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Analysing recent meteorological trends and computation of reference evapotranspiration and its effect on crop yields in semi-arid region of Haryana

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सार – हरियाणा के शुष्क क्षेत्र (हिसार) के पिछले 45 वर्षों (1972-2016) के मुख्य फसलों के उत्पादन के आकड़ों तथा उनसे संबंधित मौसम विज्ञान संबंधी प्रवृत्तियों का विश्लेषण किया गया। इस क्षेत्र के लिए वाष्पोत्सर्जन (ET_0) के संदर्भ की गणना पैनमान-मौंटीथ समीकरण के आधार पर की गई। प्रवृत्ति के महत्व के परीक्षण के लिए मौसम विज्ञानी प्राचल मान-कैंडेल (एम के) परीक्षण और परिमाण का परीक्षण करने के लिए सेन के स्लोप एस्टीमेटर का प्रयोग किया गया। इसी प्रकार ऋतु तथा वार्षिक मौसम प्राचलों में परिवर्तनशीलता की गणना के लिए परिवर्तिता सूचकांक का उपयोग किया गया। पिछले अनेक वर्षों में वार्षिक वृद्धि ह्रास की प्रवृत्ति के आकलन के लिए पैदावार के आँकड़ों के आधार पर एम के परीक्षण किया गया। पिछले 45 वर्षों के दौरान पवन गति, धूप के घंटे और संदर्भ वाष्पीकरण में क्रमशः 5%, 3.3% और 2% प्रति वर्ष की दर से कमी हई जबकि न्यूनतम तापमान 1.8% प्रति वर्ष की दर से बढ़े। वाष्पोत्सर्जन पर औसत वर्षा में 1122 मि.मी की कमी पाई गई हालांकि यह कमी वाष्पोत्सर्जन में गिरावट के कारण महसूस की गई। रबी की फसल की तुलना में खरीफ की फसल में पैदावार में वृद्धि की प्रवृत्ति अधिक पाई गई। कपास की रूई की उपज की दर सर्वाधिक (17.5% प्रति वर्ष) बाजरा (7.8% प्रति वर्ष), धान (3.1% प्रति वर्ष) तथा जौ (2.7% प्रति वर्ष) रही जबकि गेहूँ, चना और अरहर की पैदावार में अध्ययन काल में कोई महत्वपूर्ण प्रवृत्ति नहीं देखी गई।

ABSTRACT. Yield data of major crops and corresponding meteorological trends for the last forty-five years (1972-2016) were analysed for arid region (Hisar) of Haryana. Reference evapotranspiration (ET_0) for the region was calculated based on Penman-Monteith equation. Meteorological parameters were subjected to Man-Kendall (MK) test for testing the significance and Sen's slope estimator for estimating the magnitude of trend. Similarly, variability index was employed for computing variability in seasonal and annual weather parameters. Yield data was also subjected to MK test to estimate the annual increasing/decreasing trend over the years. During the last 45 years wind speed, sunshine hours and reference evaporation declined at a rate of 5%, 3.3% and 2% year^{-1} respectively while minimum temperature increased at 1.8% year^{-1}. Average rainfall deficit of 1122 mm over evapotranspiration (ET_0) was observed although it registered a declining trend owing to decline in ET_0. The increasing trend in yield was found to be more in *kharif* season crops as compared to the same during *rabi* season. Cotton lint yield increased at a maximum rate (17.5% year^{-1}) followed by pearl millet (7.8% year^{-1}), rice (3.1% year^{-1}) and barely (2.7% year^{-1}) while no significant trend was observed in wheat, gram and pigeon pea yield during the study period.

Key words – Reference evapotranspiration, Rice yield, Trend analysis, Variability index.

1. Introduction

Ambient weather parameters of a region have direct impact on productivity of crops grown in that region. Several studies have pointed out variations in crop yield due to fluctuation in weather variables (Kheiri *et al*., 2017; Li *et al*., 2016; Rao, 2016; Yadav *et al*., 2016). These fluctuation are more pronounced in arid and semi-arid areas as these are known to be more sensitive to climate change and variability. Climate ultimately plays the decisive role in these regions on final yield when all other factors remain constant (Ju *et al*., 2013; Murungweni *et al*., 2016; Sultana *et al*., 2009). Numerous studies have suggested change in annual mean temperature and long term modification in monsoonal rainfall in India (Taxak *et al*., 2014). Change in weather variables is bound to influence evapotranspiration which also reflects plant water requirement and serve as an important input for planning irrigation systems (Charchousi *et al*., 2015; Toumi *et al*., 2016). Decrease in evapotranspiration has been reported since 1950 in many parts of the world which is contrary to common belief that increasing temperatures (global warming), will increase terrestrial evaporation (Oguntunde *et al*., 2012). However this decrease in evapotranspiration is not universal and contrary results have also been reported. There is need to gather more data on local and regional scale to fill this gap. Therefore, the present study was undertaken to study long term trends in evapotranspiration, its explanatory weather variables and ultimately on yield of major crops of arid ecosystem (Hisar) in south western Haryana.

