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Trend of Reference Crop Evapotranspiration and its Correlation with Climatic Parameters in Khulna and Rajshahi Districts of Bangladesh

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Abstract

Reference crop evapotranspiration (ET_O) is an important hydro-meteorological phenomenon, which is influenced by changing climate. This study estimated the trends ET_O and identified the correlation of changes in ET_O with climatic parameters in Khulna and Rajshahi districts of Bangladesh. Daily observed climatic parameters of thirty years (1984–2013) were used in CropWat model to estimate changes in monthly and seasonal ET_O. Trend analysis of ET_O and climatic parameters were done by Mann-Kendall test and Sen's slope estimation. Correlation between ET_O and climatic parameters were analyzed. The results showed a decreasing trend of ET_O over most of the period of the year in Khulna and Rajshahi districts. On monthly basis estimation, decreasing trends of relative humidity, wind speed and sun shine hours in Khulna district, and decreasing trends of wind speed and sun shine hours in Rajshahi district played the dominant roles for the decreasing rate of ET_O under recent climate change. On seasonal basis estimation, decreasing trends of relative humidity, wind speed and sun shine hours in Khulna district, and decreasing trends of wind speed and sun shine hours in Rajshahi district played the dominant roles for the decreasing rate of ET_O under changing climatic condition. Changes in ET_O were most strongly correlated with sun shine hours and most weakly with minimum temperature for both Khulna and Rajshahi. Wind speed was most strongly correlated with ET_O for Dry/Rabi season. The findings of this study would be useful for agricultural water management of Bangladesh.

Key words: Climate Change, Climatology, Evapotranspiration, Trend analysis

Introduction

On the global level, impact of natural hazards and disasters in recent decades are staggering. Most of the climatic models project a possible decrease in precipitation in dry period and a possible increase during monsoon in South Asia and lead to extreme events. Bangladesh is not also an exception and has already started to face climate change induce problems (National Drought Mitigation Center 2006; Habiba *et al*., 2011; Islam *et al*., 2021; Bianchi *et al*., 2021; Acharjee *et al*., 2021). The North-western Bangladesh is drought prone and facing acute climate variability and extreme events, which are manifested by both spatial and temporal distribution of water resources available throughout the region (Shariot-Ullah, 2019). It is a great threat for the food security and the overall socio-economy of the region. The Southwest coastal region of Bangladesh, being under tidal influence and has a unique brackish water ecosystem. The region, having vast low-lying areas enclosed by man-made polders, is considered to be highly vulnerable to climate change induced hazards. The South-West region of Bangladesh is basically a saline affected area. Vulnerabilities to water-related fiascos are transcendently because of intense atmosphere inconstancy and outrageous occasions, which are showed by both spatial and fleeting dispersion of water assets accessible all through the area (Mondal *et al*., 2013; Shariot-Ullah *et al*., 2021).

Climate change has rigorous impacts on crop-water demand and a number of other systems, such as hydrological systems and ecosystems. Climate change induced global warming due to enhanced greenhouse effect is expected to cause major changes in various climatic variables, such as absolute humidity, precipitation, and net terrestrial and global solar radiation, and has possibility to spatio-temporally impact on water resources both surface and ground (Jones *et al*., 1992; IPCC 2007). Climate change is projected to have significant impacts on agriculture including changing in growing seasons and improved production in colder region in association with the high temperature (Eitzinger *et al*., 2009; AEA Energy and Environment 2007; Ben-Gai *et al*., 1999). Bangladesh is also under threat of the climate change, elevated greenhouse gas and temperature induced droughts in Northern Bangladesh and other climate change related hazards including salinity in the southern Bangladesh which is threatening the food security by risking agriculture (Shahid *et al*., 2008; Schlenker *et al*., 2007; Dasgupta *et al*., 2015; Uddin and Saleque 2008; Haque *et al*., 2015). So, a great challenge for the coming decades will be the task of increasing food production under water shortage due to climate change.

Demand of water for irrigation is considerably sensitive to climate change and the concept of reference crop evapotranspiration (ET_O) was introduced to study the evaporative demand of the atmosphere. It is one of the most important hydrological parameters for calculating crop water demand, scheduling irrigation systems, preparing input data to hydrological water-balance models, regional water resources assessment, and planning and management for a region and/or a basin but it influenced by the climatic parameters (Blaney *et al.* ,1950; Brown *et al*., 2001; Xu *et al*., 2002; C. yu Xu *et al*., 2006; C. Y. Xu *et al*., 2006; Karim 2010). Increase in temperature, wind speed and sunshine hour cause increased reference crop evapotranspiration. While increase in relative humidity decreases reference crop evapotranspiration. The use of ET_O permits a physically realistic characterization of the effect of the microclimate of a field on the evaporative transfer of water from the soil-plant system. It provides a measure of the integrated effect of radiation, wind speed, temperature and humidity on evapotranspiration (Karim *et al*., 2008). If ET_O decreases, crop water demand also decreases. Consequently, irrigation scheduling systems also change. So, the changes in the rates of ET_O due to climate change would be of great significance for water resource planning for irrigation on agricultural land.

Rainfall, temperature, relative humidity, wind speed and sunshine duration are the primary elements of climate, which regulates growth and development of crops. The vulnerability and risk of crop production due to climate change and climatic variability can be minimized if recent and future climate change can be adequately evaluated and predicted. Unfortunately, very limited studies on climate change, especially with respect to temperature and rainfall have been carried out so far in Bangladesh (Rahman *et al*., 1997; Mia 2003; Islam *et al*., 2004; Anwar 1999; Ali *et al*., 2007; Ara *et al*., 2005). Since, climate change is a highly complex process, repeated investigations on these aspects will be useful for further crop planning in Bangladesh (Karim, 2010).

