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An investigation of reference evapotranspiration trends for crop water requirement estimation in Rajasthan

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ABSTRACT

Trends in reference evapotranspiration (ETo) estimated using Penman-Monteith equation were analysed over arid, semi-arid and humid regions of northwest (NW) India during 1985–2018. The Mann-Kendall is used to determine significance of trends. Theil-Sen's estimator and least square linear fitting methods are adopted to find slopes of the trend lines. The results indicated a significant decrease in ETo on annual basis for most of the locations and NW India as a whole. However, the trend was not statistically significant for seasonal ETo. The significant decrease in solar radiation and wind speed nullified the impact of increased temperature and resulted in slight decrease in ETo over arid and semi-arid regions of NW India which could probably be attributed to the increased dust hazy conditions prevailing. In NW India, water is a limiting resource the decrease in ETo may help researchers in decision makers to develop water assets and utilize the irrigation systems more effectively. There was also an increasing trend in production of major crops in the study region. Further, in near future, if this decreasing ETo trend were to remain, it would help in intensification of cropping system with the existing water resource.

Keywords: Reference evapotranspiration, Trends, Penman-Monteith method, Crop water requirement

According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007), there was an increase of 0.74 ^{0}C in the global mean air temperature during past 100 years and it is also projected to increase by 1.1 to 6.4^{0}C by 2100. Due to climate change, there is projection of increase in the frequency of occurrence of temperature extremes (in the form of heat waves or cold waves) along with mean temperatures and obviously the atmospheric demand leading to higher evapotranspiration. Increase in evapotranspiration draws the attention of researchers as it is an important component of hydrological cycle and water balance (Wang *et al*., 2007) and changes in ETo are of great significance for agricultural water use planning. The earlier studies reported a decreasing trend in ETo like Bandopadyay *et al.* (2009) in India, Tabari *et al*. (2012) in Iran, Golubev *et al*. (2001) in United States. This draws the attention towards the factors responsible for decrease in reference evapotranspiration despite an increase in temperature. It shows that there are other climatic factors (Radiation, wind speed, relative humidity) which are nullifying the impact of increased temperature and contributing to decrease in evapotranspiration. The trend analyses of ETo using non-parametric statistics tests conducted by Koffi and Komla (2015) in Togo showed a decreasing trend in ETo over all stations except a significant increasing trend in annual ETo at Tabligbo and Sokode stations. In India, Bandyopadhyay *et al*. (2009) observed a decreasing trend in ETo and attributed this decrease to a significant decrease in the wind speed and increase in the relative humidity. Keeping in view the importance of these studies and the fact that changes in temperature alone do not explain reasons for changes in evapotranspiration, the present study is carried out to analyze the trends, quantifying the magnitude of temporal and spatial trends in ETo and sensitivity analysis over arid and semi-arid water scarce region of NW India to get some insight into this aspect.

MATERIALS AND METHODS

Study area and data

The study area lies in the NW part of India, Rajasthan state, between 23^o 30' and 30^o 11' N latitudes and between 69^o 29' E and 78^o 17' E longitude. The "Great Indian Desert" is in this region. As far as the agriculture production is concerned, it is one of the major producers of mustard, pearl millet, Gram, maize, sorghum, groundnut, spices, guar and barley etc. The climatic conditions of study area are broadly classified into arid, semi-arid and humid zones. The arid region consists of the north-west districts Hanumangarh, Sriganganagar, Bikaner, Jhunjhunu, Nagaur, Sikar and Jodhpur. This region is characterized by low rainfall with high variability which creates inhospitable conditions to all living beings. The semi-arid region covers the middle districts like Jaipur, Ajmer, Tonk while humid region covers the eastern districts Dholpur, Sawai Madhopur, Bhilwara, Chittorgarh, Udaipur, Dungarpur, Banswara and Kota. The daily meteorological data (1985 to 2018) are collected from India Meteorological Department (IMD), Meteorological Centre Jaipur and Universities/Institutes having IMD Agromet observatories. Monthly, seasonal and annual time series of climatic data were computed from daily weather data. The four seasons (as per IMD) were defined as winter season (January to February), Pre-Monsoon season (March to May), Monsoon season (June to September) and Post-Monsoon season (October to December).

