

Trend of irrigation water requirement in Halda River basin of Bangladesh

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ABSTRACT

The precise estimation of irrigation water requirement trends has a vital role in water resources planning for agricultural growth and development in the Halda River basin. The trend of net irrigation water requirement and irrigation parameters was detected through twenty-seven years of data. The Mann-Kendall method was tested to find out the trend before that serial correlation test was performed with rank von Neumann ratio for lag-one auto-correlation. In case of serial- correlation significance, the pre-whitened time series data was used. Results revealed that net irrigation water requirement of Boro rice, mustard, cowpea, eggplant, tomato, wheat, maize and sweet potato was the increasing trend bounded between 8.15 mm and 2.31 mm per year at 1% level of significance. The trend was an integrative effect of wind speed, relative humidity, rainfall, and Evapotranspiration (ET_0) rather than temperature. The non-significance trend of rainfall was found in this basin ($p < 0.01$). Reference ET_0 in the dry season (Nov, Dec, Jan and Feb) had trend upward at a 1% level of significance. Hence, the upward trend predicts extra demand for irrigation water in the near future for sustainable crop production in the Halda River basin.

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I. Introduction

Halda basin is named for Halda River, which originates from Badnatali hill at Ramgarh Upazila in Khagrachari district and meets with Karnafuli River at Kalurghat, Chittagong. It covers about 175700 ha area consisting of 92 unions of 18 Upazila under Chittagong, Khagrachari, Rangamati districts (Figure 01). Land use types of this basin are settlements (14%), water body (1%), vegetation (42%), agriculture land (42%), and bare soil (1%). Total cultivable area is about 797 km² in which there are single crops about 37%, double crops about 51% and triple crops 12% (Chowdhury et al., 2020). Halda River is a source of water for irrigation, fisheries, livestock and domestic water uses like Chittagong City Corporation. For crop production, approximately 347-583 Giga Liters of water are abstracted from it (Raihan et al., 2020).

Now-a-days, water resources parameters such as rainfall, evaporation, soil moisture and stream flow of rivers change globally due to climatic impact (Zhang et al., 2007). Reference evapotranspiration (ET_0) of Bogura and Dinajpur districts is a downward trend in Bangladesh (Mojid et al., 2015). In this part, Boro rice production for water requirement and also ET_0 is the declining trend at a rate of 4.4mm per year, about 6mm per year respectively (Acharjee et al., 2017). Water resources decrease approximately 85% in the Halda River basin from 1978 to 1917 and land use pattern is also different significantly (Chowdhury et al., 2020). Thus, a trend may exist in the irrigation water and its parameters of the Halda River basin like other regions of Bangladesh due to climatic effects.

The two types of methods- parametric and non-parametric - are performed to identify the trend. In parametric method, data should be independent and normal distributed significance. In the non-parametric method, data should be independent and reasonable outliers may be allowable in hydrological and water resources fields, the non-parametric Mann-Kendall method has more acceptance for trend analysis. For the Mann-Kendall method, the randomness and independence of data is a prerequisite. So, before the Mann-Kendall test performs, time series data should be serial correlation free. Otherwise, the test shows more trends where there is no trend at all in data (Hamed & Ramachandra Rao., 1998). Acharjee et al. (2017) and Mojid et al. (2015) were less clarified about serial correlation in time series data. Therefore, in this study, time series data were tested serial autocorrelation lag-one with rank von Neumann ratio before detecting trend by Mann-Kendall test.

