term changes in reference evapotranspiration in Iran using non-parametric Mann-Kendall and Sen's slope estimator. Shadmani *et al*. (2012) carried out the trend analysis of reference evapotranspiration for arid region of Iran on monthly, seasonal and annual basis. They used the non-parametric Mann-Kendall and Spearman's Rho (SR) tests at the 5% significant level. It is evident from above studies that nonparametric methods namely Mann-Kendall test and Sen's slope estimator are widely used for the trend analysis of hydro-meteorological parameters and assess the climatic variability. Rao and Wani (2011) observed a decreasing trend in evaporation and evapotranspiration despite increase in air temperature for Patancheru region of Andhra Pradesh, India. Ficklin *et al.* (2010) reported increase of temperature in the California Central Valley of USA, which was due to temporal shift in plant growth pattern, redistributed evapotranspiration and irrigation water use during beginning of growing season. Yano *et al*. (2007) studied the effects of climate change on crop growth and irrigation water demand for wheat-maize cropping system in a Mediterranean environment of Turkey. They reported that doubling of the CO_2 concentration relative to the baseline period would decrease the evapotranspiration from wheat by 28% and 8% during 2070 and 2079, respectively. These studies also indicated that the evapotranspiration is affected due to changing climate in India and elsewhere. Knowledge of climatic variability over the period is very essential for estimating the crop water requirement and water resource planning mainly in arid and semi-arid region. In view of above, this study was undertaken to analyse long term annual mean of daily time series of climatic parameters namely temperature, wind speed, relative humidity, and sunshine hours and reference evapotranspiration (ET_o) to detect the trend and to identify the impact of climate variability on crop water requirement of Karnal district of Haryana falling under semi-arid region.

MATERIALS AND METHODS

The study was conducted using climatic data of Karnal district in Haryana state of India. The study area is located between 29°25' to 29°59' North latitudes and 76°27' to 77°13' East longitudes covering an area of 2520 km^2. The district is agriculturally dominated with good network of canals and tube wells. Rice and wheat are the major cropping system practiced in the district. District has 189 thousand hectare net sown area which is 90.9% of total cultivable area. Total area under rice and wheat are 169 and 171 thousands hectares. Percentage net irrigated area of the district is 98.9 as compared to net sown area which is mostly irrigated by canals and groundwater. The climate of the district is sub-tropical monsoon type. It is characterized by hot summer and cold winter. Temperature starts rising from March and continues till June end. Major portion of the rainfall is received during the months of July to September under the influence of southwest monsoon. The normal annual rainfall of the district is 739.61 mm based on the record for the period 1981–2011. Average annual minimum and maximum temperature are 16.99°C and 29.94ºC. The average annual relative humidity and wind speed are 65.74% and 86.16 km/day, respectively. The soil of the district is alluvial in nature and varies from sandy loam to clay loams throughout the district. Soils in major portion of district are heavily textured varying from sandy loam at the surface to clayey loam at about one meter depth.

Daily meteorological data consisting of minimum and maximum temperature, relative humidity, wind speed, sunshine hours and rainfall for the period of 1981–2011 were collected from the observatory of Central Soil Salinity Research Institute (CSSRI), Karnal (Haryana). From the daily data, annual means were computed for parameters namely minimum temperature, maximum temperature, average temperature, relative humidity, wind speed and sunshine hours, respectively. Thus data set of 31 years consisting 31 annual mean values of each parameter were used for the further analysis. Daily data of minimum and maximum temperature (°C), relative humidity (%), wind speed (km/day) and sunshine hours (hr) were used for computing reference evapotranspiration (ET_o).

In the present study, the procedure described by Mann (1945) for non-parametric test of trend detection and the test statistic distribution given by Kendall (1975) for testing of non linear trend were adopted. The combined method is popularly known as Mann-Kendall test. This method is commonly used for trend analysis of meteorological and hydrological time series data. The change per unit time within time series was estimated by non-parametric Sen's slope estimator (Sen 1968). Reference evapotranspiration (ET_o) were estimated using CROPWAT model of FAO. Detailed descriptions of all these methods are given below.

