Journal of Soil Salinity and Water Quality 5(2), 84-90, 2013

Trend analysis of reference evapo-transpiration and governing meteorological parameters in an arid saline region of Haryana

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ABSTRACT

Long-term changes in reference evapo-traspiration (ET_o) can have profound implications on water balance, salinity development and agricultural production in any region. Temporal trends of ET_o values, estimated by Penmen Monteith approach utilizing historical weather data, were investigated for an arid region (Hisar) of Haryana. Thirty years (1981-2010) meteorological data of Hisar was statistically analyzed for estimating the trends in ET_o and governing climate parameters. Statistical significance trends in annual and seasonal (monsoon, post monsoon, winter, summer) ET_o, maximum and minimum temperature, bright sunshine hours (BSS), morning and afternoon relative humidity and wind speed was evaluated using nonparametric Mann-Kendall (MK) tests at the 10% significant level. In order to identify the dominant weather variables influencing ET_0, backward stepwise regression method was adopted. During the last 30 years, ET_o has been found to decrease significantly at annual and seasonal time scales at Hisar. Of the governing weather parameters, temperature (both maximum and minimum) showed no clear trend at annual or seasonal scales, while significant decreasing trends have been observed in BSS hours and wind speed on annual and all seasons except during monsoon. The contribution of the temperature on ET_o seems to be offset by steady reduction in wind speed and BSS hours, also reflected by strong correlation of BSS and wind speed with ET_0 evaluated through regression analysis at almost all the time scales. The nature and magnitude of trends of ET_o and other weather parameters can be purposefully utilized to derive rational climate change scenarios and evaluate their impact through controlled crop physiological and modelling studies on soil, water, salinity and crop production in arid regions of Haryana.

Key words: reference evapo-transpiration, trend analysis, Mann-Kendall test

Introduction

Anthropogenic emissions of greenhouse gases caused most of the warming during the latter half of the century. The atmospheric concentrations of the greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have all increased since 1750 due to human activity. In 2011 the concentrations of these gases were reported as 391ppm, 1803 ppb, and 324 ppb, exceeding the pre-industrial levels by about 40%, 150%, and 20%, respectively (IPCC, 2013). Almost all processes in the biosphere are influenced in some way by climate change phenomena, but environment and water resources are of the most serious concern. Spatio-temporal changes in evapotraspiration and its governing meteorological parameters are good indicators for the occurrence and impact of climate change on surface eco-hydrological system. This type of inquiry is fundamental to understand the link between ecosystem dynamics and the water cycle, particularly in arid and semi-arid environments, where water is limited in terms of scarcity but also for its intermittency and unpredictable presence (Liu *et al.*, 2010). Long-term changes in evaporation and potential evapotraspiration can have profound implications for hydrologic processes, salinity development as well as for agricultural crop performance (Chattopadhyay and Hulme, 1997).

The general expectation is that global warming will lead to an increase in evaporation (E) or reference evapotraspiration (ET_o), a key component of the hydrologic cycle. However, there are reports (Bandoyopadhyay *et al.*, 2009; Dinpashoh *et al.*, 2011) that despite an increase in air temperature, E and/or ET_o decreased in some regions across the globe. This shows that in addition to air temperature, interactive impact of changes in climatic parameters like wind speed, relative humidity, radiation, etc. could be responsible for the observed decreases in E and/or ET_o, offsetting the influence of increasing temperature. Donohue *et al.* (2010) reported that, even though changes in temperature produced the largest change (increase or decrease) in evapotraspiration, other variables such as relative humidity, wind speed and bright sunshine hours played a major role in governing evapotraspiration.

The arid climate of Hisar (Haryana) is related to its continental location on the outer margins of the south-west (SW) monsoon region. The climate of Hisar district can be classified as tropical, arid and hot being mainly dry with very hot summer and cold winter except during monsoon season when moist air of oceanic origin penetrates into the area. Dust storms, hot desiccating winds (*loo*) and chilly winds are quite common. Temperature ranges from 1 to 48°C. The hot weather season starts from mid March and continues up to the onset of monsoon in July, with April, May and June being the driest months.