2. Data and methodology

Study area : Hisar which lies between 29°13'43" to 29°28'18" N latitude and 75°44'39" to 76°05'46" E longitude at an elevation of 215 m above mean sea level was chosen for this study to analyse recent trends in weather parameters and corresponding yield of major crops. Hisar is typically arid with only 472 mm annual precipitation but still is one of the most agriculturally active region of Haryana. It receives 80% of its annual precipitation in just three months (July-September) from south westerly current. Hisar represents western agro-climatic region of Haryana with hot summers and chilling winters.

Weather variables : The daily weather data consisting of maximum temperature (T_{max}), minimum temperature (T_{min}), mean temperature (T_{mean}), wind speed (WS), sunshine hour (SS), average relative humidity (RH_{mean}) and rainfall for last 45 years (1972-2016) was collected from Agro-meteorology observatory of CCS Haryana Agricultural University. Daily data was then converted to monthly and annual values which was then further analysed for trend detection using Man-Kendall test and Sen's slope estimator. Daily reference evapotranspiration (ET_0) was calculated using FAO ET_0 calculator which is based on the Penman-Monteith equation (Allen *et al*., 1998), using daily weather variables. Likewise, daily calculated ET_0 was then averaged to monthly and annual means and used for evaluating its trend over the years. The Penman-Monteith method used for calculating ET_0 is the most adopted method globally and is affected only by local climatic conditions and not affected by the types of crops or the types of soils (Allen *et al*., 1998; Gao *et al*., 2017) and is represented by the equation:

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

where,

ET_0 = reference evapotranspiration [mm day^{-1}]

Rn = 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 temp. 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]

Δ = slope vapour pressure curve [kPa °C^{-1}]

γ = psychrometric constant [kPa °C^{-1}]

ET_0 calculator is a software developed by the Land and Water Division of FAO (FAO, 2009). Its main function is to calculate Reference evapotranspiration (ET_0) according to FAO standards.

Mann-Kendall (MK) test (Kendall, 1975; Mann, 1945) was used for detecting temporal variation in ET_0 and related meteorological data as well as yield of major crops. This test does not necessitate data to follow any distribution and is not easily affected by the outliers. It is one of the widely used nonparametric tests which tests the presence of monotonic temporal increasing and decreasing trends (Dinpashoh *et al*., 2011).

Further, the magnitude of change per unit time within time series was estimated by non-parametric Sen's slope estimator (Sen, 1968). The magnitude of trend is predicted by the Sen's estimator. Slope is given by :

$$Q_i = \frac{X_j - X_k}{j - k} \text{ for } i = 1, 2, \ldots, N$$

where, X_j and X_k are data values at time *j* and *k* (*j*>*k*) respectively. The median of these N values of Q_i is represented as Sen's estimator. Variability index of seasonal and annual weather variables from 1972-2016 was calculated as standard variable departure (Oguntunde *et al*., 2012, 2006) using the expression:

$$VI_i = (X_i - \mu) / \sigma$$

where, VI_i is the variability index for the i^{th} year, X_i is the annual value of the variable for i^{th} year, μ and σ are mean annual value and standard deviation respectively of the period of analysis.

3. Results and discussion

The meteorological factors were analysed for each month as well as calendar year to identify peculiar pattern which may have washed out in annual analysis only. The annual change in meteorological parameters and their corresponding monthly trends are presented in Figs. 1(a-g) and summarised in Tables 1 and 2 along with respective confidence level.

Climate : During the study period (1972-2016), annual average maximum and minimum temperatures were found to be 31.5 and 16.4 °C respectively, while annual average relative humidity was 60.5 per cent (Table 1). Average annual wind speed was 5.68 km hr^{-1} while for sunshine hours which varied least (CV = 20.85) among all studied variables, the average value was 7.53 hours. The mean daily evapotranspiration for Hisar was 4.42 mm/day during the same period while average annual total rainfall was 474.7 mm/year.