FAO Penman-Monteith (PM) Method

Among the different techniques for estimating ETo, the most common and reliable technique for estimating ETo is Penman-Monteith FAO-56 method (Allen *et al*., 1998). The equation is:

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

where,

ETo= Reference evapotranspiration ($mmday^{-1}$)

Rn= Net radiation at the crop surface ($MJm^{-2}day^{-1}$)

G= Soil heat flux density ($MJm^{-2}day^{-1}$)

T= Mean daily air temperature (^oC)

u2 = Wind speed at a 2 m height above the ground ($msec^{-1}$)

es = Saturation vapour pressure (kPa)

ea = Actual vapour pressure (kPa)

Δ = slope of vapour pressure *curve* (kPa^oC^{-1})

ϒ = Psychrometric constant (kPa^oC^{-1})

Trend analysis method

In this study, both non-parametric and parametric methods were used to know the trends of reference evapotranspiration. Since, there is problem of missing values in hydrological time series data, non-parametric tests are more appropriate for the data which are not normally distributed.The non-parametric methods also take care of the outliers present in the long time seriesdata.

Mann–Kendall test

The Mann-Kendall test or Mann-Kendall rank statistic (Mann 1945, Kendall, 1975) test was employed to assess the temporal variations in the monthly, seasonal and annual ETo and to confirm the significance of the observed trend in the long series ETo data.

In Mann–Kendall rank statistic, the rank obtained by each data replaces the time series values and S is calculated using the given formulae-

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

Where

$sgn(x_i - x_j) = 1$ for $x_i > x_j$, $sgn(x_i - x_j) = 0$ for $x_i = x_j$, $sgn(x_i - x_j) = -1$ for $x_i < x_j$

In case, the null hypothesis Ho (there is no trend in the data) is true, then S is approximately normally distributed with $\mu = 0$

$\sigma = n(n-1)(2n+5)/18$

Therefore, z-statistic can be obtained from normal probability tables.

$$z = \frac{|s|}{\sigma^{0.5}}$$

The positive value of S indicates the increasing trend and negative value of S indicates the decreasing trend in rainfall data. In order to verify the results obtained by Mann-Kendall rank statistic test, the linear trend in the data is also tested.

Theil-Sen's estimator

Theil-Sen's estimator is a robust estimator of the slope to compute the magnitude of a trend and is widely used for computing the slope of a trend line in a hydrological time series (Yue *et al*., 2002). The slope of n pairs of datapoints is calculated using the given formulae-

$$\beta = Median\left(\frac{x_j - x_l}{j - l}\right) \quad \forall\ 1 < l < j$$

RESULTS AND DISCUSSION

General characteristics of reference evapotranspiration

The average ETo varied from 1619.7 to 1794.3 mm

Table 1: Average (1985-2018) and decadal trend of observed weather parameters and reference evapotranspiration of arid region

	Jan	Feb	Winter	Mar	Apr	May	Pre-monsoon	Jun	Jul	Aug	Sep	Monsoon	Oct	Nov	Dec	Post-monsoon	Annual
Mean																	
ET_0	88.5	111	199.5	151.2	195.2	213.8	560.1	204.1	169.4	154.1	153.8	681.4	147.6	114.5	91.3	353.4	1794.3
T_{max}	22.2	25.4	23.8	31.5	37.6	41.0	36.7	40.6	37.0	35.4	35.4	37.1	34.9	29.7	24.3	29.6	32.9
T_{min}	6.7	9.7	8.2	15.2	20.7	25.7	20.6	27.7	27.0	25.9	23.9	26.1	18.7	12.5	7.7	13.0	18.4
RF	5.5	11.4	16.9	6.4	7.4	15.7	29.5	49.0	103.5	95.7	54.4	302.6	7.9	2.5	2.6	13.1	362.0
RS	13.3	15.8	14.6	18.9	21.9	22.3	21.1	21.1	18.1	16.9	17.2	18.3	16.9	14.4	12.9	14.7	17.5
Trend																	
ET_0	-ve	-ve	-ve	+ve	+ve	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve*
T_{max}	-ve	+ve	-ve	+ve	+ve	-ve	+ve	-ve	+ve	+ve	+ve	+ve	+ve	+ve	-ve	+ve	+ve
T_{min}	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
RF	-ve	-ve	-ve	+ve	-ve	+ve	+ve	-ve	-ve	+ve	+ve	+ve	-ve	+ve	+ve	-ve	-ve