The effects of climatic change and variability have been investigated by many researchers throughout the world. Gao *et al*. (2006) found decreasing trends in ET_o in China and for most river basins, except for a slightly increasing trend in the Songhua River basin. Chen *et al*. (2006) reported decreasing trends in average seasonal and annual ET_o over entire Tibetan Plateau. Wang *et al*. (2007) detected decreasing trends in E_{pan} and ET_o during summer months over the upper and middle-lower Yangtze River basin. Despite a general rise in annual mean temperature during recent decades over the Yangtze River basin, both E_{pan} and ET_o indicated decreasing trend. Similarly Zhang *et al*. (2007) found decreases in E_{pan} and ET_o at 47% and 38% of the respective stations over the Tibetan plateau. Jhajharia *et al.* (2009) observed that reference evapotraspiration decreased significantly at annual and seasonal time scales for 6 sites in NE India and even NE India as a whole. Singh and Bala (2012) reported ET_o to having a decreasing trend for January, February, March and June and an increasing trend during July, august and September and without any trend during remaining months for Gurgaon, Hisar and Ambala district during 1998-2008. Narjary and Kamra (2013) reported significant negative trend in number of rainy days, but absence of significant trends in annual and seasonal rainfall and evapotranspiration for semi- arid Karnal district of Haryana. Bandyopadhyay *et al.* (2009) also found decreasing trend in ET_o and E_{pan} all over India and attributed these to respective significant increase and decrease in relative humidity and wind speed throughout the country.

The objective of this study was to investigate the temporal trends ET_o time series over a arid region of Haryana (Hisar), using the non parametric Mann-Kendall (MK) trend test and to identify the most dominant meteorological variables affecting such changes. The study will help in understanding the trends related to crop water requirement.

Materials and methods

In order to study the changing trend of evapotraspiration and it's contributing weather parameters, 30 years (1981-2010) meteorological data was collected from Agromet observatory, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar representing saline arid zones of Haryana.

Estimation of Evapotranspiration

The most reliable and universally accepted method to estimate reference evapotraspiration (ET_o) under various types of climate is the Penman-Monteith (PM) FAO-56 method. The modified Penman- Monteith equation for estimating ET_o is a physically based model that incorporates explicitly both physiological and aerodynamic parameters. By defining the reference crop as a hypothetical crop with an assumed height of 0.12 m and having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman-Monteith method was developed. The most recommended form of the PM method in computing ET_o is given as (Allen *et al*., 1998)

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

where, ET_o reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [MJ m^{-2} day^{-1}], G soil heat flux density [MJ m^{-2} day^{-1}], T mean daily air temperature at 2 m height [°C], u_2 wind speed at 2 m height [m s^{-1}], e_s saturation vapour pressure [kPa], e_a actual vapour pressure [kPa], e_s - e_a saturation vapour pressure deficit [kPa], D slope vapour pressure curve [kPa °C^{-1}], g psychrometric constant [kPa °C^{-1}].

Data analysis of weather variables influencing ET_o

Multilinear prediction models based on the weather parameters as independent variables and ET_o as dependent variable were fitted by backward step multiple regression (Chattopadhayay and Hulme, 1997). Based on correlation coefficients between ET_o and different weather variables, 't' test analysis was employed to select the most significant parameters, while the most significant weather parameters were selected through stepwise regression methods. Statistical analysis was done using Excel and SPSS packages (Version 16.0).

Trend Analysis

The Mann-Kendall (MK) test is a non-parametric method for identifying trends in time series data. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, τ (tou), is assumed to be 0 (i.e. no trend). If a data value at a later time is higher than a data value of an earlier time, τ is incremented by 1. On the other hand, if the data value at a later time is lower than a data value sampled earlier, τ is decremented by 1. The net result of all such increments and decrements yields the final value of τ.

Let x_1, $x_{2...}$ x_n represent n data points where x_j represents the data point at time j. Then the Mann-Kendall statistic (τ) is given by

$$\boldsymbol{\tau} = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} sign\ (x_j - x_k)$$

$$Sign(x_j - x_k) = 1\ if\ x_j - x_k > 0$$

$$= 0\ if\ x_j - x_k = 0$$

$$= -1\ if\ x_j - x_k < 0$$

A high positive value of τ is an indicator of an increasing trend, and a low negative value indicates a decreasing trend. The p-value for the Mann-Kendall test indicates whether there are any statistically significant trends or not. If the computed value of p> $p_{á}$, the null hypothesis (H_0) is rejected at á level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 90% confidence level.