3.1. *Annual, monthly and seasonal trends of weather parameters during 1972-2016*

Maximum temperature : Summary statistics of temporal series of maximum temperature reveal that it ranged from 16.5 °C (January, 2015) to 43.8 °C (May, 1978) with mean value of 31.45 ± 0.30 °C. Test result of Sen's slope estimator does not reveal any significant trend in annual mean maximum temperature (Table 1). Similarly, no significant trend was observed in seasonal and monthly time series data of maximum temperature, except January (Table 2).

Minimum temperature : The annual mean minimum temperature was 16.35 ± 0.35 °C and ranged from 1.9 °C (January, 1997) to 29.2 °C (June, 1984). Time series and linear trends of minimum temperature showed significant annual increasing trend (0.018 °C/year; α = 0.05) as evident from Sen's slope (Q_i) value (Table 1). Concomitant increasing trend in the month of February (0.037 °C/year; α = 0.1), August (0.019 °C/year; α = 0.05) and September (0.033 °C / year; α = 0.01) might have contributed towards annual increase in minimum temperatures over the years. Seasonal analysis revealed that maximum increase (2.7% $year^{-1}$) in minimum temperature was observed during post monsoon (September - November) followed by winter (December - February) season.

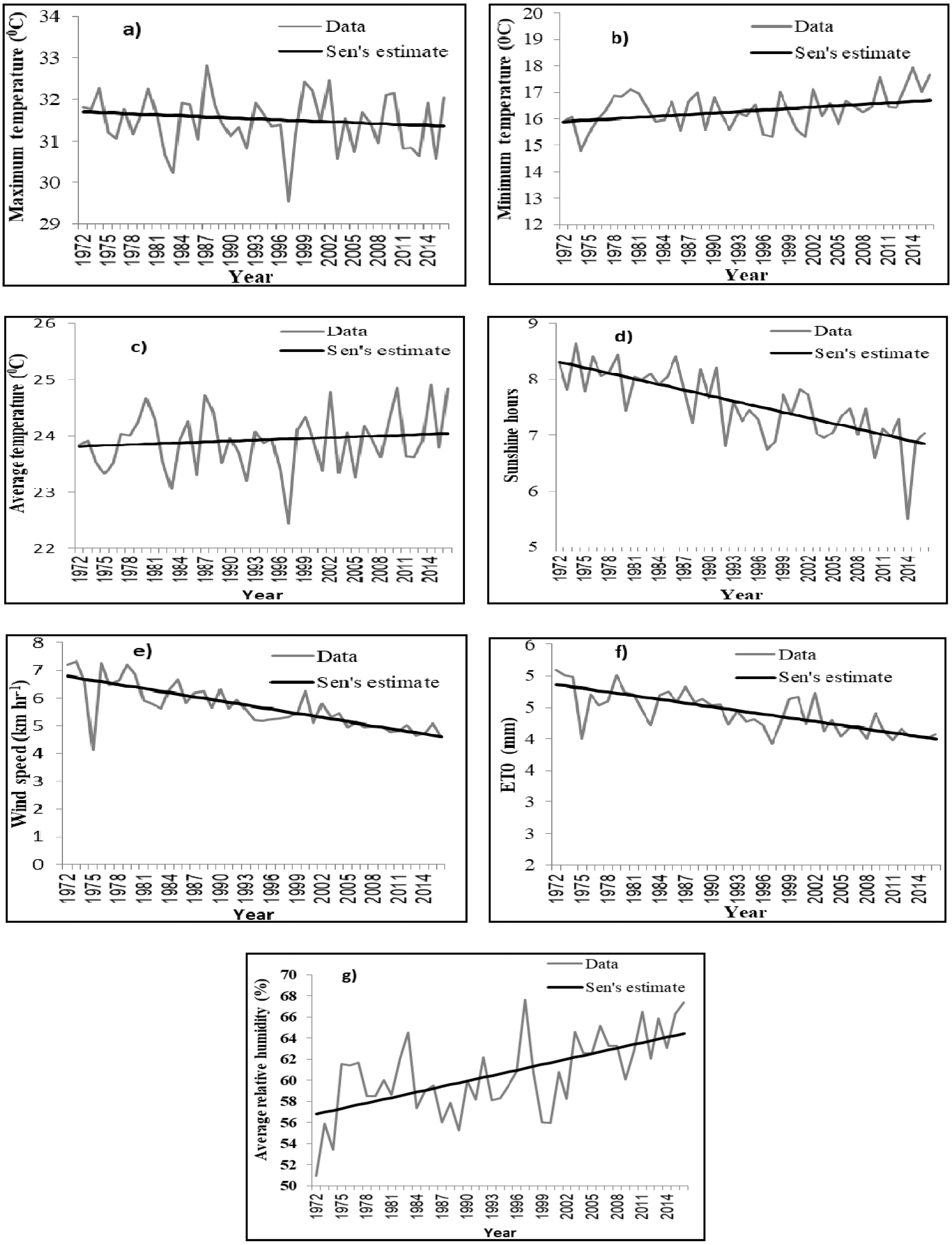
Mean temperature : The average of minimum and maximum temperature was found to be statistically stable over the years of study as evident from non-significant Q_i value (0.005) (Table 1). Its value was found minimum in January, 2003 (10.1 °C) and maximum in June 1984 (35.4 °C) with a mean value of 23.9 ± 0.31 °C over the years.