Recently, scarcities of surface water in dry season, groundwater mining, pollution of surface water and groundwater have become the common phenomena of Bangladesh. Beside this, conjunctive use of water is also increasing day by day due to rapid growth of water demand to different sectors. So, proper management of irrigation water on crop land has become a vital concern in recent years for irrigation engineers, hydrologist, agronomist, ecologist and water policy makers. To comprehend the changes in the rates of ET_O due to climate change, evapotranspiration and hydrologic budget would be of great significance for agricultural water resource planning effectively (Ayub *et al*., 2011). In this regard, a research was intended to carry out to analyze the long-term trends of agro-climatic parameters and reference crop evapotranspiration and estimate the correlation of reference crop evapotranspiration with climatic parameters on monthly and seasonal basis to understand how changes in climatic conditions affect reference crop evapotranspiration.

Materials and Methods

Study area

The study area Khulna and Rajshahi districts are located in the Southwest and Northwest hydrological regions of Bangladesh, respectively (Bengal Institute 2021; Mojid et al. 2019). Khulna is located in between 21°41'–23°00' N latitudes and 89°14'–89°45' E longitudes and Rajshahi is located in between 24°07'–24°43' N latitudes and 88°17'–88°58' E longitudes. The predominant soil textures are clay loam soil and silty clay in Khulna district and the predominant soil textures are loamy and clayey in Rajshahi district. Khulna has relatively high humidity (80–90%). The annual mean temperature varies from 12.5 °C minimum to 35.5 °C maximum and the mean annual rainfall is around 1710 mm (Hossain et al. 2019; Rashid et al. 2014). Rajshahi district is characterized by humid and tropical climate. The maximum mean temperature varies from 32–36 °C and the minimum temperature varies from 7–16 °C. The annual rainfall is 1448 mm in this region (Ferdous and Baten, 2012; BMD, 2013; Belda *et al*., 2014).

Data collection

Daily climate data on maximum and minimum temperature, relative humidity, wind speed and sunshine hour for Khulna and Rajshahi districts for the period of 1984 to 2013 were collected from Bangladesh Meteorological Department (BMD). A monthly overview of collected climate data for Khulna and Rajshahi were presented in **Table 1** and **Table 2**, respectively.

Reference crop evapotranspiration estimation

The daily values of different parameters and constants of FAO Penman-Monteith method were used to compute daily ET_O, and the monthly values of different parameters and constants of FAO Penman-Monteith method were used to compute monthly ET_O by FAO Penman-Monteith method as:

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

Where,
ET_O = reference crop evapotranspiration, mm day^{-1},
R_n = net radiation at the crop surface, M J m^{-2}day^{-1},
G = soil heat flux density, M J m^{-2}day^{-1},
T = air temperature at 2 m height, °C,
u_2= wind speed at 2 m height, ms^{-1},
e_s = saturation vapour pressure, kpa,
e_a = actual vapour pressure, kpa,
(e_s-e_a) = saturation vapour pressure deficit, kpa,
Δ = slope vapor pressure curve, kpa°C^{-1}, and
γ= psycrometric constant, kpa°C^{-1}.

The net radiation at a crop surface was calculated by the following equation in CropWat.

$$R_n = R_{ns} - R_{nl} \quad (2)$$

Where,
R_n = net radiation at a crop surface, M J m^{-2} day^{-1}.,
R_{ns} = incoming net short-wave radiation, M J m^{-2} day^{-1} and
R_{nl} = net long-wave radiation, M J m^{-2}day^{-1}.

Table 1. Monthly average and standard deviation of minimum and maximum temperatures (°C), relative humidity (%), wind speed (km/day) and sunshine hour in Khulna districts of Bangladesh.

Parameters		Months											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Minimum temperature	Avg.	12.2	15.6	20.6	24.3	25.4	26.3	26.2	26.3	25.9	24.1	19.4	14.2
	Std.	1.1	1.2	1.3	1.0	0.8	0.7	0.5	0.4	0.4	0.7	1.1	1.0
Maximum temperature	Avg.	25.3	28.9	33.2	34.9	34.8	33.3	32.1	32.3	32.5	32.2	30.0	26.7
	Std.	0.9	1.2	1.2	0.9	0.8	1.0	0.5	0.6	0.5	0.7	0.6	0.8
Relative humidity	Avg.	73.00	70.5	70.4	74.4	78.2	83.7	86.3	85.5	85.2	81.5	75.7	73.9
	Std.	2.8	2.7	3.5	3.3	2.3	2.2	1.6	1.8	1.8	2.6	2.3	2.8
Wind speed	Avg.	108.1	112.3	145.4	180.9	171	160.2	152.2	141.6	113	85.0	75.2	85.9
	Std.	43.6	43.6	63.8	80.8	77.6	68.2	65.1	54.2	42.0	31.6	32.8	34.7
Sunshine hour	Avg.	7.3	8.1	8.3	8.5	7.6	4.7	3.7	4.4	4.7	6.9	7.7	7.4
	Std.	0.9	0.8	0.6	0.5	1.2	1.0	0.8	0.9	0.8	1.1	1.0	1.1

Table 2. Monthly averages, standard deviation, maximum and minimum values of daily minimum and maximum temperatures (°C), relative humidity (%), wind speed (km/day) and sunshine hour in Rajshahi districts of Bangladesh.