Note:+ve means positive trend: -ve means negative trend, *significant at 5 %.

yr^{-1} with mean value of 1715.0 mm yr^{-1} and temporal low variability (2.5 %). However, the spatial variability was high among the regions. The lowest ETo (1619.7 mm yr^{-1}) is observed in semi-arid region probably due to mild temperatures (Table1, 2 and 3). In arid region (Jodhpur district) highest reference evapotranspiration (1794.3 mm yr^{-1}) is observed which could be attributed to higher temperatures coupled with higher solar radiation in this region while the monthly analysis revealed that highest ETo is recorded in May over all the regions, contributing 11.9 % to the annual ET_0. Seasonal analysis revealed that the mean annual ETo values during pre-monsoon and monsoon seasons observed in the arid region were 560.1 mm and 681.4 mm with highe r% contribution of Hanumangarh district.

Sensitivity of ETo to meteorological parameters

The sensitivity analysis is done in order to evaluate the most influencing weather parameter contributing to ETo. During May, the highest ETo is observed over the study area. As can be expected, in winter season lowest values of ETo all across the study sites are observed probably due to the lowest average temperatures and solar radiation. Maximum ETo is observed during monsoon season all across the study sites because of relatively higher average temperatures, solar radiation and rainfall. In order to identify the dominant variables associated with ETo, stepwise regression method is adopted. Several researchers, namely, Thomas (2000), and Dinpashoh *et al.* (2011) also used a similar procedure to identify the most important variable responsible for ETo changes under different types of climatic conditions of India, China and Iran, respectively. The stepwise regression analysis is performed between ETo as the dependent variable and the meteorological parameters, i.e., net radiation, wind speed, and temperature, as independent variables on annual and seasonal time scales using SPSS (Norusis, 1988) to possibly explain the underlying mechanisms of ETo changes. On the annual time scale, the net radiation is observed to be the most dominating variable which affected the changes in ETo in the humid region of NW India. On examining the results of stepwise regression to determine the causal mechanisms of ETo changes at the seasonal scale, net radiation is found to be the most dominating variable for all the sites in all the four seasons over NW India. Following the net radiation, wind speed stands next important variable responsible for the observed ETo changes mainly in winter, pre and post-monsoon seasons. However, temperature is found to be the most insignificant causative variable for the ETo changes in all the seasonal

Table 2: Average (1985-2018) and decadal trend of observed weather parameters and reference evapotranspiration of semi-arid region