Relative humidity : The average of morning and evening relative humidity (RH) was 60.52 ± 0.54% (SD = 12.60 and CV = 20.8). There was significant positive trend (0.17% $year^{-1}$ at α = 0.001) in annual RH during the last 45 years. The maximum significant positive trend was noticed in the month of January (0.42% $year^{-1}$ at α = 0.001) and lowest in October (0.18% $year^{-1}$ at α = 0.05). Among different seasons, maximum increasing trend was noticed in winter season (0.29% $year^{-1}$ at α = 0.001), followed by summer (0.17% $year^{-1}$ at α = 0.01), monsoon (0.16% $year^{-1}$ at α = 0.1) and least in post monsoon season (0.14% $year^{-1}$ at α = 0.01).

Wind speed : The wind speed was found to be significantly declining over the years. Except in the month of October, it showed a significant declining trend from 1972 to 2016 in rest of the months (Tables 1 and 2). Highest declining trend in wind speed over the years was observed in June (0.102 km hr^{-1} $year^{-1}$; α = 0.001) and lowest in November (0.023 km hr^{-1} $year^{-1}$; α = 0.01). Overall, wind speed decreased at a rate of 0.050 km hr^{-1} $year^{-1}$ (α = 0.001) from 1972 to 2016. The wind speed was blowing at an average speed of 5.68 ± 0.11 km hr^{-1} (SD = 2.6; CV = 45.96%) over the years.

Sunshine (SS) hours : The trend in sunshine hours was highly variable among the months over the years. Overall monthly duration of sunshine hours showed declining trend from 1972 to 2016 at a rate of 0.033 hour $year^{-1}$. Average sunshine duration during 1972-2016 was 7.5 ± 0.07 hours with SD of 1.57 and CV of 20.85%. On average basis, April (9.0 SS hours) was found to be brightest month while January (6.1 SS hours) remained the shadiest month. Maximum declining trend on seasonal basis was noticed in winter season (5.8% $year^{-1}$), followed by post monsoon (4.3% $year^{-1}$) and summers (2% $year^{-1}$) while it declined non significantly during monsoon season.

Reference evapotranspiration (ET_0) : Except during the month of July and August, significant reduction in mean monthly evapotranspiration was noticed on monthly and annual basis. Maximum reduction was found to be in the month of June (4.3% $year^{-1}$) and minimum in August (1% $year^{-1}$). Overall over the years from 1972-2016, it decreased annually at a rate of 2% every year. During the span of 45 years' maximum value of mean ET_0 was observed during May, 1978 (10 mm), while lowest during January, 2014 (0.9 mm). Decline in ET_0 was similar in both post monsoon and winter season (1.4% $year^{-1}$ in each), while



Figs. 1(a-g). Sen's linear estimate of annual mean of daily time series data (a) maximum temperature, (b) minimum temperature, (c) mean temperature, (d) Sunshine hours (e) wind speed, (f) reference evapotranspiration and (g) average relative humidity

TABLE 1

Annual change in meteorological variables at Hisar (1997-2016)

Parameters	Mean	SD	CV (%)	Man-Kendall trend (Test Z)	Annual change (Sen's slope, Q_i)
Maximum temperature (°C)	31.45	6.87	21.85	-0.89	-0.008
Minimum temperature (VC)	16.35	8.08	49.39	2.40	0.018*
Mean temperature (°C)	23.90	7.29	30.49	0.99	0.005
Average RH (%)	60.52	12.60	20.80	4.17	0.173***
Wind speed (Km hr^{-1})	5.68	2.62	45.96	-6.41	0.050***
Sunshine hours (hrs)	7.53	1.57	20.85	-5.23	0.033***
Total rainfall (mm)	474.7	59.82	151.21	-	-
Mean annual Reference evapotranspiration (ET_0) (mm)	133.05	63.13	47.45	-5.28	-0.020***
Mean daily Reference evapotranspiration (ET_0) (mm)	4.42	2.07	46.99	-5.28	-0.020***