Sen's slope estimator provides an estimate of the magnitude of the detected trend and is calculated as

$$T_i = \frac{x_i - x_k}{j-k} for\ i = 1,2, \ldots, N \quad \ldots(1)$$

Where x_i and x_j are data values at time j and k (j>k) respectively. The median of (â) N values of T_i is the Sen's slope estimator

$$\beta = T_{\frac{N+1}{2}} \text{ if N is odd}$$

$$\beta = \frac{1}{2}(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}) \text{ if N is even}$$

Positive value of â indicates an increasing trend while negative value indicates a decreasing trend in the time series.

Results and discussion

The monthly data were used to compute seasonal and annual time series of climatic data. Four seasons of the study area were defined viz. winter (December-February), summer (March-May), monsoon (June-September) and post-monsoon (October-November) on the pattern of Jhajharia *et al*. (2009).

Estimation of ET and its sensitivity to meteorological variables

The annual average ET_o of Hisar, calculated using the PM method, varied from about 3.14 mm/day to 4.87 mm/day. In the summer months ET_0 reached its peak value 4.5 to 7 mm/day. In the winter months ET_0 ranged between 1.67 to 2.36 mm/day. In order to identify the dominant variables associated with ET_0, stepwise regression method was adopted. Several researchers, namely, Chattopadhayay and Hulme (1997), Thomas (2000), and Dinpashoh *et al*. (2011) also used a similar procedure to look for the most important variable responsible for ET_o changes under different types of climatic conditions of India, China and Iran, respectively. In the present study, the stepwise regression analysis was performed between ET_0 as the dependent variable and the meteorological parameters, i.e., bright sunshine hrs (BSS), wind speed (WS), morning and afternoon relative humidity (RH_m, RH_e) and maximum and minimum temperature (T_{max}, T_{min}), as independent variables on annual and seasonal time scales by using SPSS. From the backward stepwise regression analysis of average annual data indicated bright sunshine hours, wind speed and maximum temperature having most significant influence on ET_o with coefficient of determination of 0.68. In the monsoon and winter season, BSS, wind speed and daily maximum temperature was found to be the most dominating weather variable affecting ET_o with respective coefficients of determination of 0.83 and 0.84. After BSS and wind speed, morning relative humidity was the third most important weather variable governing ET_o during summer and post monsoon season, with coefficients of determination 0.8 and 0.76 respectively (Table 1). Of all parameters affecting ET_0, minimum temperature was found to be insignificant during all seasons.

Chattopadhayay and Hulme (1997) reported that although most parts of India (except Gujarat and few parts on west coast) have witnessed temperature increases, both pan evaporation (E_{pan}) and ET_o have witnessed decreasing trends over a majority of sites in India. They also found that the relative humidity was strongly associated with changes in E_{pan}. The increasing trends in RH have counter balanced the effect of rising temperature on E_{pan} by hampering the evaporative process. Bandyopadhyay et al. (2009) also found decreasing trends in ET_o over various sites in India and attributed there to notable decrease in wind speed and significant increase in air relative humidity. Sunshine duration was also found to be the most influencing variable responsible for the observed changes in E_{pan} in winter, pre-monsoon and monsoon seasons in north east India (Jhajharia *et al*., 2009).

Table 1. Backward multiple regression analysis for estimating the influence of weather parameters on ET_o

ET_o	Regression Equation	R^2	P
Annual	- 4.64 + 0.21 BSS + 1.01 WS + 0.19	0.68	0.000001
Monsoon (June – September)	- 10.7 + 0.24 BSS + 1.02 WS + 0.35 T_{max}	0.83	0.0000000003
Post-monsoon(October- November)	3.43+ 0.08 BSS + 0.73WS + 0.01RH_e + 0.02 RH_m	0.76	0.0000001
Summer (March- May)	-0.82 +0.24 BSS + 1.43WS+ 0.11 T_{max} -0.02 RH_m	0.81	0.00000001
Winter (December – February)	-1.01 + 0.11 BSS + 0.45 WS + 0.19 T_{max}	0.84	0.0000000001