	Jan	Feb	Winter	Mar	Apr	May	Pre-monsoon	Jun	Jul	Aug	Sep	Monsoon	Oct	Nov	Dec	Post-monsoon	Annual
Mean																	
ET_0	89.9	109.7	199.6	142.7	172.9	187.7	503.3	175.9	138.5	125.3	137.4	577.2	135.2	111.1	93.4	339.7	1619.7
T_{max}	23.4	26.5	25.0	32.5	37.6	40.7	36.9	39.3	34.5	32.5	33.7	35.0	34.1	30.0	25.6	29.9	32.5
T_{min}	9.2	12.5	10.8	17.9	23.5	27.6	23.0	27.9	26.0	24.7	24.1	25.7	20.5	15.1	10.5	15.4	20.0
RF	4.1	9.8	13.9	5.5	7.7	13.6	26.8	60.1	165.1	169.6	79.8	474.5	11.3	5.0	2.8	19.1	534.3
RS	9.0	9.4	9.2	9.7	10.2	10.3	10.1	9.5	7.3	7.0	8.9	8.2	9.4	9.2	9.0	9.2	9.1
Trend																	
ET_0	-ve	-ve	-ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	+ve	+ve*
T_{max}	-ve	-ve	-ve	+ve	+ve	+ve	+ve	-ve	+ve	-ve	-ve	+ve	-ve	-ve	-ve	-ve	+ve
T_{min}	-ve	+ve	-ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
RF	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	+ve	+ve	-ve	+ve	-ve	-ve	-ve
RS	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	+ve	+ve	-ve	+ve	+ve	-ve	-ve	+ve	+ve

Note:+ve means positive trend: -ve means negative trend, *significant at 5 %.

Table 3: Average (1985-2018) and decadal trend of observed weather parameters and reference evapotranspiration of humid region

	Jan	Feb	Winter	Mar	Apr	May	Pre-monsoon	Jun	Jul	Aug	Sep	Monsoon	Oct	Nov	Dec	Post-monsoon	Annual
Mean																	
ET_0	99.4	111.9	211.3	160.2	189.2	210.4	559.8	181.4	135.3	121.2	133.7	571.7	144.2	116.2	101.7	362.1	1704.9
T_{max}	24.2	27.3	25.7	32.9	38.0	40.4	37.1	38.4	32.9	30.9	32.4	33.6	33.8	30.3	26.2	30.1	32.3
T_{min}	8.6	11.1	9.9	16.2	21.6	26.4	21.4	27.2	25.3	24.2	23.1	25.0	19.2	14.4	10.0	14.5	18.9
RF	21.0	12.9	33.9	5.7	7.2	13.4	26.2	68.6	236.5	241.4	125.3	671.9	21.3	8.1	3.9	33.3	765.3
RS	12.0	14.2	13.1	16.6	18.7	19.6	18.3	17.5	12.9	11.9	14.2	14.1	14.5	12.7	11.5	12.9	14.7
Trend																	
ET_0	-ve	-ve	-ve	+ve	+ve	-ve	+ve	-ve	+ve	-ve	-ve	-ve	+ve	-ve	-ve	-ve	-ve*
T_{max}	-ve	-ve	-ve	+ve	+ve	-ve	-ve	-ve	+ve	-ve	+ve	-ve	-ve	-ve	-ve	-ve	-ve
T_{min}	+ve	+ve	+ve	+ve	+ve	+ve	+ve	-ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
RF	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	-ve	+ve	+ve	+ve	-ve	+ve	+ve	+ve	-ve
RS	-ve	+ve	-ve	-ve	-ve	-ve	-ve	-ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	+ve	+ve

Note:+ve means positive trend: -ve means negative trend, *significant at 5 %.