Parameters		Months											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Minimum temperature	Avg.	10.4	13.2	18.0	22.9	24.4	25.9	26.1	26.2	25.6	22.9	17.5	12.7
	Std.	1.1	1.0	1.2	1.1	0.9	0.5	0.5	0.4	0.5	0.9	1.1	1.1
Maximum temperature	Avg.	24.1	28.0	33.3	36.2	35.2	34.0	32.6	32.9	32.6	31.7	29.3	25.7
	Std.	1.1	1.4	1.4	1.7	1.4	1.2	0.7	0.6	0.8	0.7	0.5	0.9
Relative humidity	Avg.	78.5	71.6	63.0	65.8	75.9	83.4	87.2	86.5	86.6	83.5	79.2	78.9
	Std.	2.7	3.8	5.4	6.0	4.2	2.8	1.7	1.3	1.9	2.5	2.3	2.8
Wind speed	Avg.	100.6	111.4	122.0	150.9	158.2	154.0	145.3	132.6	124.3	100.0	95.9	97.2
	Std.	17.4	24.8	30.4	49.5	58.5	56.2	48.8	39.5	35.8	20.8	20.1	16.8
Sunshine hour	Avg.	6.7	8.2	8.3	8.2	7.2	5.3	4.4	5.0	5.5	7.2	7.9	7.0
	Std.	1.0	0.7	0.6	0.5	1.0	0.9	0.8	0.9	0.8	1.0	0.8	1.3

Seasonal analysis of reference crop evapotranspiration

Three cropping seasons and two climatic seasons were selected in this study for seasonal reference crop evapotranspiration estimation (Table 3).

Table 3. Details of the season for seasonal analysis of reference crop evapotranspiration.

	Season	Duration	Major crops
Crop season	Kharif-1	Mid-March to Mid-July	Aus rice, jute, vegetables etc.
	Kharif-2	Mid-July to Mid-November	Aman rice, groundnut, mungbean, blackgram, vegetables etc.
	Rabi	Mid-November to Mid-March	Boro rice, wheat, maize, potato, lentil, vegetables etc.
Climate	Wet season	May to October	Aus & Aman rice, jute, groundnut, mungbean, blackgram, vegetables etc.
	Dry season	November to April	Boro rice, wheat, maize, potato, lentil, vegetables etc.

Trend analysis

MAKESENS model of Mann-Kendall test and Sen's slope estimate for the trend of time series of annual data was used in this study. The non-parametric Mann-Kendall test is used for testing the presence of monotonic increasing or decreasing trend. The non-parametric Sen's method is used for estimating the slope of a linear trend. The Mann-Kendall test determines a statistics called Z-statistics, which is a deterministic index of the trend. The Sen's slope of the trend lines reveals if the trend is increasing or decreasing. Also, the slope determines the magnitude of the trend.

Correlation coefficient estimation

When an increase or a decrease in one variable is accompanied by an increase or a decrease in another variable, the two variables are said to be correlated and the phenomenon is known as correlation. Correlation coefficient is a measure of the relationship between two variables, which are at an interval or a ratio level of measurement and are linearly related. Correlation coefficient (r_{xy}) was computed by (Ray and Mondal, 2004):

$$r_{xy} = \frac{N\sum XY-(\sum X)(\sum Y)}{\sqrt{[N\sum X^2-(\sum X)^2][N\sum Y^2-(\sum Y)^2]}} \qquad (3)$$

Where,
r_{xy} = correlation coefficient,

X= determining parameters of reference crop evapotranspiration,

Y= reference crop evapotranspiration,

N= number of observation,

Results and Discussion

Trends of changes in monthly reference crop evapotranspiration (ET_O) and climatic parameters

Decreasing trends of reference crop evapotranspiration (ET_O) were found in most of the months in Khulna (**Table 4**).

Table 4. Mann-Kendall trends of climatic parameters, radiation and reference crop evapotranspiration (ET_O) on monthly basis in Khulna during 1984–2013.

Month	Minimum temperature	Maximum temperature	Relative humidity	Wind speed	Sun shine hours	Radiation	ET_O
January	2.34*	–1.52	1.54	–3.89***	–2.99**	–3.07**	–4.07***
February	3.26**	0.32	–1.30	–4.32***	–0.16	–0.21	–2.66**
March	2.36*	–1.06	–0.72	–4.01***	–1.96*	–2.11	–3.46***
April	1.93+	0.14	–2.39*	–5.09***	–0.27	–0.23	–2.46*
May	2.15*	2.87**	–2.86**	–4.76***	–0.68	–0.77	–2.00*
June	2.35*	2.02*	–1.97*	–5.39***	–0.64	–0.71	–0.66
July	3.09**	2.66**	–1.48	–5.52***	1.99*	1.95+	1.34
August	1.78+	1.56	–0.04	–4.87***	–0.66	–0.57	–1.50
September	3.09**	1.58	–1.43	–4.76***	0.79	0.91	0.14
October	1.76+	0.88	–0.11	–4.02***	–1.73+	–1.70+	–2.45*
November	1.25	1.22	–0.60	–3.80***	–0.80	–0.88	–2.44*
December	2.48*	–1.41	1.30	–4.09***	–3.34***	–3.38***	–4.07***

[+, *, ** and *** signs indicate significant at 0.10, 0.05, 0.01 and 0.001 level of significance, respectively.]