The Mann-Kendall test is a non-parametric method used for trend analysis of time series data (Kendall 1975). Major advantage of Mann-Kendall test is that it is free from statistical distributions which are required for parametric method. Due to its simplicity and broader application, World Meteorological Organization (WMO) has recommended this method to assess the monotonic trend in hydro-meteorological time-series (Tian *et al.* 2012). The null hypothesis (H0) for the Mann-Kendall test is that there is no trend or serial correlation among the analysed population against the alternative hypothesis (H1), which assumes increasing or decreasing monotonic trend. 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 and 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 (Shahid 2011).

The Mann-Kendall statistic S is given as

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

where, S is Mann-Kendall statistic and sgn is the signum function. The application of trend test is done to a time series x_i that is ranked from i = 1, 2,………n-1 and x_j, which is ranked from j = i+1, 2,……….n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$sgn(xj - xi) = \begin{cases} 1 \, if \, (x_j - x_i) > 0 \\ 0 \, if \, (x_j - x_i) = 0 \\ -1 \, if \, (x_j - x_i) < 0 \end{cases}$$

If n < 10, then value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. At certain probability level H0 is rejected in favour of H1 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 $\alpha/2$ to appear in case of no trend. A positive value of S indicates an upward trend and negative value indicates downward trend (Salmi *et al.* 2002, Luo *et al.* 2008). For n > 10, the statistic S is approximately normally distributed with the mean E(s)=0 and variance.

The variance statistic is given as

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18}$$

where, t_i is considered as the number of ties up to sample i. The presence of a statistically significant trend is evaluated using the Z_c value. Where, Z_c test statistics and is given by

$$Zc = \begin{cases} \dfrac{S-1}{\sqrt{Var\,(S)}} \, if \, S > 0 \\ 0 \, if \, S = 0 \\ \dfrac{S+1}{\sqrt{Var\,(S)}} \, if \, S < 0 \end{cases}$$

A positive value of Z_c indicates an increasing trend and negative value indicates decreasing trend. The statistic Z_c is normally distributed. To test an increasing or decreasing monotone trend, a two-tailed test at α level of significance is used. Null hypothesis (H0) is rejected if the absolute value of Z_c is greater than $Z_{1-\alpha/2}$ where, $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. Where, α is the significance level for the test and $\pm Z_{1-\alpha/2}$ are the standard normal deviates. In this study, α and $Z_{1-\alpha/2}$ were taken as 95% and ±1.96, respectively.

True slope (change per unit time) within the time series is estimated through procedure laid by Sen (1968) in case the trend is linear. The magnitude of trend is predicted by the Sen's estimator. Slope is given by

$$Qi = \frac{x_j - x_k}{j - k} \; for \, i = 1, 2, ..., N$$

where, x_j and x_k are data values at times j and k (j > k) respectively. The median of these N values of Q_i is represented as Sen's estimator. $Q_{med} = Q_{(N+1)/2}$ if N is odd, and $Q_{med} = [Q_{N/2} + Q_{(N+2)/2}]/2$ if N is even. Positive value of Q_i indicates an increasing trend and a negative value of Q_i shows decreasing trend in the time series.

Potential evapotranspiration of a specified crop is estimated from Reference evapotranspiration (potential evapotranspiration of reference crop, ET_o) and crop factor. The evapotranspiration from a reference surface, not short of water, is known as reference evapotranspiration and is denoted as ET_o. This was estimated using the CROPWAT 8.0 model of FAO. CROPWAT for Windows uses Penman-Monteith method for estimation of reference evapotranspiration from the reference surface. The reference surface is a hypothetical grass with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 s m^{-1} implies a moderately dry soil surface resulting from about a weekly irrigation frequency. Penman Monteith equation (Allen *et al.* 1998) for estimation of ET_o is

$$ET_0 = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34) u_2}$$

where, ET_o : Reference evapotranspiration [mm/day], Rnet: net radiation at the crop surface [MJ/m^2/day], G: soil heat flux density [MJ/m^2/day], T: mean daily air temperature at 2 m height [°C], u_2: wind speed at 2 m height [m/s], e_s: saturation vapour pressure [kPa], e_a: actual vapour pressure [kPa], e_s-e_a: saturation vapour pressure deficit [kPa], Δ: slope vapour pressure curve [kPa/°C], γ: psychrometric constant [kPa/°C].