Note : +, *, ** and *** indicates significant values at the level of α = 0.1, α = 0.05, α = 0.01 and α = 0.001, respectively

TABLE 2

Monthly and seasonal trends as estimated by Mann-Kendall test of the meteorological parameters for different years (1972-2016) in Hisar

Time series	T_{max} (°C $year^{-1}$)	T_{min} (°C $year^{-1}$)	T_{mean} (°C $year^{-1}$)	RH_{mean} (% $year^{-1}$)	WS (km hr^{-1} $year^{-1}$)	SS (hrs $year^{-1}$)	ET_0 (mm $year^{-1}$)
January	-0.067* * *	0.016	-0.025*	0.419***	-0.036**	-0.085***	-0.018***
February	0.007	0.037+	0.025	0.298***	-0.042***	-0.046***	-0.014***
March	0.000	0.017	0.002	0.292**	-0.056***	-0.010	-0.018***
April	-0.011	-0.002	-0.007	0.000	-0.043***	-0.023***	-0.020**
May	-0.008	0.018	0.004	0.215*	-0.063***	-0.026*	-0.031***
June	-0.030	-0.013	-0.025+	0.339**	-0.102***	0.013	-0.043***
July	0.005	0.004	0.009	0.013	-0.097***	0.002	-0.009
August	-0.004	0.019*	0.007	0.040	-0.038*	-0.029+	-0.010
September	-0.012	0.033**	0.005	0.181*	-0.033**	-0.023*	-0.015*
October	-0.008	0.033	0.011	0.177*	-0.019	-0.037***	-0.013**
November	0.001	0.016	0.011	0.100	-0.023**	-0.064***	-0.011***
December	0.007	0.015	0.003	0.127	-0.026**	-0.042***	-0.009***
Seasonal trends							
Summer (March - May)	-0.008	0.012	0.004	0.174**	-0.053***	-0.020**	-0.024***
Monsoon (June - August)	-0.009	0.003	-0.001	0.157+	-0.081***	-0.003	-0.021**
Post-monsoon (Septemebr - November)	-0.013	0.027+	0.008	0.143**	-0.028**	-0.043***	-0.014***
Winter (December - February)	-0.012	0.023+	0.005	0.278***	-0.033***	-0.058***	-0.014***

Note : +, *, ** and *** indicates that it passes the significance test at the level of α = 0.1, α = 0.05, α = 0.01 and α = 0.001, respectively