Results indicate significant decreasing trends of ET_O during October to May. The highest decreasing trend of ET_O was found in January. Results also showed non-significant increasing trends of ET_O in the month of July and September. The Mann-Kendall test values indicate increasing trends of temperature and decreasing trends of relative humidity, wind speed, sun shine hours and radiation in Khulna. The trends of changes in wind speed showed comparatively more significant changes than other parameters. Significant increasing trends of minimum temperature were found in most of the months. However, non-significant trends were found in most of the months for maximum temperature.

More variation of changes in monthly reference crop evapotranspiration (ET_O) were found from estimated Sen's slope during February, March and less variation of changes in monthly reference crop evapotranspiration (ET_O) were found in April, January, November and December **(Fig. 1).** Highest variation of reference crop evapotranspiration (ET_O) rate was found in March. Lowest variation of reference crop evapotranspiration (ET_O) rate was found in December.

More variation rates of reference crop evapotranspiration (ET_O) were found from estimated Sen's slope during May & June and less variation of changes in monthly reference crop evapotranspiration (ET_O) were found in July, August, September and October **(Fig. 2).** Highest variation of rates of reference crop evapotranspiration (ET_O) rate was found in May. Lowest variation of reference crop evapotranspiration (ET_O) rate was found in October. The estimated Sen's slope indicate decreasing trends of reference crop evapotranspiration (ET_O) in Khulna for most of the months and increasing trends were found only in July and September**.** The highest decreasing trend of ET_O was found in March. The estimated Sen's slope indicate increasing trends of temperature and decreasing trends of relative humidity, wind speed, sun shine hours and radiation in Khulna during 1984–2013. The rate of changes of wind speed is comparatively higher than other parameter. The rate of change of reference crop evapotranspiration does not differ significantly in different months of the year.

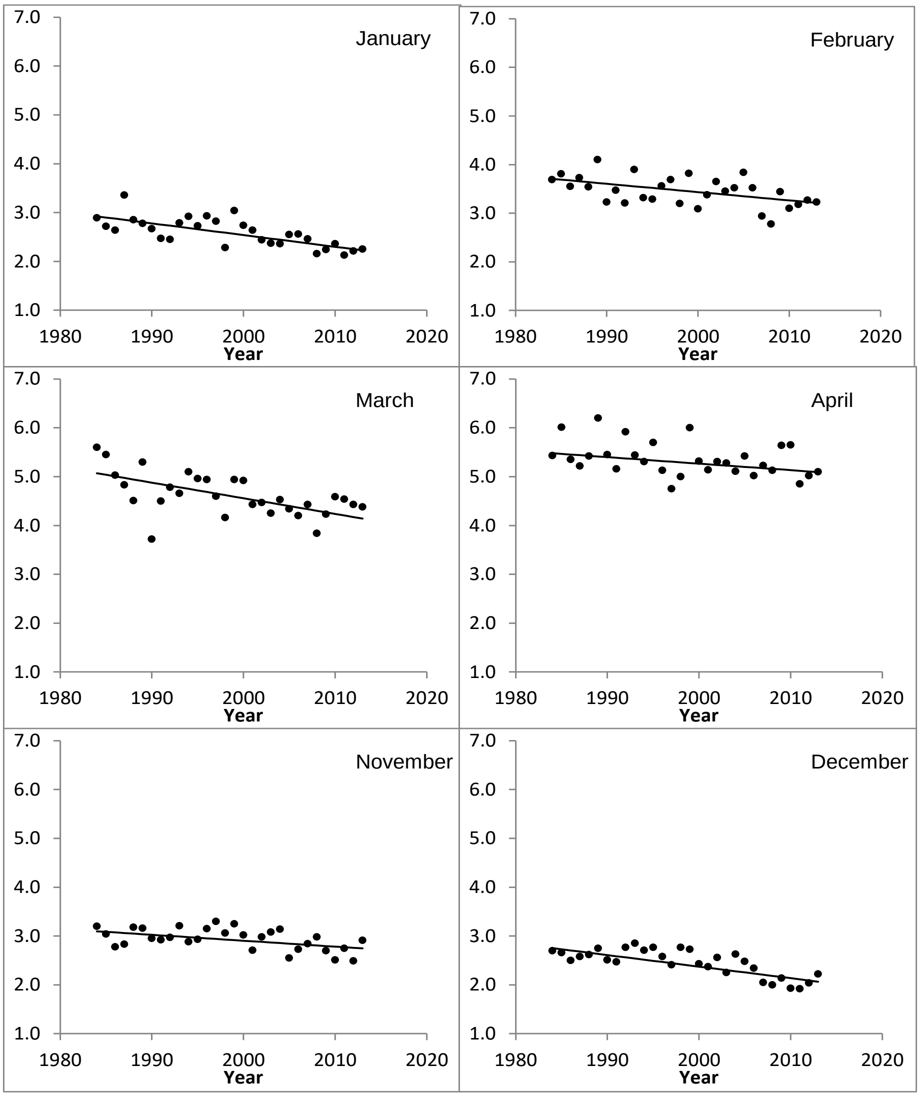

Fig. 1. Sen's slope of estimated reference crop evapotranspiration during 1984–2013 in Khulna during dry season months.