RESULTS AND DISCUSSION

Annual mean of daily time series data of climatic parameters, viz. temperature (minimum, maximum and average), relative humidity, wind speed, sunshine hour and reference evapotranspiration were analysed using Mann-Kendall test for Karnal district. 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 Zc 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.

Mean temperature

Kendall's tau, S statistic, Z_c statistic and p-value for annual mean of daily temperature were 0.197, 84, 1.33 and 0.137, respectively at 95% confidence level. The positive value of Kendall's tau and S statistic indicated increasing trend of mean temperature over the period 1981-2011. Since, $Z_c<Z_1$-α/2, time series of mean temperature did not reveal the statistically significant trend.

Minimum temperature

In case of annual mean of daily minimum temperature, Kendall's tau, S statistics, Z_c statistics and p-value for minimum temperature were 0.299, 184, 2.33 and 0.012, respectively at 95% confidence level. The positive value of Kendall's tau and S statistics showed increasing trend in the time series data of minimum temperature. From Z_c statistic, it was revealed that trend was statistically significant over the period of 1981-2011.

Maximum temperature

In case of annual mean of daily maximum temperature, Kendall's tau, S statistic, Zc statistic and p-value for maximum temperature were 0.914, 70, 0.22 and 0.017, respectively at 95% confidence level. Positive Kendall's tau and S statistics show the increasing trend in time series of maximum temperature but the Zc statistics does not reveal the statistically significant trend.

Relative humidity

Kendall's tau, S statistic, Z_c statistic and p-value for annual mean of daily relative humidity were 0.379, 154, 2.75, 0.006, respectively at 95% confidence level. Test results of S statistic and Kendall's tau showed the increasing trend in the time series data of relative humidity. From Z_c statistics (2.75) it was revealed that there was a significantly increasing trend in case of relative humidity.

Wind speed

Kendall's tau, S statistics, Z_c statistics and p-value for annual mean of daily wind speed were 0.305, 131, 1.70 and 0.020, respectively at 95% confidence level. Test results of S statistic and Kendall's tau showed increasing trend in the time series data of wind speed. Since, $Zc<Z_{1-\alpha/2}$, the test result did not reveal the statistically significant trend.

Sunshine hours

Kendall tau, S statistic, Z_c statistic and p-value are –

Table 1 Mann-Kendall's Statistic for climatic parameters

Parameters	Kendall's tau	S statistic	Zc statistic	p-value (Two-tailed)	Confidence level (95%)	Tests results
Mean temperature	0.197	84	1.33	0.137	0.95	Increasing
Minimum temperature	0.299	184	2.33*	0.012	0.95	Increasing
Maximum temperature	0.914	70	0.22	0.017	0.95	Increasing
Relative humidity	0.379	154	2.75*	0.006	0.95	Increasing
Wind speed	0.305	131	1.70	0.020	0.95	Increasing
Sunshine hours	–0.661	–284	–5.33*	< 0.0001	0.95	Decreasing
ETo	–0.256	–110	–2.37*	0.051	0.95	Decreasing

*Statistically significant at 95 % confidence level

0.661, –284, –5.33 and < 0.0001, respectively at 95% confidence level. Results showed the decreasing trend in time series as the Kendall' tau and S statistic were negative at derived p-value (0.137). Results of Z_c statistics (–5.33) revealed that there was a statistically significant decreasing trend in time series of annual mean of daily sunshine hours.