Trend analysis of ET_o and governing meteorological variables

Trends in ET_o and governing meteorological variables over Hisar were analyzed on monthly, seasonal and annual time scales. The results relating to seasonal and annual trends are presented in this paper. Statistically significant decreasing trends in annual, monsoon (June-September), post-monsoon (October-November) and winter (December-February), ET_o were observed at 10 % level of significance, while non significant decreasing trend were observed during summer (March-May). From the Sen's slope analysis (Fig. 1), the corresponding reduction in annual, monsoon, post monsoon and winter ET_o were estimated at 0.02, 0.03, 0.01 and 0.01 mm/day respectively. There were no perceivable trends in annual and seasonal maximum and minimum temperature reflected by non- significant nature as well as small values of τ (Fig. 2a and 2b). Trends in morning relative humidity (RH_m) and afternoon relative humidity (RH_e), derived through the MK test, at seasonal and annual time scales are presented in Fig. 2 c and Fig. 2d respectively. Statistically significant increasing trend in RH_m were observed in post-monsoon and winter season months. Similarly increasing trends in RH_e were observed in monsoon, post-monsoon, winter seasons months. From the Sen's slope analysis, it was revealed that RH_m increased @ 0.12 and 0.14% during post-monsoon and winter seasons while RH_e increased by 0.24, 0.21 and 0.38 % during monsoon, post-monsoon and winter season, respectively (Fig. 2c and Fig. 2d).

Similarly significant decreasing trends in daily BSS hours and wind speed were observed at annual and all seasonal scales, except for BSS during monsoon (Fig. 2e and Fig. 2f). The decrease in daily BSS hours occurred @ 0.06, 0.055, 0.02 and 0.04 hours per day respectively during post monsoon, winter, summer season and annually. Wind speed witnessed significant decreasing trends @ 0.02 m/s/day during monsoon and between 0.01- 0.02 m/s/day during other seasons and annually. The significant parameters governing trends of ET_o at Hisar are summarized in Table 2.

It can be seen that wind speed and bright sunshine hours have negative trends, significant at annual scale and during all seasons except of BSS during monsoon. It means that wind speed and bright sunshine hours are decreasing over time in Hisar with related affects on ET_o. Cloud cover during monsoon offsets the BSS hours resulting in non- significant negative trends. Both RH_m and RH_e have significant rising (positive) trends at all time scales, more particularly of RH_e, except during summer, while T_{max} and T_{min} have non- significant trends of similar

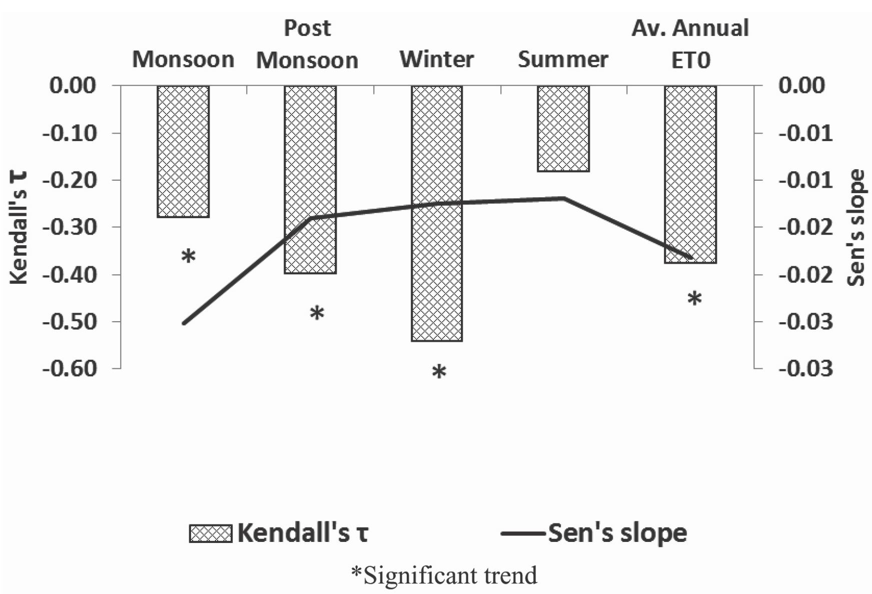

Fig. 1. Mann-Kendall trend test for ET_o (1981-2010)