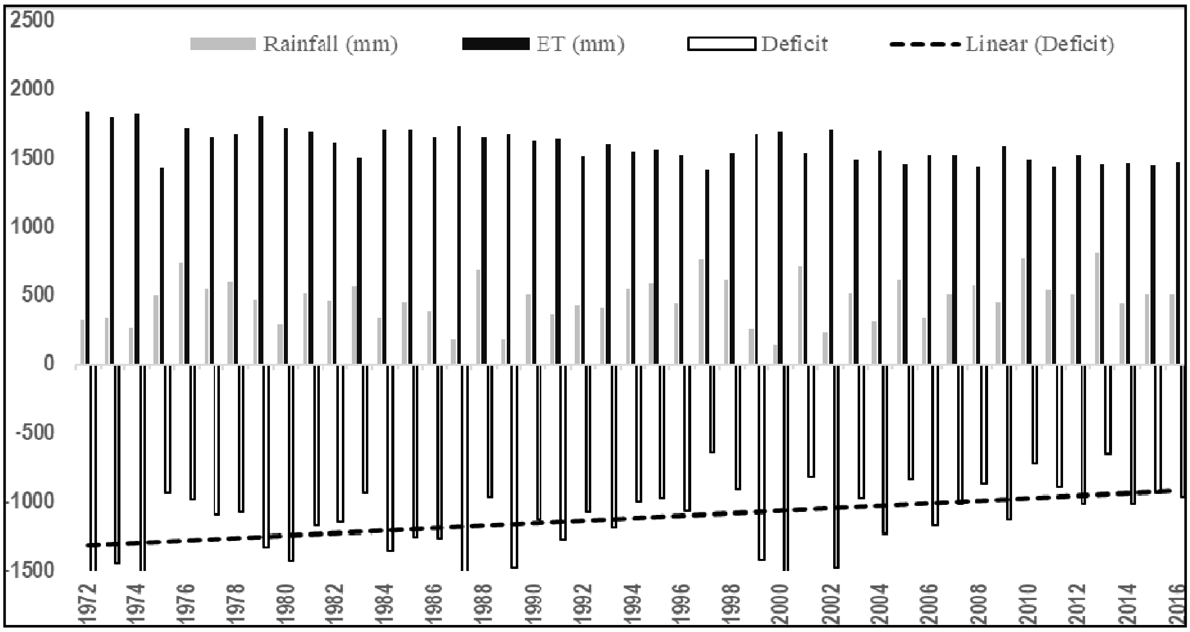


Fig. 2. Total annual reference evapotranspiration, rainfall and deficit rainfall in Hisar