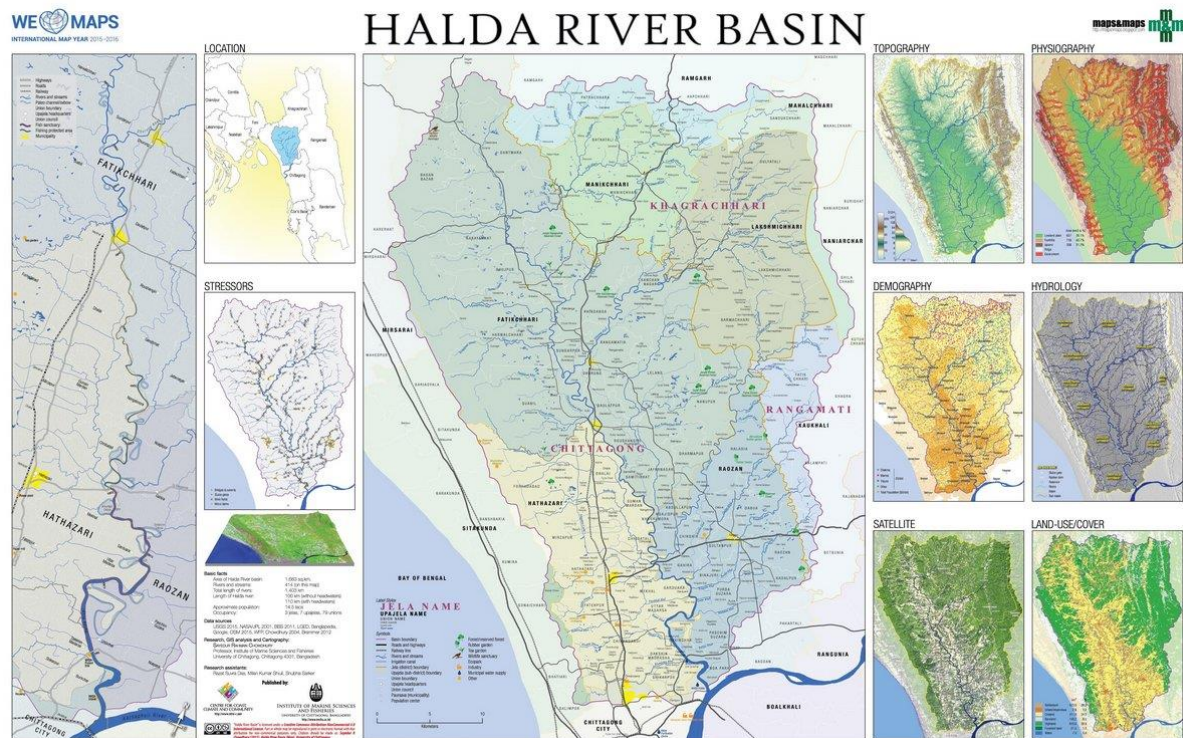


Figure 01. Halda River basin in Bangladesh (Das et al., 2015)

II. Materials and Methods

The study was performed during the period from November 2018 to January 2020 at Regional Agricultural Research Centre, Hathazari, Chittagong.

Data collection

The weather data (Temperature, Relative Humidity, Sunshine Hours, Rainfall, and Wind Speed) from 1990 to 2016 were collected from Bangladesh Meteorological Department, Agargaon, Dhaka, Bangladesh Water Development Board, Chittagong (Figure A1). Crops data and information (Figure 02) were taken from Upazila Agriculture offices, Department of Agriculture Extension, Chittagong and Bangladesh Agricultural Research Council, Farmgate, Dhaka, Bangladesh.

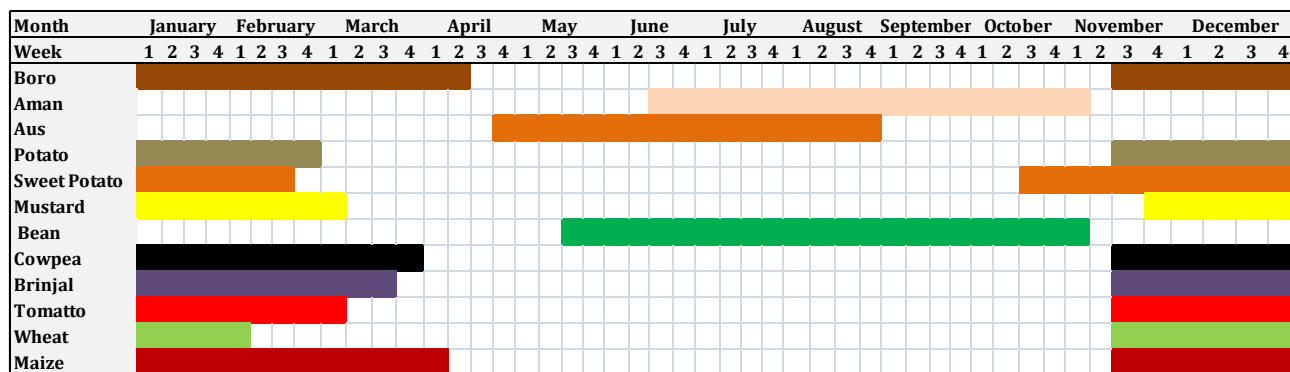


Figure 02. Crops calendar of Halda River basin

Methodology

The trend analysis was executed through time series data serial correlation test and trend detection. The procedure was shown in Figure 03.

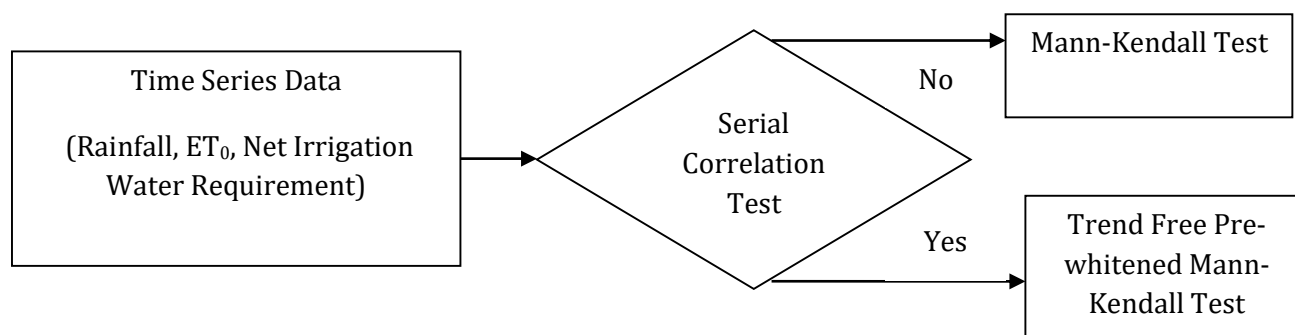


Figure 03. Flowchart for trend analysis

Determination of reference crop evapotranspiration (ET₀)