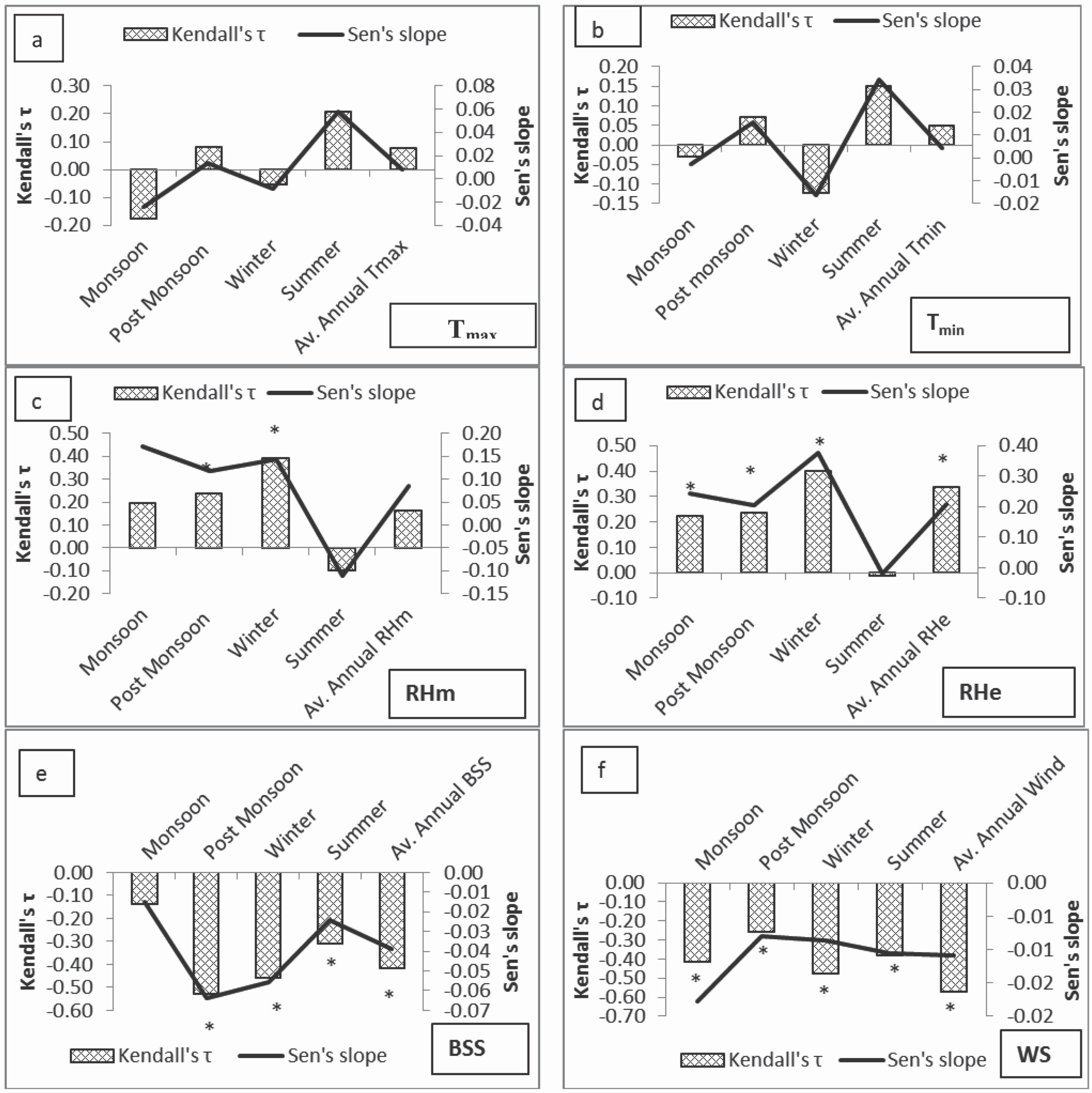

Fig. 2. Results of Mann Kendall trend test for T_{max} (a), T_{min} (b), RH_m (c), RH_e (d), BSS (e) and WS (f) for Hisar (**indicates significant trend*)

nature, rising during annual, post monsoon and summer and falling during monsoon and winter seasons. Since ET_o is linked to these weather parameters in complex intrinsic ways, such trends may be useful in creating reliable weather scenarios in modeling studies on evaluating the impact of climate change on soil, water and crop production in arid regions of Haryana and also for undertaking controlled crop physiological studies.