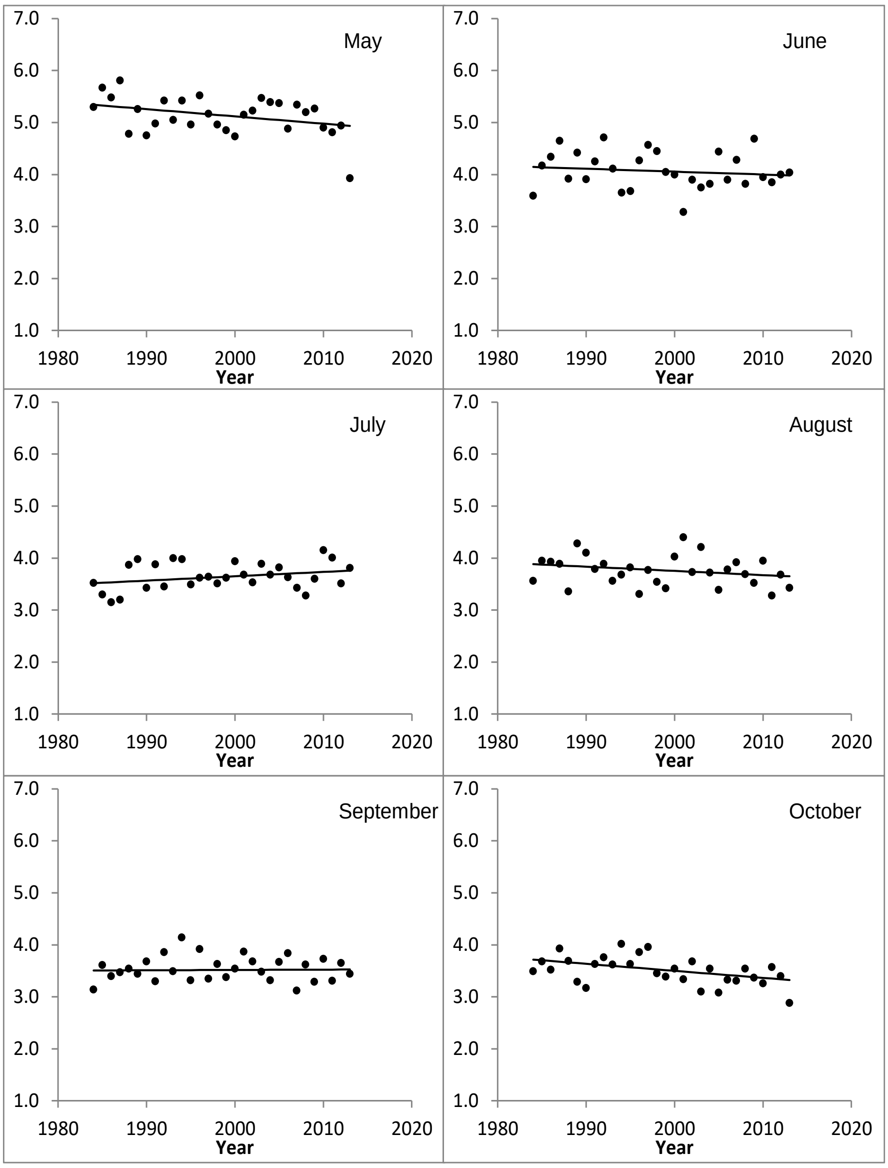

Fig. 2. Sen's slope of estimated reference crop evapotranspiration during 1984–2013 in Khulna during wet season months.

Decreasing trends of reference crop evapotranspiration (ET_O) were found in most of the months in Rajshahi (**Table 5**). Results indicate decreasing trends in January, February, March, April, May, August, October, November, December; the declining rates were significant in January, March, April, May, October, November, December. The highest decreasing trend of ET_O was found in January. Results also showed non-significant increasing trends of ET_O in the month of February, June, August and September.

The Mann-Kendall test values indicate increasing trends of temperature, relative humidity and decreasing trends of wind speed, sun shine hours and radiation in Rajshahi during 1984–2013. The trends of changes in wind speed showed comparatively more significant changes than other parameters. Significant increasing trends of minimum temperature were found in most of the months, but mostly non-significant trends were found for maximum temperature.

Table 5. Mann-Kendall trends of climatic parameters, radiation and reference crop evapotranspiration (ET_O) on monthly basis in Rajshahi during 1984–2013.

Month	Minimum temperature	Maximum temperature	Relative humidity	Wind speed	Sun shine hours	Radiation	ET_O
January	–0.50	–2.50*	2.75**	–2.84**	–4.02***	–4.05***	–4.68***
February	1.05	0.57	0.77	–3.14**	–0.70	–0.54	–1.45
March	2.09*	0.00	2.04*	–3.71***	–1.18	–1.11	–2.30*
April	2.07*	–0.82	2.13*	–5.25***	–3.02**	–3.06**	–4.19***
May	1.76+	0.38	0.75	–5.89***	0.30	0.25	–2.43*
June	2.19*	2.39*	–1.79+	–6.05***	0.95	0.81	0.05
July	4.30***	4.17***	–3.48***	–5.69***	3.28**	3.16**	3.32***
August	3.51***	2.54*	–0.97	–5.23***	–0.21	–0.29	–0.23
September	3.31***	2.70**	–0.82	–4.80***	0.82	0.95	1.00
October	0.68	0.20	0.79	–3.05**	–1.18	–1.18	–2.34*
November	0.21	0.68	1.31	–3.13**	–0.72	–0.71	–1.84+
December	0.55	–1.97*	1.64	–3.98***	–3.88***	–3.84***	–3.88***

[+, *, ** and *** signs indicate significant at 0.10, 0.05, 0.01 and 0.001 level of significance, respectively]

The highest decreasing trend of ET_O was found in April. The estimated Sen's slope indicate increasing trends of temperature, relative humidity and decreasing trends of wind speed, sun shine hours and radiation in Rajshahi during 1984–2013. The rate of changes of wind speed is comparatively higher than other parameter. The rate of change of reference crop evapotranspiration does not differ significantly in different months of the year.