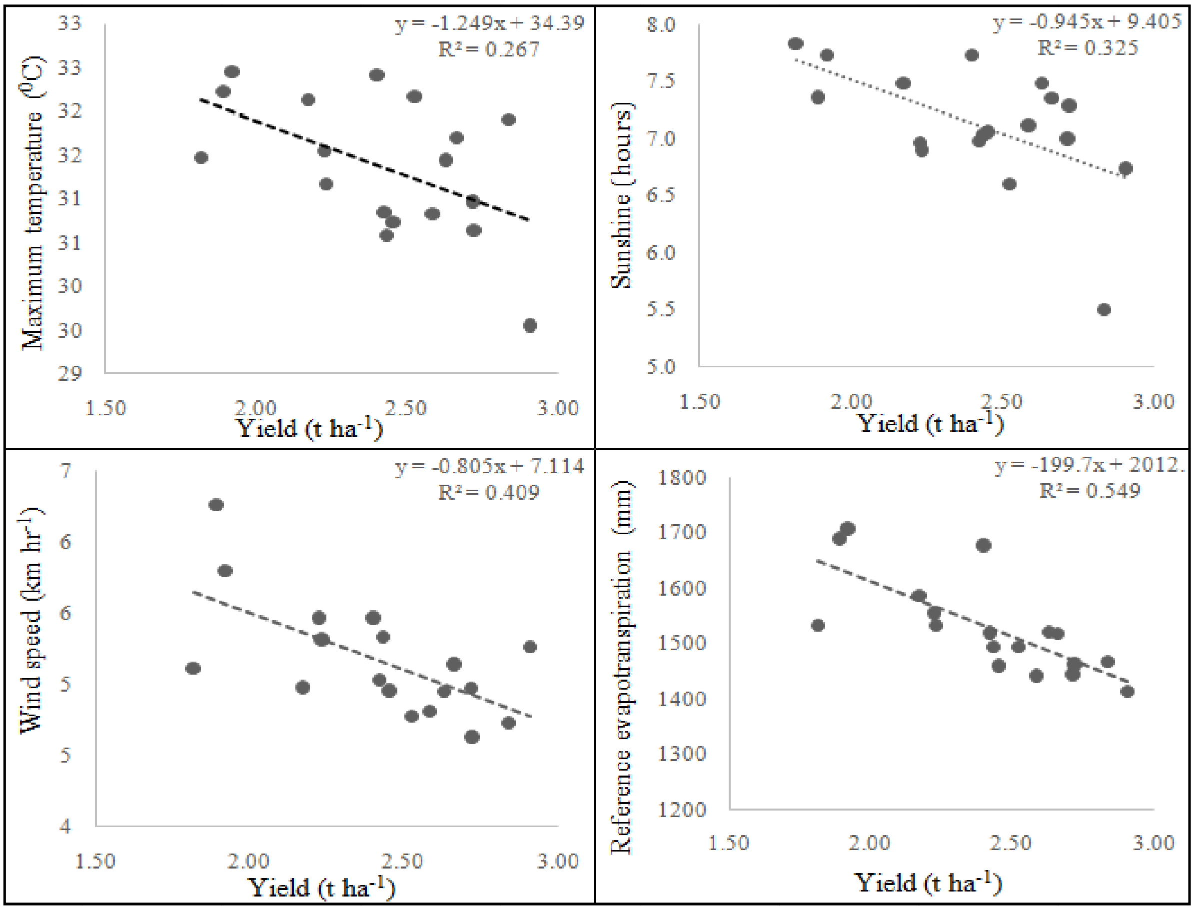
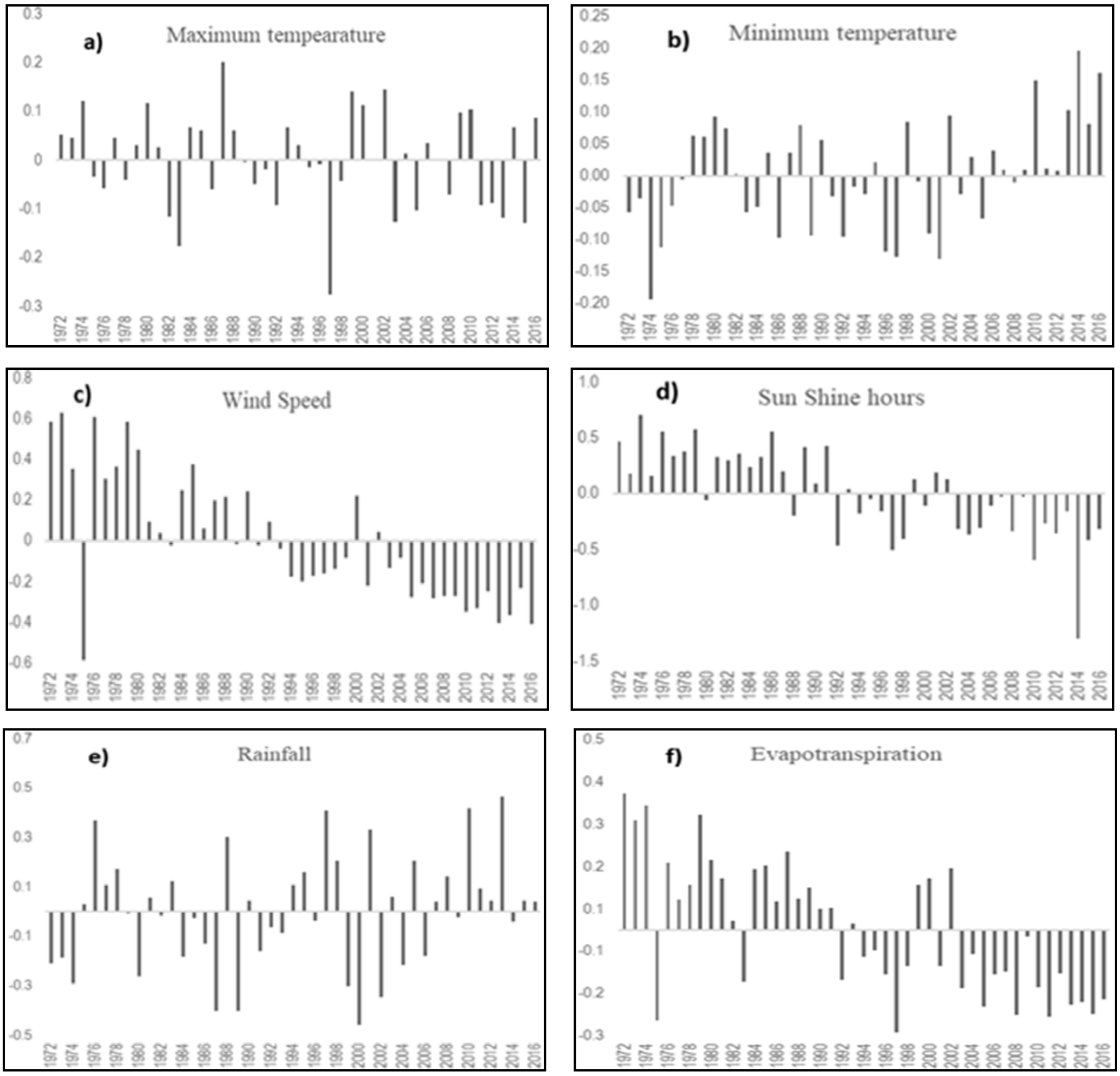


Fig. 3. Correlation between weather variables and rice yield during 1997-2014 period



Figs. 4(a-f). Annual variability index for (a) maximum temperature, (b) minimum temperature, (c) wind speed, (d) sunshine hours, (e) rainfall and (f) evapotranspiration from 1972-2016

maximum decline (2.4% year^{-1}) was observed in summer season, followed by monsoon (2.1% year^{-1}).