The results also point out that except in summer season, a significant decrease in ET_o was mainly due to the occurrence of decreased bright sunshine hours and significant decrease in wind speed. Although air temperature did not change so much but change in BSS and wind speed neutralized the effect of temperature on ET_o, but might have actually caused ET_o to decline further in seasonal and annual time scale. The findings of this study are also supported by the observed decreases in ET_o over the Yangtze River basin in China (Xu *et al.*, 2006) essentially due to significant changes in net radiation and wind speed. Goyal (2004) reported that temperature followed by radiation, wind speed and vapor pressure affected ET_o significantly in an arid region in Rajasthan of India. Thomas (2000) reported sunshine duration, wind speed, relative humidity and maximum temperature to

Table 2. Significance of trends of weather parameters affecting ET_o at Hisar at different time scales

Time scale	Significant (S)/ Non- significant (NS) trends of weather parameters					
	T_{max}	T_{min}	RH_m	RH_e	BSS	WS
Annual	Positive (NS)	Positive (NS)	Positive (NS)	Positive (S)	Negative (S)	Negative (S)
Monsoon (June – September)	Negative (NS)	Negative (NS)	Positive (NS)	Positive (S)	Negative (NS)	Negative (S)
Post-monsoon (October- November)	Positive (NS)	Positive (NS)	Positive (S)	Positive (S)	Negative (S)	Negative (S)
Summer (March- May)	Positive (NS)	Positive (NS)	Negative (NS)	Negative (NS)	Negative (S)	Negative (S)
Winter (December – February)	Negative (NS)	Negative (NS)	Positive (S)	Positive (S)	Negative (S)	Negative (S)

be the main parameters affecting ET_o in the South China. Donohue *et al*. (2010) also find that the overall contribution from increases in temperature is almost entirely cancelled out by the decreases in wind speed alone over Australia.

Bright sunshine hours provide the major energy input to any evaporative process, and are an excellent estimator of evapo-transpiration. Over India, a significant continued reduction in incoming radiation was observed under all sky conditions (Padma Kumari and Goswami, 2010; Ramanathan *et al*., 2005) where aerosols and clouds together contributed to decrease in incoming radiation. Decrease in surface solar radiation may lead to decrease in evaporation and slowdown the onset of monsoon rains (Wild *et al*., 2005; Ramanathan *et al*., 2005). It is widely perceived that in all the major cities of India, aerosol concentrations have been increasing, resulting in decreased BSS hours (Ramachandran *et al*., 2006). Bandyopadhyay *et al.* (2009) related the steady wind speed decreases witnessed over India to the obstruction of wind flow offered by the ever-increasing construction works, while Vautard *et al*. (2010) and McVicar and Roderick (2010) attribute these to increases in terrestrial surface roughness at global level.

Summary and Conclusions

The nature and estimates of trends in ET_o and governing meteorological parameters of Hisar district in Haryana were investigated through the Mann-Kendall and Sen's nonparametric tests, respectively. Thirty year (1981-2010) climate data was utilized for estimation of reference ET using Penmen – Monteith method and were utilised further along with important weather parameters for trend analysis. Statistically significant decreasing trends of ET_o were observed at annual scale as well as during winter, monsoon and post-monsoon seasons. Temperature (both maximum and minimum) at Hisar has remained practically trend-less both at annual and all seasonal scales, while significant decreasing trends have been observed in BSS hours and wind speed on annual and seasonal scales except during monsoon. The contribution of the temperature, if any, on ET_o seems to be offset by steady reduction in wind speed and BSS hours. This observation is also confirmed by the strong and high sensitivity of BSS and wind speed with ET_o derived through backward stepwise regression at almost all time scales. The results of this study can be usefully utilized to create rational climate change scenarios for conducting controlled cop physiological and modelling studies on the impact of envisaged climate change on soil, water, salinity and crop production in arid regions of Haryana.

Acknowledgements

The authors wish to thank Dr. D.K. Sharma, Director, CSSRI, Karnal for his constant encouragement and support and Agromet Division, CCS Haryana Agricultural University, Hisar (Haryana) for providing the historical meteorological data of Hisar for this study.

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Received:_________; Accepted__________

: October, 2013; Accepted December, 2013