Trends of changes in seasonal reference crop evapotranspiration (ET_O) and climatic parameters

Decreasing trends of reference crop evapotranspiration (ET_O) were found in every season in Khulna **(Table 6).** Results indicate significant decreasing trends of ET_O during Kharif-1, Rabi, Wet season, Dry season and Annual average. The highest decreasing trend of ET_O was found in Dry season. Results also showed non-significant increasing trends of ET_O in Kharif-2.

Table 6. Mann-Kendall trends of climatic parameters, radiation and reference crop evapotranspiration (ET_O) on seasonal basis in Khulna during 1984 to 2013.

Season	Minimum temperature	Maximum temperature	Relative humidity	Wind speed	Sun shine hours	Radiation	ET_O
Kharif-1	3.14**	1.00	–2.34*	–5.64***	–1.41	–1.36	–3.16**
Kharif-2	2.98**	2.66**	–0.97	–5.32***	–0.07	–0.02	–1.07
Rabi	3.71***	–0.45	0.56	–4.64***	–3.28**	–3.14**	–4.37***
Wet season	3.77***	3.39***	–1.99*	–5.42***	–1.41	–1.32	–2.14*
Dry Season	4.21***	–0.71	–0.79	–5.37***	–2.94**	–2.73**	–4.71***
Annual average	4.16***	1.23	–0.84	–5.35***	–2.77**	–2.59**	–4.64***

[*, ** and *** signs indicate significant at 0.05, 0.01 and 0.001 level of significance, respectively]

The Mann-Kendall test values indicate increasing trends of temperature and decreasing trends of relative humidity, wind speed, sun shine hours and radiation in Khulna during 1984–2013. The decreasing trends of changes in wind speed showed comparatively more significant changes than other parameters. The estimated Sen's slope indicate decreasing trends of reference crop evapotranspiration (ET_O) in Khulna for Kharif-1, Rabi, Wet season, Dry season and Annual average and increasing trends were found in Kharif-2 **(Fig. 3).** The estimated Sen's slope indicates increasing trends of temperature and decreasing trends of relative humidity, wind speed, sun shine hours and radiation in Khulna during 1984–2013. The change of wind speed rate is comparatively higher than other parameter. The rate of changes of minimum temperature indicates positive change. The rate of change of reference crop evapotranspiration does not differ significantly in different season of the year.

More variation of changes in seasonally reference crop evapotranspiration (ET_O) were found from estimated Sen's slope during Kharif-1, Rabi & Dry season and less variation of changes in seasonally reference crop evapotranspiration (ET_O) were found in Kharif-2, Wet season & Annual average **(Fig. 3**).Highest variation of reference crop evapotranspiration (ET_O) rate was found in Kharif-1. Lowest variation of reference crop evapotranspiration (ET_O) rate was found in Annual average.