Evapotranspiration rate of a hypothetical grass crop with actively and uniformly growing, no short of water is ET₀. It was determined with the guideline of FAO Penman-Monteith method (Allen et al., 1998) shown in Eq.(1).

$$ET_0 = \frac{0.408(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{Eq.(1)}$$

Where, R_n= net radiation at crop surface (MJm⁻²day⁻¹), G= soil heat flux density (MJm⁻²day⁻¹), T= mean daily air temperature (°C), u₂= wind speed at 2m height (ms⁻¹), e_s= saturation vapour pressure (kPa), e_a= actual vapor pressure (kPa), Δ= slope of vapor pressure curve (kPa/°C), γ= psychrometric constant (kPa/°C)

Estimation of Net Irrigation Water Requirement (NIWR)

The amount of water application is required to maintain soil moisture without water stress in crop production. For rice production (Boro, Aman, Aus), net irrigation water requirement was calculated in the Eq. (2) (Brouwer & Heibloem, 1989).

$$NIWR = K_c \times ET_0 + PERC + SAT + WL - P_e \quad \text{Eq.(2)}$$

Where, K_c= crop coefficient of rice used in this research from (Acharjee, Ludwig et al., 2017), PERC= percolation and seepage i.e. 4.63 mm/day in Halda basin (BWDB, 2017), SAT= land preparation i.e.180mm, WL= water level -transplanting, vegetative, mid and late stages is 50mm, 20mm, 50mm, 0mm respectively (Brouwer and Heibloem, 1989), P_e= effective rainfall.

For non-rice production, NIWRI was calculated following eq. (3) (Savva and Frenken, 2002).

$$NIWR = K_c \times ET_0 - P_e \quad \text{Eq.(3)}$$

Where K_c = crop coefficient for non-rice crops value is taken from (Savva and Frenken, 2002), P_e = effective rainfall.

Serial correlation test

The presence of serial correlation for lag -one was performed with rank von Neumann ratio test (RVN) (Bartels, 1982).

$$RVN = \frac{\sum_{i=1}^{n-1} (X_i - X_{i+1})^2}{\sum_{i=1}^n (X_i - \bar{X})^2} \quad \text{Eq.(4)}$$

Where, X = time series data and \bar{X} = mean value of observations

RVN values range between 0 and 4. When RVN is about 2, it is random symmetrically. If $RVN < 2$, data would be positive autocorrelation and if $RVN > 2$, it indicates positive autocorrelation. If there was serial correlation, the data was pre-whitened as described in (Yue and Wang, 2002). In this research, “EnvStats” R package was run for the serial correlation test with lag-one.

Mann-Kendall test

The non-parametric Mann-Kendall test was used to detect the trend in this study. The null hypothesis (H_0): there was no trend and the alternative hypothesis (H_1): there was an increase or decrease trend. Mann-Kendall statistics: S , $V(S)$ and Z are below (Ahmad et al., 2015).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(X_j - X_i); \quad \text{sign}(X_j - X_i) \begin{cases} +1 \text{ if } (X_j - X_i) > 0 \\ 0 \text{ if } (X_j - X_i) = 0 \\ -1 \text{ if } (X_j - X_i) < 0 \end{cases} \quad \text{Eq.(5)}$$

$$V(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5) \right] \quad \text{Eq.(6)}$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases} \quad \text{Eq.(7)}$$

Where, X = time series data, n = length of data, t_p = number of ties

When $|Z| > Z_{1-\frac{\alpha}{2}}$, Null hypothesis is rejected and there was trend in data. In this study, “modifiedmk” R package are used to detect trend and “trend change” R package to change year trend with sequential Mann Kendall test.

III. Results and Discussion

Rainfall trend in Halda River basin

The peak rainfall was in June and July (Kharif season) and the lowest was in December as well as January (Rabi season) (Figure 04). Total monthly rainfall from 1990 to 2016 was tested at rank von Neumann Lag-1 Autocorrelation at 5% level of significance for serial correlation identification. Rainfall in March, June and July had non-significance in serial correlation as RVN value was about to the critical value ($RVN = 2$). The remaining months had significantly serial correlation ($p < 0.05$). The trend free pre-whitened Mann-Kendall trend test was performed for serial correlated time series data (i.e. Jan, Feb, April, May, Aug, Sept, Nov and Dec) and the test showed non-significance in trend at 1% and 5% level. The remaining months (Mar, June and July) were also non-significance in Mann-Kendall trend test as shown in Table 01. Total annual rainfall was also no trend either 5% or 1% level of significance. Hasan et al. (2014) also

found non-trending in both annual and monthly rainfall in the Chittagong region. As the Halda River basin includes this region, this study also showed non-trending in rainfall. So, the rainfall of the Halda River basin might be climate change effect-free.