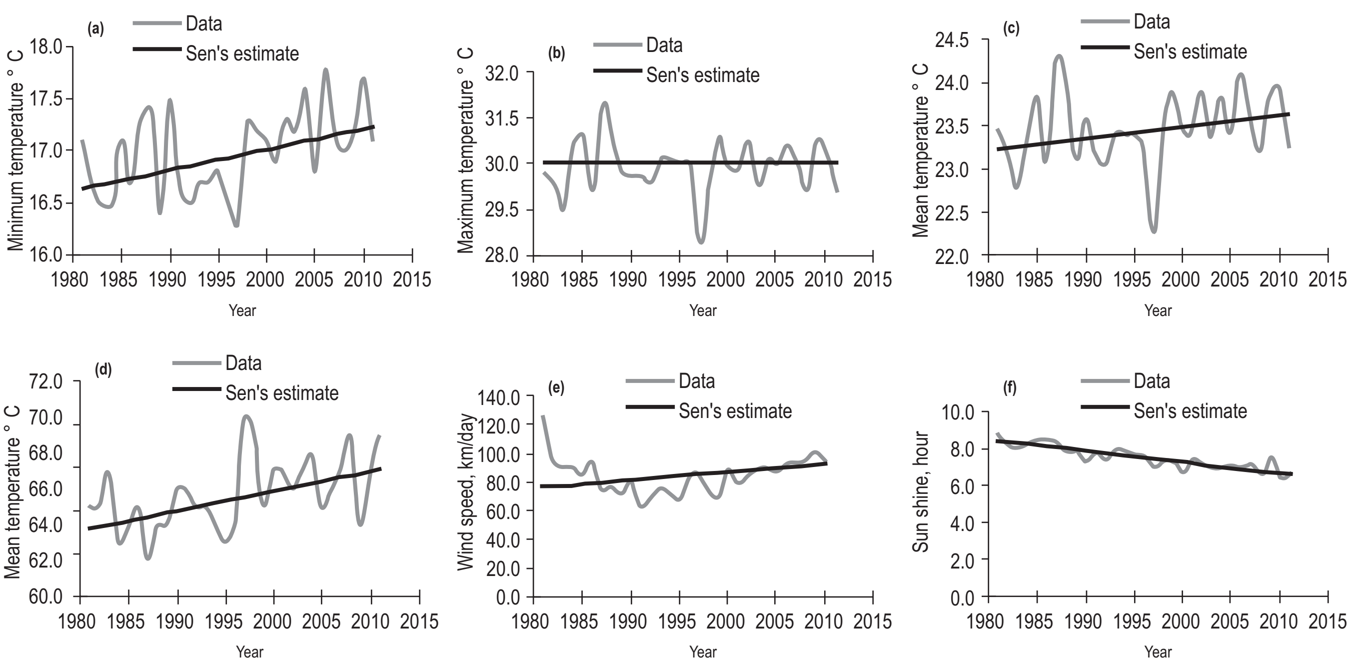
Reference evapotranspiration (ETo)

In case of reference evapotranspiration, Mann-Kendall test parameters namely Kendall's tau, S statistic, Z_c statistic and p-value of annual mean of daily reference evapotranspiration were –0.256, –110, –2.37 and 0.051, respectively at 95% confidence level. The negative value of Kendall tau and S statistic depicted the decreasing trend in the time series of reference evapotranspiration (ET_o). Negative Z_c statistic indicated decreasing trend which was statistically significant over the period of 1981-2011.

Time series data of annual mean of daily climatic parameters, viz. temperature (minimum, maximum and average), relative humidity, wind speed, sunshine hour and reference evapotranspiration were analysed using Sen's slope estimator, following the Mann-Kendall test. Sen's slope estimators were used to find out the change 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 minimum temperature, maximum temperature, mean temperature, relative humidity, wind speed and reference evapotranspiration (ET_o) are shown in Table 2 and Fig 1(a to g), respectively. The estimated Sen's slope for time series of the climatic parameters namely mean daily temperature (minimum, maximum and average

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

Parameters	Years	Mean	Standard Deviation	Sen's slope (Qi)
Minimum temperature	1981-2011	16.990	0.405	0.02
Maximum temperature	1981-2011	29.940	0.577	0.00
Mean temperature	1981-2011	23.465	0.425	0.01
Relative humidity	1981-2011	65.767	1.995	0.11
Wind speed	1981-2011	83.800	10.206	0.57
Sunshine hours	1981-2011	7.497	0.588	–0.06
Reference evapotranspiration (ET_o)	1981-2011	3.703	0.143	–0.01



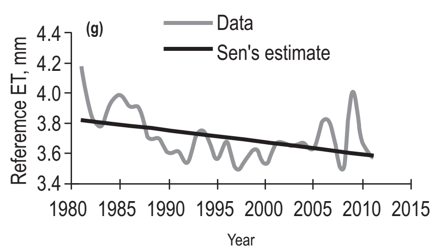


Fig 1 Sen's linear estimates of annual mean of daily time series data a) minimum temperature, b) maximum temperature, c) mean temperature, d) relative humidity, e) wind speed, f) sunshine hours and g) reference evapotranspiration.