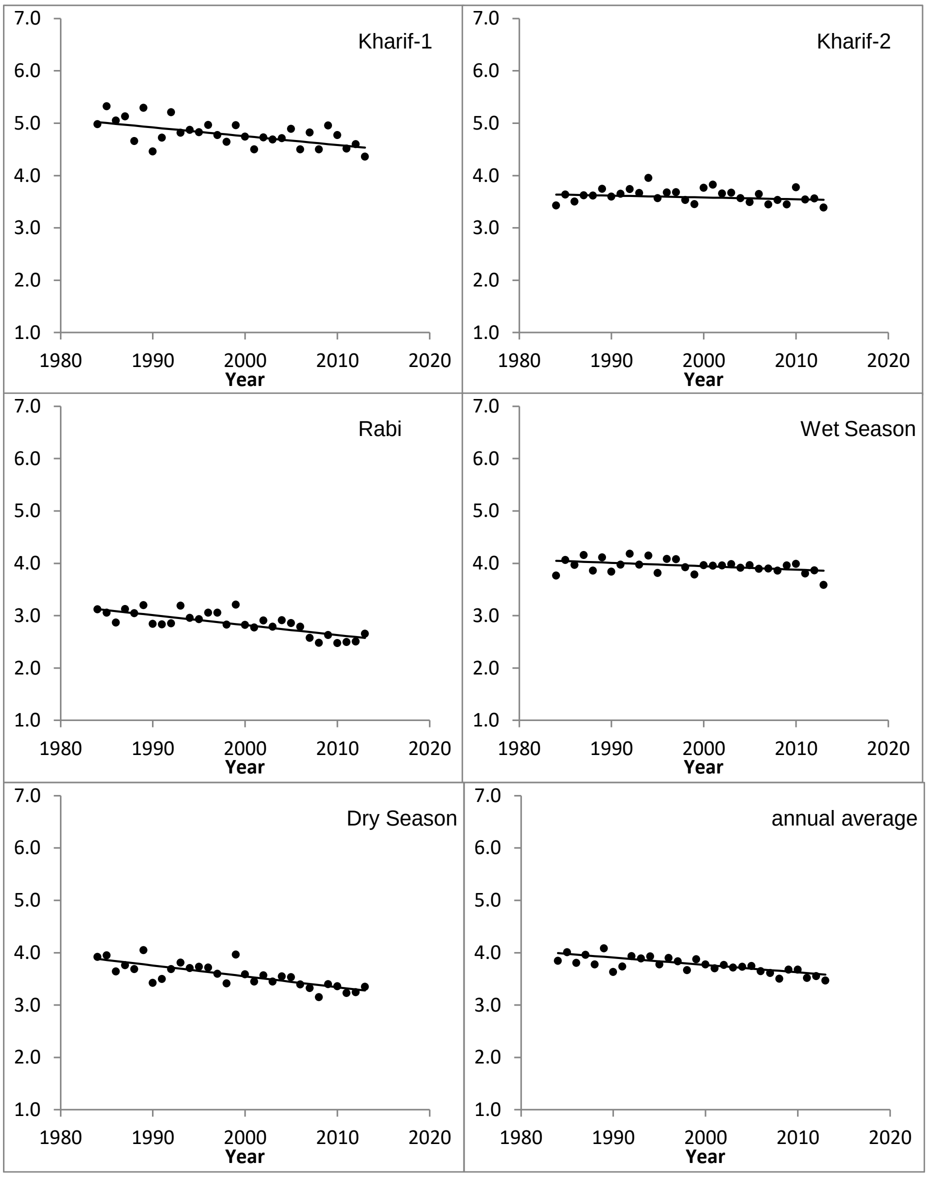

Fig. 3. Sen's slope of estimated reference crop evapotranspiration during 1984–2013 in Khulna seasonally.

Decreasing trends of reference crop evapotranspiration (ET_O) were found in most of the season in Rajshahi **(Table 7).** Results indicate significant decreasing trends of ET_O during Kharif-1, Rabi, Dry season and Annual. The highest decreasing trend of ET_O was found in Dry season. Results also showed non-significant increasing trends of ET_O in Kharif-2 and non-significant decreasing trends of ET_O in Wet season. (Akhter et al. 2019) also reported almost the same declining trend for the northern district Dinajpur.

The Mann-Kendall test values indicate increasing trends of temperature, relative humidity and decreasing trends of wind speed, sun shine hours, radiation in Rajshahi during 1984–2013. The decreasing trends of changes in wind speed showed comparatively more significant changes than other parameters.

Table 7. Mann-Kendall trends of climatic parameters, radiation and reference crop evapotranspiration (ET_O) on seasonal basis in Rajshahi during 1984–2013.

Season	Minimum temperature	Maximum temperature	Relative humidity	Wind speed	Sun shine hours	Radiation	ET_O
Kharif-1	2.86**	0.50	1.68+	–6.12***	–0.95	–1.04	–3.16**
Kharif-2	3.38***	3.86***	–1.43	–5.34***	0.91	0.96	0.91
Rabi	0.32	–1.37	3.10**	–4.12***	–4.14***	–4.03***	–4.34***
Wet season	3.61***	4.07***	–0.73	–5.96***	0.91	1.14	–0.14
Dry Season	1.75+	–1.59	3.36***	–4.53***	–4.12***	–4.03***	–4.42***
Annual average	2.96**	0.89	2.07*	–5.55***	–2.39*	–2.25*	–3.25**

[+, *, ** and *** signs indicate significant at 0.10, 0.05, 0.01 and 0.001 level of significance, respectively]

The estimated Sen's slope indicate decreasing trends of reference crop evapotranspiration (ET_O) in Rajshahi for Kharif-1, Rabi, Dry season and Annual average and increasing trends were found in Kharif-2, Wet season**.** The estimated Sen's slope indicates increasing trends of temperature, relative humidity and decreasing trends of wind speed, sun shine hours, radiation in Rajshahi during 1984–2013. The rate of changes of wind speed is comparatively higher than other parameter. The rate of changes of minimum temperature indicates positive change. The rate of change of reference crop evapotranspiration does not differ significantly in different season of the year.

Correlation coefficient of monthly ET_0 with climatic parameters

Negative correlations of reference crop evapotranspiration with minimum temperature were found for most of the months **(Table 8).** However, positive correlation between reference crop evapotranspiration and maximum temperature, sun shine hour, radiation were found for all months. Negative correlation between reference crop evapotranspiration and relative humidity were found for all months. Positive correlation of reference crop evapotranspiration with Wind speed were found for most of the months. Changes in reference crop evapotranspiration were strongly correlated with minimum temperature during April, July, and October but not so strongly correlated in other months.

Table 8. Correlation coefficients of climatic parameters and radiation with reference crop evapotranspiration in Khulna on monthly basis during 1984–2013.