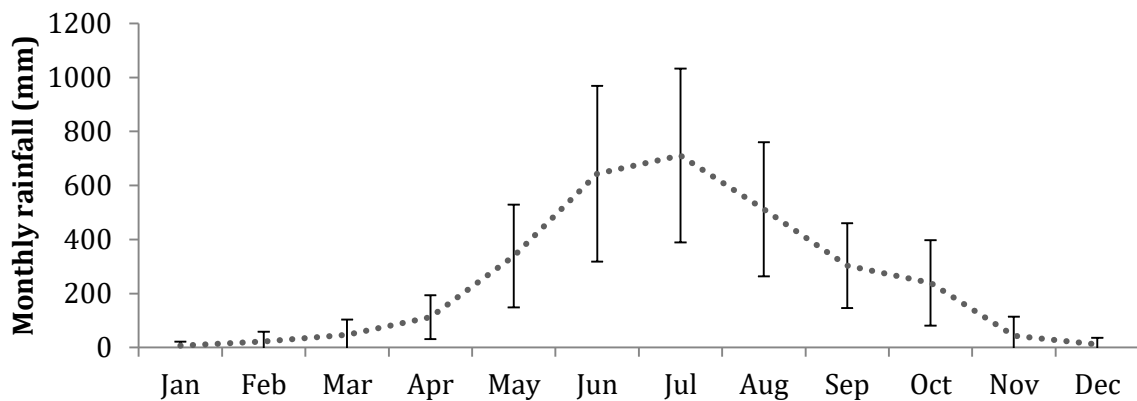


Figure 04. Total monthly rainfall average in Halda river basin from 1990 to 2016

Table 01. Results of rainfall trend analysis (1990-2016)

Month	Rank von Neumann Test for Lag-1 Autocorrelation		Trend-Free Pre-whitened Mann-Kendall Trend Test		Mann-Kendall test	
	RVN	rho	Z-Value	Sen's Slope	Z-Value	Sen's Slope
Jan	1.64	-0.18	-1.13	0.00		
Feb	1.53	0.11	-1.98	-0.42		
Mar	2.01*	0.28			-1.48	-1.40
Apr	2.69	-0.42	-0.04	-0.04		
May	2.51	-0.25	-0.66	-2.30		
Jun	2.07*	-0.10			0.17	1.80
Jul	2.00*	-0.08			0.02	0.75
Aug	1.82	0.09	0.04	0.08		
Sep	1.83	-0.08	0.84	2.43		
Oct	2.29	-0.19	0.79	3.31		
Nov	1.60	-0.10	-1.81	-1.01		
Dec	1.68	-0.13	-1.48	-0.13		
Annual	2.17	-0.16	0.53	0.01		

*, Significance at 95% confidence interval

Trend analysis of ET_0

In the Halda River basin, ET_0 was above 2 mm/day from 1990 to 2016. ET_0 in April and December were high and low (Figure 05) respectively as the daily maximum and minimum temperatures of both months were highest and lowest (above 33°C and 25°C in April; 26°C and 14°C in Dec) shown in Figure A1. As the serial correlation test of ET_0 with rank von Neumann at 5% level showed significance for all months ($RVN < 2$), thus the trend free pre-whitened Mann-Kendall test was done for trend analysis. The presence of ET_0 trend in Jan, Feb, Nov and Dec (Rabi season) were significant ($p < 0.05$) and the average sen's slope of ET_0 in these months was 0.03 i.e. .03mm/day increase in a year. During Rabi season, the ET_0 trend change year was 2012 with Sequential Mann-Kendall at a 95% confidence interval as shown in Table 02. The ET_0 trend of the Chittagong division during Rabi season was similar to Rahman et al. (2019). In the Halda River basin during this period, the upward trend of sunshine hours and wind speed with ET_0 was present (Table A2 and Table A3). The Rabi season ET_0 in this basin is more viable to the climate change effect.