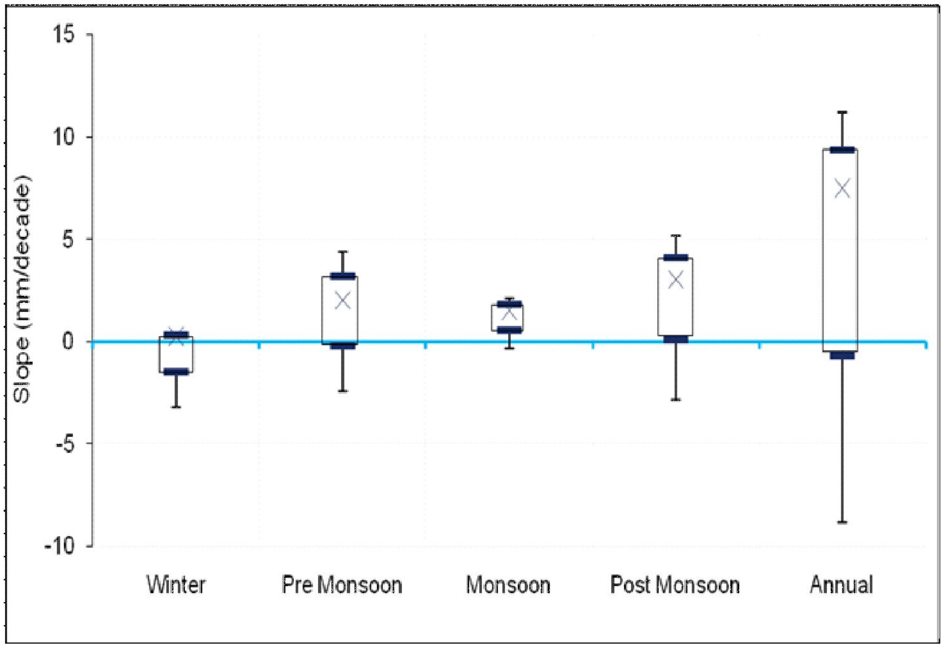

Fig.1: Box and Whisker plot of decadal slopes of the annual and seasonal ETo. The dark line on upper and lower side of box denotes the value of 25 and 75 percentile and the cross inside the box denotes the median and the whiskers show the 5 and 95 percentile value

time scales. Chattopadhayay and Hulme (1997) reported that although most parts of India except Gujarat and a few parts on the west coast witnessed temperature increase, both Epan and PET showed decreasing trends over a majority of places in India. They also found that the relative humidity was strongly associated with changes in Epan. The increasing trends in RH counter-balanced the effect of rising temperature on Epan by hampering the evaporative process. Bandyopadhyay *et al*. (2009) also found decreasing trends in ETo over various places in India. They attributed such downward trends in ETo to the significant steady decrease in wind speed and significant increase in relative humidity. Wind is strongly related to decrease in Epan during pre-monsoon and monsoon seasons over NE India. Sunshine duration was also found by Jhajharia *et al*. (2009) to be the most influencing parameter responsible for the observed changes in Epan in winter, pre-monsoon and monsoon seasons. A positive correlation is observed with Tmax at all study sites and regions on annual basis (Table 4). During all the seasons, a positive correlation is observed with Tmax, Tmin and Rs in all the regions. The trend analysis results reveal a decreasing trend in ETo at most of the sites but no significant trend in rainfall over NW India and similar results were observed by Jhajharia *et al*. (2012) for NE India and Bandyopadhyay *et al*. (2009) for all over India during 1971–2002.

Trend analysis of ETo and meteorological parameters

Annual trends

The Mann-Kendall test results of monthly, seasonal and annual ETo and maximum temperature (Tmax), minimum temperature (Tmin) and solar radiation (Rs) in different study regions (Table 1, 2 & 3) revealed that out of 18 study sites, 10 sites show significant decreasing trend ranging from 33 mm to 53 mm/decade. There is a significant decrease in ETo (48.3 mm/decade) over north west India. The box and whisker plot of slopes of annual ETo are presented in Fig.1. The median of ETo slopes lies above zero line and also the maximum of ^{2} is located above zero line which indicates an increasing trend at some sites and decreasing trend at other sites. The variability of ^{2} below the median is more compared to corresponding value below the median. The lower most point is at 9.2 mm per decade pointing that the crop water requirement is stable and more likely to increase in crop water requirement in future. The annual Tmax and Tmin trends are presented in Table 1, 2 and 3. There is increasing trend in Tmax at arid and semi-arid regionswhile in humid region and North West India decreasing trend is observed as a whole on annual basis. An increasing trend in Tmin is observed at all the regions and NW West India as a whole on annual basis while Tmax and Rs showed a decreasing trend. When the trends in Tmax and ETo are compared, it is

Table 4: Correlation of Tmax, Tmin and Rs with ETo at annual and seasonal basis at different study sites and regions.