Month	Minimum temperature	Maximum temperature	Relative humidity	Wind speed	Sun shine hours	Radiation
January	–0.35	0.55	–0.54	0.87	0.79	0.79
February	–0.24	0.47	–0.43	0.71	0.72	0.72
March	–0.13	0.68	–0.25	0.84	0.79	0.81
April	0.47	0.61	–0.18	0.56	0.80	0.80
May	–0.19	0.42	–0.20	0.24	0.90	0.91
June	0.02	0.67	–0.76	0.04	0.94	0.94
July	0.47	0.44	–0.58	–0.03	0.96	0.96
August	0.20	0.65	–0.66	0.01	0.98	0.98
September	0.27	0.50	–0.68	0.07	0.96	0.96
October	–0.45	0.41	–0.66	0.37	0.92	0.92
November	–0.38	0.32	–0.39	0.58	0.74	0.76
December	–0.35	0.66	–0.57	0.84	0.83	0.83

Positive correlations of reference crop evapotranspiration with minimum temperature were found for most of the months (**Table 9).** However, positive correlation between reference crop evapotranspiration and maximum temperature, sun shine hour, radiation were found for all months. Negative correlation between reference crop evapotranspiration and relative humidity were found for all months. Positive correlations of reference crop evapotranspiration with wind speed were found for most of the months. Changes in reference crop evapotranspiration were strongly correlated with minimum temperature during June and July but not so strongly correlated in other months.

Table 9. Correlation coefficient of climatic parameters and radiation with reference crop evapotranspiration in Rajshahi on monthly basis during 1984–2013.

Month	Minimum temperature	Maximum temperature	Relative humidity	Wind speed	Sun shine hours	Radiation
January	0.17	0.77	–0.77	0.72	0.88	0.88
February	–0.05	0.59	–0.85	0.66	0.71	0.70
March	0.03	0.75	–0.79	0.77	0.64	0.65
April	0.13	0.70	–0.79	0.79	0.72	0.73
May	0.11	0.67	–0.78	0.30	0.71	0.70
June	0.33	0.62	–0.68	–0.03	0.54	0.58
July	0.65	0.78	–0.76	–0.41	0.92	0.92
August	–0.03	0.63	–0.79	0.19	0.97	0.97
September	0.24	0.69	–0.74	–0.16	0.97	0.97
October	–0.06	0.65	–0.53	0.04	0.94	0.94
November	–0.04	0.48	–0.44	0.65	0.85	0.85
December	0.09	0.82	–0.74	0.67	0.94	0.94

Correlation coefficient of seasonal ET_O with climatic parameters

Negative correlations of reference crop evapotranspiration with minimum temperature were found for most of the seasons (**Table 10**). However, positive correlation between reference crop evapotranspiration and maximum temperature, sun shine hour, radiation were found for all seasons. Negative correlation between reference crop evapotranspiration and relative humidity were found for all seasons. Positive correlation of reference crop evapotranspiration with Wind speed were found for most of the seasons. Changes in reference crop evapotranspiration were strongly correlated with minimum temperature during dry season, annual average and rabi season but not so strongly correlated in other seasons.

Table 10. Correlation coefficient of climatic parameters and radiation with reference crop evapotranspiration in Khulna on seasonal basis during 1984–2013.

Season	Minimum temperature	Maximum temperature	Relative humidity	Wind speed	Sun shine hours	Radiation
Kharif-1	–0.19	0.38	0.06	0.63	0.82	0.82
Kharif-2	0.06	0.36	–0.53	0.21	0.89	0.89
Rabi	–0.55	0.42	–0.54	0.88	0.80	0.80
Wet season	–0.38	0.19	–0.46	0.24	0.87	0.87
Dry Season	–0.62	0.43	–0.28	0.88	0.83	0.83
Annual average	–0.61	0.06	–0.15	0.75	0.80	0.79

Negative correlation of reference crop evapotranspiration and minimum temperature were found for most of the seasons **(Table 11).** However, positive correlation between reference crop evapotranspiration and maximum temperature, sun shine hour, radiation were found for all seasons. Negative correlation between reference crop evapotranspiration and relative humidity were found for all seasons. Positive correlation of reference crop evapotranspiration with Wind speed were found for most of the seasons. Changes in reference crop evapotranspiration were strongly correlated with minimum temperature during annual average but not so strongly correlated in other seasons.

Table 11. Correlation coefficient of climatic parameters and radiation with reference crop evapotranspiration in Rajshahi on seasonal basis during 1984–2013.

Season	Minimum temperature	Maximum temperature	Relative humidity	Wind speed	Sun shine hours	Radiation
Kharif-1	–0.16	0.52	–0.81	0.74	0.42	0.45
Kharif-2	0.05	0.58	–0.61	–0.04	0.88	0.89
Rabi	0.13	0.59	–0.80	0.83	0.84	0.84
Wet season	–0.13	0.32	–0.65	0.11	0.68	0.69
Dry Season	–0.17	0.63	–0.83	0.89	0.74	0.76
Annual average	–0.36	0.28	–0.78	0.78	0.61	0.60

Conclusions

This study was carried out to explore the recent trends of reference crop evapotranspiration (ET_O) and identify the correlation of changes in ET_O with climatic parameters in Khulna and Rajshahi districts of Bangladesh. The governing climatic parameters of reference crop evapotranspiration changed consistently in both study areas. ET_O decreased significantly in most of the months in Khulna and Rajshahi. Decreasing trends of relative humidity, wind speed and sun shine hours in Khulna, and decreasing trends of wind speed and sun shine hours in Rajshahi played dominant role for decreasing the rate of ET_O. Changes in reference crop evapotranspiration were most strongly correlated with sun shine hours and most weakly with minimum temperature for both Khulna and Rajshahi. Wind speed was most strongly correlated with ET_O during Dry/Rabi season. Relative humidity was also more strongly correlated than maximum or minimum temperatures with ET_O. More detailed Estimation of changes in monthly and seasonal reference crop evapotranspiration in all regions of Bangladesh and projecting for the future would be useful for agricultural water demand estimation of the country.

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