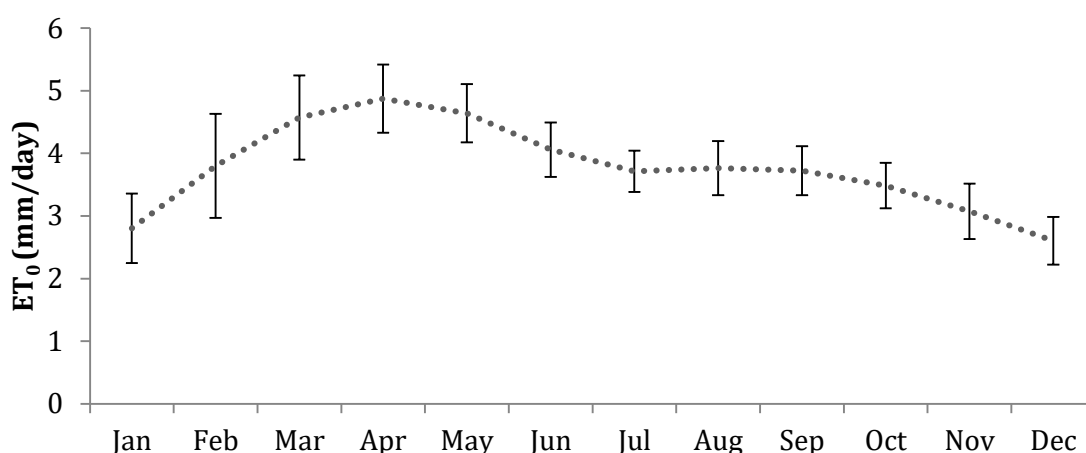


Figure 05. Average monthly reference evapotranspiration (ET₀) in the Halda River basin (1990-2016)

Table 02. Results of reference evapotranspiration (ET₀) trend analysis (1990-2016)

Month	Rank von Neumann Test for Lag-1 Autocorrelation		Trend-Free Pre-whitened Mann-Kendall Trend Test		Trend change year
	RVN	rho	Z-Value	Sen's Slope	
Jan	0.92	0.69	3.31**	0.03	2012*
Feb	0.98	0.68	2.42*	0.05	2012*
Mar	1.01	0.47	1.19	0.02	
Apr	1.08	0.51	-0.84	-0.01	
May	1.19	0.36	-1.37	-0.02	
Jun	1.17	0.28	-0.62	-0.01	
Jul	1.18	0.41	-1.81	-0.01	
Aug	1.34	0.27	-1.45	-0.02	
Sep	0.84	0.53	-1.59	-0.02	
Oct	1.10	0.40	-0.97	-0.01	
Nov	0.56	0.67	3.57**	0.03	
Dec	0.79	0.61	3.31**	0.02	2012*
Annual	0.91	0.59	1.37	0.01	

*, significance at 95% confidence interval; **, significance at 99% confidence interval; SQMK is sequential Mann-Kendall test

Trend analysis of net irrigation water requirement

There are two cropping seasons in the Halda River basin: one is Rabi (Nov-March) and other is Kharif (April to Oct). Net irrigation water requirement in the Halda basin for Boro rice production was high ranging from 776 mm to 1087 mm during 1990-2016. Usually, Rabi season crops (e.g. Boro, potato, maize) were more irrigation water demanding crops as the rainfall was low in this period. In Kharif season, the irrigation water required less -such as bean irrigation water requirement was zero (Figure 06). In the serial correlation test of net irrigation water requirement at 95% confidence interval, there was positive autocorrelation (RVN<2) which was a more probability risk to detect more trend in the Mann-Kendall test -actually none of the existence. So, trend free Mann-Kendall test was performed for trend detecting and trend change year was observed with sequential Mann-Kendall test. There was the trend in irrigation water requirement, except for Aman, Aus, and Bean during Kharif season, at 1% and 5% level of significance. The net irrigation water requirement of Boro and Maize had an upward trend (above 8 mm per year) since the sen's slope estimator was about 8. The significant trend change year at 95% confidence interval was Boro and Tomato in 2006 and 2010 respectively (Table 03). Rabi season crops were a more viable trend than Kharif season crops since the trend of minimum temperatures, sunshine hours, relative humidity, wind speed found upward- as shown in (Table A1, Table A2, and Table A3). The Rabi season crops in the Halda River basin were more sensitive to a positive trend change. So, the historical trend analysis implies that the irrigation water requirement in this basin increases and gradually Rabi crops face water stress. The water stress hampers the yield of crop and this basin would fall into food security risk (Steduto et al., 2012). Ahammed et al. (2020) had also observed that the trend

of water stress in Chittagong region was upward. The stream of the Halda River meets up the demand for irrigation, aquaculture, domestic and minor industries. So, there should be the optimal water distribution in the Halda River basin due to climatic effects.