Rainfall deficit : A comparison was done on yearly basis between total rainfall and total evaporation to assess the deficit or excess rainfall during the last 45 years (Fig. 2). During all the years of assessment amount of total rainfall remained less compared to reference evapotranspiration. The deficit in rainfall as compared to ET_0 ranged from 643 to 1553 mm. The estimated normal reference evapotranspiration was 1597 mm as compared to normal rainfall of 475 mm leading to deficit of 1122 mm, but over the years rainfall deficit is showing a declining trend owing to declining ET_0. This results conform with declining trend in ET_0 estimated using MK test and Sen's slope estimation.

Yield trends of major crops : The rice yield during 1997-2014 period ranged from 1.82 to 2.91 t ha^{-1} with average mean yield of 2.42 ± 0.08 t ha^{-1}(Table 3). It increased significantly at 3.1% (α = 0.05) on yearly basis. Cotton with an average lint yield of 2.85 ± 0.24 t ha^{-1} registered a steady growth of 17.1% (α = 0.001) on yearly basis from 1997-2012. Significant increasing trend (7.8% yearly; α = 0.05) was also noticed in pearl millet yield during 1997-2010 period with

TABLE 3

Summary of yield trends of major crops of Hisar

Crop	Years	Mean yield (*t* ha^{-1})	Standard Deviation	CV (%)	Z statistics	Annual change (Sen's slope)
Rice	1997-2014	2.42	0.32	13.22	2.05	0.031*
Cotton	1997-2012	2.85	0.97	34.04	3.38	0.171***
Pearl millet	1997-2010	1.75	0.59	33.71	2.19	0.078*
Pigeon pea	1997-2010	0.96	0.65	67.71	0.11	0.000
Wheat	1997-2012	4.27	0.35	8.20	1.04	0.020
Barely	1997-2012	3.10	0.33	10.65	1.76	0.027+
Gram	1997-2010	0.76	0.12	15.79	1.64	0.010

Note : +, *, ** and *** indicates significant values at the level of α =0.1, α = 0.05, α = 0.01 and α = 0.001, respectively

TABLE 4

Correlation between weather variables and rice yield (*t* ha^{-1}) from 1997 to 2014

Weather variables	R^2	Coefficient of correlation (*r*)	P-value	*t* stat value
Maximum temperature (°C)	0.27	0.52	0.028	-2.41
Sunshine hours	0.33	0.57	0.013	-2.78
Wind speed (km hr^{-1})	0.41	0.64	0.004	-3.33
ET_0 (mm)	0.55	0.74	0.0004	-4.42

an average yield of 1.75 ± 0.16 t ha^{-1}. During *rabi* season only barley registered significant trend in yield with an average increase of 2.7% year wise from 1997 to 2012.

Correlation between yield and weather variables (1997-2014) : Among the major crops cultivated in Hisar, notable negative correlation was observed only between rice yield and weather variables (maximum temperature, wind speed, sunshine hour and ET_0) (Table 4 and Fig. 3). Among the variables, reference evapotranspiration had maximum negative correlation (r = 0.74), followed by wind speed (r = 0.64), sunshine hours (r = 0.57) and maximum temperature (r = 0.52). The decreasing ET_0 trend observed by MK test and Sen's slope estimation and increasing rice yields over the years corroborate the result findings.

Variability index (VI) : Annual variability index of different weather variables is presented in Fig. 4. Two extremes in maximum temperature variability occurred during 1987 and 1997 with highest and lowest VI values in the respective years. As evident from VI graph maximum variability in minimum temperature was observed in 1974 and 2014. Hisar experienced brightest year in 1974 and shadiest in 2014. Almost similar trend in VI values was observed in wind speed although the year 1975 was an exception. Maximum VI values of wind speed was in 1973 while lowest in 2013. Rainfall showed more variability from the mean values over the years. The year 2000 was driest with highest negative variability while 2013 was rainiest. Variability observed in reference evapotranspiration was less as compared to rainfall although a declining trend was observed in VI values from 1972 to 2016.

4. Conclusions

Climate parameters subjected to MK test and Sen's slope estimation indicate significant decreasing trend in wind speed, sunshine hours and reference evapotranspiration while minimum temperature increased during the period of last 45 years (1975-2016). Maximum temperature also declined but the decline was not significant. Sen's slope estimation indicated a year wise decline of 5%, 3.3% and 2% in wind speed, sunshine hours and reference evapotranspiration respectively while minimum temperature increased at the rate of 1.8% during the same period. The decreasing trend in ET_0 values and its negative correlation with rice yields might indicate further increasing trends in rice yields at Hisar, if others factors are not limiting. This study at a broader scale (ecological regions) might provide policy solutions through well suited crop selection based on prevailing weather conditions.

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