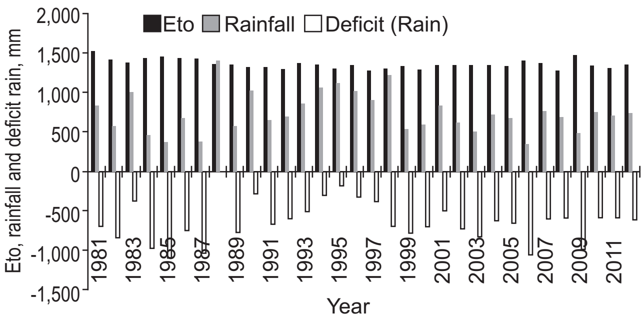


Fig 2 Annual total reference evapotranspiration, total rainfall and deficit rainfall

temperature), mean daily wind speed, mean daily relative humidity, mean daily sunshine hours and the mean daily reference evapotranspiration were 0.02, 0.00, 0.01, 0.11, 0.57, –0.06 and –0.01 per year respectively. The negative sign represents the decreasing slope and the positive sign represents the increasing slope. Results revealed that mean daily minimum temperature increased by 0.02 °C/year, whereas mean daily temperature increased by 0.01 °C/year. Mean daily maximum temperature remained constant over the period as indicated by the Sen's slope. Mean daily relative humidity increased by 0.11% per year and mean daily wind speed by 0.57 km/year during 1981-2011. Results from Sen's slope estimate also revealed that the mean daily sunshine hours and mean daily reference evapotranspiration decreased by 0.06 hour/year and 0.01 mm/year, respectively during 1981-2011. Table 2 also shows the mean of annual time series data and standard deviation. The results from the estimated Sen's slope are quite similar as derived from the Mann-Kendall non parametric test presented in Table 1.

Annual reference evapotranspiration of Karnal district were estimated for the period 1981-2011. The year wise comparison of rainfall and reference evapotranspiration was performed to assess the surplus or deficit of rainfall compared to the reference evapotranspiration (Fig 2). From the figure 2, it is revealed that in almost all the year's rainfall was less than the reference evapotranspiration except 1988. Rainfall deficit compared to ET_o ranged from 82.10 to 1 098.15 mm. Estimated normal reference evapotranspiration was 1 356.98 mm against normal rainfall of 739.61 mm showing the average rainfall deficit of 617.36 mm.

Climatic variability and its impact on potential evapotranspiration was evaluated using time series data of climatic parameters. Climate parameters which influence the reference evapotranspiration namely minimum and maximum temperature, relative humidity, wind speed and sunshine hour were subjected to the trend analysis using Mann-Kendall test and Sen's slope estimator. Analysis showed increasing trend for mean daily minimum temperature, mean daily temperature, mean daily relative humidity and mean daily wind speed, whereas decreasing trend was observed for mean daily sunshine hour and mean daily reference evapotranspiration. Z_c statistics revealed significantly increasing trend in case of mean daily minimum temperature and mean daily relative humidity and statistically significant decreasing trend for mean daily sunshine hours and mean daily reference evapotranspiration. From Sen's slope estimator it was observed that mean daily minimum temperature increased by 0.02 °C/year and mean daily temperature by 0.01 °C/year. Mean daily maximum temperature did not show any trend. Mean daily relative humidity showed the increasing trend with slope magnitude of 0.11% per year, whereas mean daily wind speed increased by 0.57 km/year. Mean daily sunshine hours decreased by 0.06 hour/year. Mean daily reference evapotranspiration decreased by 0.01 mm/year. Analysis revealed that the Mann-Kendall test with Sen's slope estimator can be used to describe the variability of climatic parameters. Based on the results it can be concluded that all climatic parameters need to be considered for evaluating the impact of climate changes on crop water requirements. It is suggested to undertake similar studies in other districts of the country to derive meaningful conclusion on the impact of climate variability on potential evapotranspiration.

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