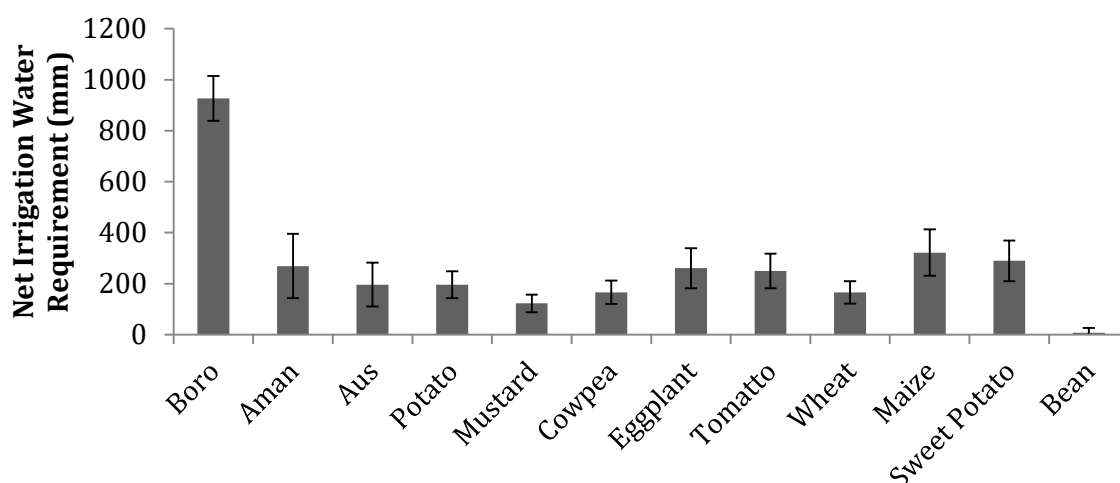


Figure 06. Average net irrigation water requirement in the Halda River basin (1990-2016)

Table 03. Trend analysis results of net irrigation water requirement in the Halda River basin (1990-2016)

NIWR of Crops (mm)	Rank von Neumann Test for Lag-1 Autocorrelation		Trend-Free Pre-whitened Mann-Kendall Trend Test		Trend change year
	RVN	rho	Z-Value	Sen's Slope	SQMK
Boro	0.64	0.64	3.66**	8.15	2006*
Aman	1.84	0.00	-1.81	-5.10	
Aus	2.46	-0.21	6.61	1.42	
Potato	0.88	0.59	2.47*	3.36	
Mustard	1.15	0.54	2.64**	2.31	
Cowpea	0.95	0.58	3.04**	3.45	
Eggplant	0.76	0.63	3.35**	5.36	
Tomato	0.94	0.60	3.39**	5.20	2010*
Wheat	0.91	0.58	2.91**	2.99	
Maize	0.89	0.60	3.57**	8.44	
Sweet Potato	0.76	0.67	3.61**	5.48	
Bean	1.17	-0.02	-1.76	0.00	

NIWR is net irrigation water requirement of crops ;*, significance at 95% confidence interval; **, significance at 99% confidence interval; SQMK is sequential Mann-Kendall test

Climatic parameters impact on net irrigation water requirement

Net irrigation water requirements highly positively correlated with wind speed and ET_0 . It implies the more the trend of wind speed and ET_0 arise, the more the trend in Net irrigation water requirement (Table 04, Table A3 and Table 02). Other hands, the Net irrigation water requirement negatively correlated with relative humidity and rainfall. In the Halda River basin, relative humidity and monthly rainfall had statistically non-significance in trend (Table A2 and Table 01). Thus, these basin climatic parameters – wind speed and ET_0 had an impact on net irrigation water requirement of crops. Only net irrigation water requirement of Mustard and Wheat was the opposite correlation at 5% level significance with sunshine hours and it was declining trend in growing periods (Dec and Jan) (Figure 02 and Table A2).

Table 04. Correlation coefficient of net irrigation water requirement with maximum and minimum temperature, wind speed, relative humidity, sunshine hours, rainfall and ET₀

NIWR of Crops (mm)	Correlation coefficient of NIWR with						
	Maximum temperature (°C)	Minimum temperature (°C)	Wind speed (m/s)	Relative humidity (%)	Sunshine (hour)	Total monthly rainfall (mm)	ET ₀ (mm/day)
Boro	-0.02	0.16	0.76**	-0.43*	-0.29	-0.72**	0.74**
Potato	-0.18	-0.09	0.82**	-0.51**	-0.36	-0.40*	0.80**
Mustard	-0.22	-0.07	0.80**	-0.54**	-0.47*	-0.27	0.76**
Cowpea	-0.12	0.06	0.87**	-0.61**	-0.38	-0.37	0.86**
Eggplant	-0.12	-0.02	0.85**	-0.61**	-0.32	-0.50**	0.83**
Tomato	-0.13	0.03	0.86**	-0.64**	-0.36	-0.40*	0.85**
Wheat	-0.14	0.06	0.87**	-0.60**	-0.40*	-0.33	0.87**
Maize	-0.08	0.08	0.84**	-0.58**	-0.34	-0.55**	0.85**
Sweet potato	-0.14	-0.01	0.87**	-0.58**	-0.32	-0.50*	0.85**

NIWR is Net irrigation water requirement of crops ;*,** are denoted significance at 95%, 99% confidence intervals respectively with Pearson's product-moment correlation

IV. Conclusion

In this research, the 27 years (1990-2016) of net irrigation water requirement and irrigation parameters (rainfall and ET₀) data were analyzed to detect the trends in the Halda River basin. Almost all of the time series were serial correlation by testing rank Von Neumann for lag-one test. So, data was pre-whitened removing serial correlation. The trend of net irrigation water requirements was tested through the Mann-Kendall method. The Rabi season crops, which start in November, and end up in March, detected an upward trend at 1% level of significance and Kharif season crops are statistically non-significance in this basin. Maize and Boro rice cultivation were more susceptible to raising net irrigation water requirements that were 8.44 mm and 8.15 mm in a year respectively. The trend of irrigation water requirement was the composite trend effect of wind speed, relative humidity; rainfall and reference evapotranspiration (ET₀) in spite of relative humidity and rainfall being individually non-trending. So, wind speed and ET₀ were more contributing parameters in net irrigation water requirement. However, this research assists to consider extra agricultural water demand which is about 85mm extra for rice crop and about 45mm extra for non-rice crop in next decade of year due to climate changes during Rabi season in Halda river basin.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Appendix A