Sites	Annual			Winter			Pre-monsoon			Monsoon			Post monsoon		
	Tmax	Tmin	Rs	Tmax	Tmin	Rs	Tmax	Tmin	Rs	Tmax	Tmin	Rs	Tmax	Tmin	Rs
Sriganganagar	0.82	0.48	0.84	0.91	0.00	0.36	0.94	0.78	0.44	0.77	0.25	0.97	0.94	0.05	0.80
Hanumangarh	0.82	0.53	0.75	0.93	0.02	0.79	0.82	0.65	0.81	0.74	0.12	0.88	0.96	-0.01	0.80
Bikaner	0.74	-0.23	0.85	0.91	0.04	0.77	0.67	0.14	0.76	0.80	-0.12	0.92	0.88	-0.25	0.80
Jhunjhunu	0.78	-0.49	0.95	0.94	-0.44	0.95	0.75	-0.31	0.91	0.71	-0.54	0.97	0.93	-0.41	0.96
Nagaur	0.84	-0.66	0.97	0.95	-0.43	0.94	0.81	-0.44	0.93	0.74	-0.62	0.97	0.89	-0.49	0.93
Sikar	0.76	-0.56	0.91	0.92	-0.44	0.80	0.76	-0.35	0.91	0.73	-0.53	0.97	0.91	-0.36	0.83
Jodhpur	0.80	0.31	0.72	0.92	0.17	0.62	0.81	0.53	0.66	0.85	0.45	0.94	0.92	-0.23	0.54
Arid Region (Avg.of above 7 locations)	0.74	0.45	0.26	0.87	0.11	0.56	0.85	0.74	0.08	0.81	0.32	0.56	0.83	0.06	0.62
Jaipur	0.84	0.24	0.85	0.94	0.30	0.53	0.88	0.57	0.61	0.85	0.33	0.96	0.91	-0.03	0.82
Ajmer	0.86	0.50	0.90	0.93	0.64	0.68	0.84	0.62	0.67	0.88	0.44	0.97	0.91	0.48	0.85
Tonk	0.72	-0.57	0.50	0.67	-0.07	0.34	0.64	-0.46	0.50	0.88	-0.22	0.60	0.92	-0.35	0.58
Semi-Arid Region (Avg. of above 3 locations)	0.83	0.26	0.89	0.89	0.46	0.61	0.82	0.44	0.68	0.90	0.37	0.96	0.93	0.13	0.82
Sawai Madhopur	0.56	-0.23	0.80	0.89	0.19	0.52	0.77	0.05	0.61	0.67	-0.13	0.89	0.85	-0.02	0.83
Dholpur	0.78	0.09	0.84	0.95	0.22	0.95	0.87	0.46	0.92	0.69	0.09	0.76	0.84	0.08	0.77
Kota	0.74	0.73	0.81	0.91	0.62	0.82	0.63	0.71	0.73	0.88	0.72	0.93	0.86	0.41	0.68
Bhilwara	0.67	-0.02	0.70	0.83	0.00	0.50	0.78	0.47	0.38	0.82	0.47	0.92	0.83	-0.40	0.70
Chittorgarh	0.67	-0.02	0.71	0.82	-0.01	0.51	0.78	0.47	0.38	0.82	0.46	0.92	0.82	-0.40	0.70
Udaipur	0.73	0.13	0.88	0.75	-0.13	0.69	0.74	0.41	0.50	0.82	0.52	0.94	0.81	-0.35	0.87
Dungarpur	0.98	-0.25	-0.94	1.00	0.02	-0.89	0.99	-0.25	-0.94	0.11	0.26	0.28	0.99	-0.24	-0.93
Banswara	0.69	-0.04	0.69	0.81	-0.06	0.50	0.75	-0.05	0.64	0.62	0.20	0.86	0.86	0.05	0.78
Humid Region (Avg.of above 8 locations)	0.86	-0.05	0.06	0.95	0.08	0.02	0.87	0.27	0.06	0.84	0.45	0.78	0.92	-0.31	0.38

observed that there is similar trend insemi-arid, humid and NW India and reverse trend at arid region which led us to probe further to find the parameter acting as a driving force behind ETo. Hence, the trends in Rs are also analysed. There is similar trend in ETo and Rs in arid region indicating influence of Rs on ETo. The decreasing trend in ETo is attributed to decrease in Rs and rainfall.