Table A1. Trend analysis of monthly average maximum and minimum temperature from 1990-2016

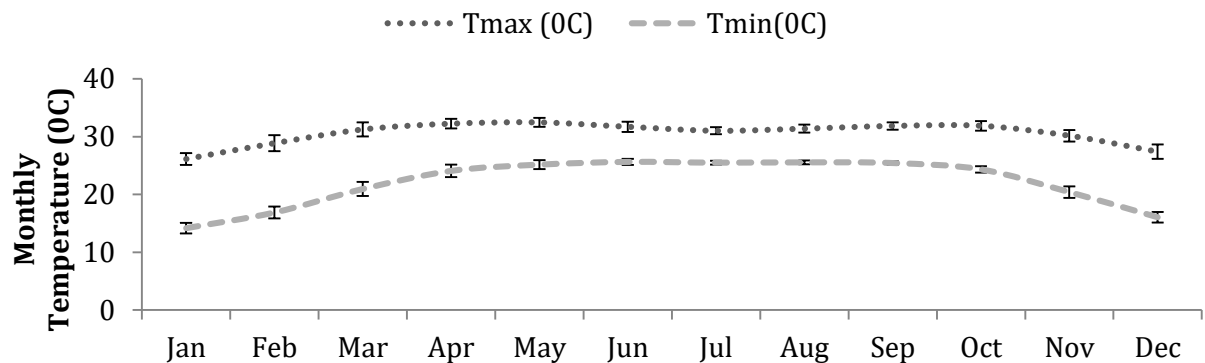
Month	Maximum temperature (°C)					Minimum temperature (°C)				
	Rank von Neumann Test for Lag-1	Trend-Free Prewhitened Mann-Kendall Trend Test		Mann-Kendall Test		Rank von Neumann Test for Lag-1	Trend-Free Prewhitened Mann-Kendall Trend Test		Mann-Kendall Test	
	RVN	Z-Value	Sen's Slope	Z-Value	Sen's Slope	RVN	Z-Value	Sen's Slope	Z-Value	Sen's Slope
Jan	1.33	-0.31	-0.01			2.34	1.98*	0.04		
Feb	1.29	1.10	0.05			1.48	1.41	0.03		
Mar	1.64	1.19	0.05			2.04*			1.25	0.01
Apr	1.75	-0.09	0.00			2.05*			2.36*	0.04
May	1.09	0.07	0.00			1.60	1.32	0.03		
Jun	1.19	0.26	0.01			1.94	0.79	0.01		
Jul	2.06*			-0.56	-0.01	1.62	1.61	0.01		
Aug	1.78	-1.06	-0.03			1.72	2.03*	0.02		
Sep	1.46	-0.71	-0.01			1.57	1.63	0.01		
Oct	0.76	-0.31	-0.01			1.95*			1.25*	0.02
Nov	0.81	-1.45	-0.04			2.21	0.40	0.01		
Dec	0.95	-0.48	-0.02			1.51	2.38*	0.07		

**, significance at 95% and 99% confidence interval respectively.

Table A2. Trend analysis of monthly relative humidity and sunshine hours from 1990-2016

Month	Relative humidity (%)			Sunshine hours				
	Rank von Neumann Test for Lag-1	Trend-Free Prewhitened Mann-Kendall Trend Test		Rank von Neumann Test for Lag-1	Trend-Free Prewhitened Mann-Kendall Trend Test		Mann-Kendall Test	
	RVN	Z-Value	Sen's Slope	RVN	Z-Value	Sen's Slope	Sen's Slope	Z-value
Jan	1.77	0.13	0.02	1.25	-2.34*	-0.06		
Feb	1.59	-1.63	-0.20	1.98	-0.53	-0.01		
Mar	1.82	-1.72	-0.30	2.00*			0.00	-0.19
Apr	1.72	-0.75	-0.08	1.38	-1.68	-0.03		
May	1.64	-0.64	-0.03	1.83	1.50	0.03		
Jun	1.66	-0.11	0.00	1.67	1.59	0.04		
Jul	1.21	0.71	0.03	1.48	1.06	0.02		
Aug	1.81	0.02	0.00	1.79	-0.18	0.00		
Sep	0.88	-0.46	-0.02	1.48	-0.22	-0.01		
Oct	1.45	-0.02	0.00	1.18	-2.51	-0.07		
Nov	1.57	-1.41	-0.10	1.50	-0.97	-0.02		
Dec	1.41	1.32	0.11	1.17	-2.82**	-0.09		