Seasonal trends

Anon-significant decreasing trend is observed atmost of the study sites, regions and NWIndia as a whole during most of the seasons (Table 1, 2 and 3). It is interesting to note that in NW India, the median lines (50 percentile) and third quartile (75 percentile) are located above zero in all the seasons except winter season (Fig.1). The end points of whisker line from the top during all the seasons are located below zero line clearly indicating a marginal decreasing trend in ETo over North West India. The lowest median slopes indicate less variability. The distance between the median and 75 percentile value (the upper top of boxes) is smaller than the corresponding distance between the median and the 25-percentile value (lower most bottom of boxes) in all the seasons. This means that the variability of slopes for the median till 25 percentiles is greater than that of 75 percentiles till 50 percentiles.The seasonal trend analyses of Tmax and Tmin (Table 1, 2 and 3) showed decreasing trend in Tmax and Rs while increasing trend in Tmin is observed at all the regions during winter and post monsoon season. An increasing trend in Tmax, Tmin and decreasing trend in Rs are observed at most of the regions and NW India during pre-monsoonand monsoon season. There is similar trend in ETo, Tmax and Tmin in most of the study sites in various seasons. Concomitant ETo decrease and temperature increase are observed at NW India (during winter and pre-monsoon season) and arid region (during monsoon and post monsoon season). Seasonal trends in Rs (Table 1, 2 and3) show an increasing trend at few study sites during different seasons. In the humid region, the concomitant ETo decrease and Rs increase are observed during monsoon and post monsoon seasons probably because the increase in Rs might have effectivelyprevailed only for two to three hours a day which didn't contribute in ETo. Seasonal decrease in ETo despite increase in temperatures may be attributed to decrease in Rs and may be relatively higher wind speed.

Monthly trends

There is decreasing trend of ETo at all study sites during January and February (Table 1,2 and 3). During March and April, an increasing trend is observed in all the regions while during May and June, decreasing trend is observedover all the regions (except semi-arid region) which could be attributed to late onset of monsoon. An increasing trend is observed at all the regions and NW India as a whole during July due to increase in rainfall.Though NW India as a whole showed decreasing trend in ETo in most of the months, an increasing trend during monsoon months may be alarming as it is the time of sowing or vegetative phase for rainfed *kharif* crops. This situation will exaggerate in case of drought or below normal rainfall conditions. To meet high evapotranspiration, there will be more pumping of ground water for irrigation which may not be in favour of water bearing strata and water balance in the area.

CONCLUSION

Rajasthan state being in the proximity of desert is quite hot and warm. But from agricultural point of view, it is one of the major producers of many crops like mustard, pearl millet, Gram, maize, sorghum, groundnut, guar, barley and spices. The trend analysis of reference evapotranspiration for 18 districts of Rajasthan (North West India) during last 3 decades (1985–2018) concluded that - (i) The average annual ETo was lowest in semi-arid region and highest in arid region. (ii) A significant decreasing trend in ETo is observed during all the seasons over NW India which is associated with increasing productivity of major crops good crop growth and development. (iii) During winter and pre-monsoon seasons, increasing trend in Tmax and Tmin is observed which draws attention for possible negative influence on *rabi* crop production. (iv) Annual ETo is also found to show a decreasing trend despite an increase in temperatures.This could possibly be due to the fact that the decrease in solar radiation and wind speed might have offset the impact of warming.

Further, this study is very useful for the development of existing water assets, designing of irrigation system, irrigation scheduling and water balance studies as well as in water resources planning besides recognizing the importance of evapotranspiration as the main driving force of the hydrological cycle.

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