**, significance at 95% and 99% confidence interval respectively.



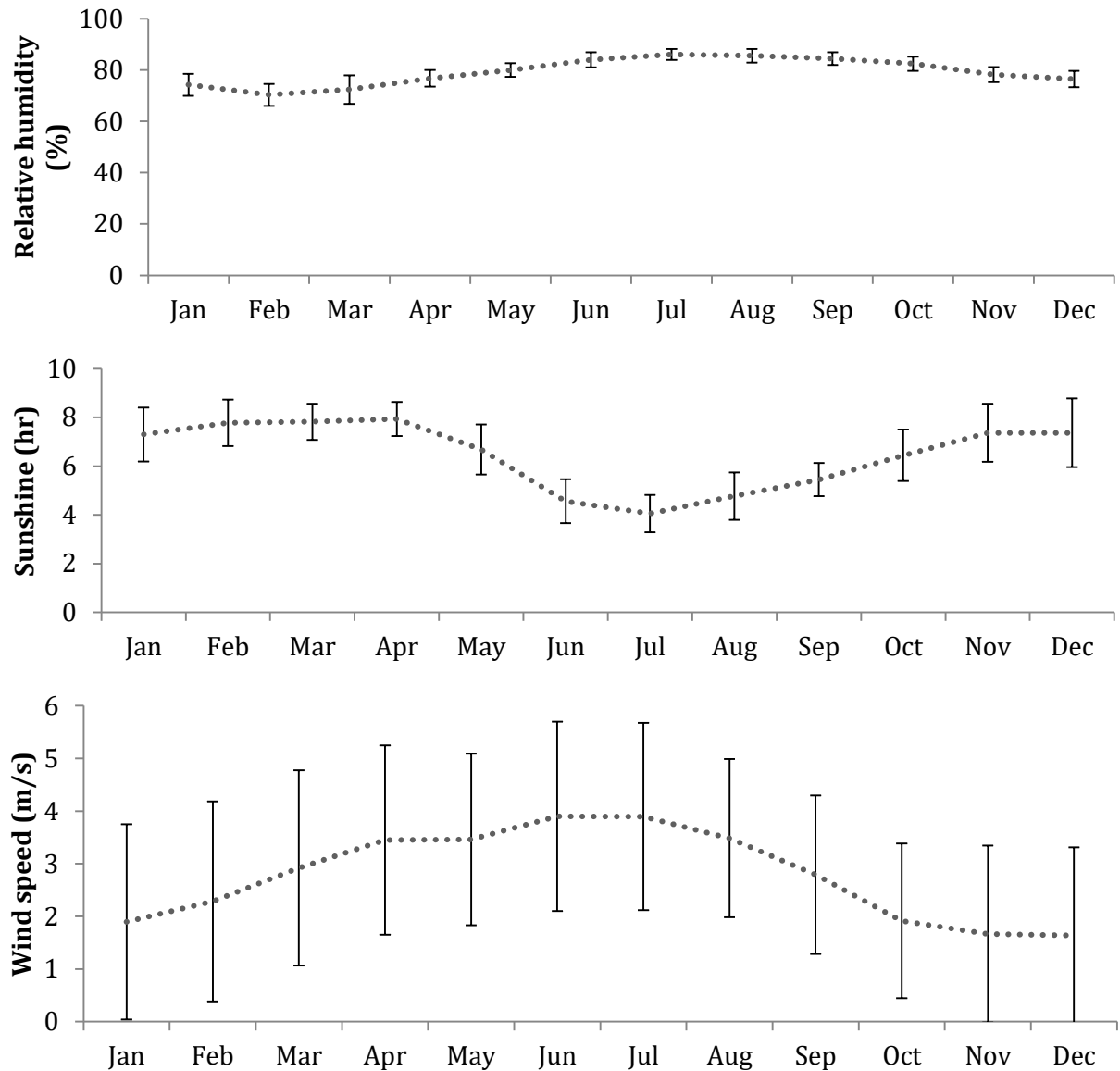


Figure A1. Monthly average maximum-minimum temperature, relative humidity, sunshine hours, wind speed from 1990-2016

Table A3. Trend analysis of monthly average wind speed (m/s) from 1990-2016

Month	Rank von Neumann Test for Lag-1 Autocorrelation	Trend-Free Prewhitened Mann-Kendall Trend Test		Trend change year
	RVN	Z-Value	Sen's Slope	SQMK
Jan	0.61	3.70**	0.11	2010*
Feb	0.69	3.70**	0.12	2010*
Mar	0.80	1.98*	0.10	2011*
Apr	0.55	2.51*	0.08	2011*
May	0.67	1.41	0.05	
Jun	0.77	-0.04	0.00	
Jul	0.75	-0.53	-0.01	
Aug	1.00	-0.97	-0.03	
Sep	0.91	1.94	0.05	
Oct	0.73	3.53	0.09	
Nov	0.56	4.23	0.11	
Dec	0.53	4.23	0.10	

**, significance at 95% and 99% confidence interval respectively; SQMK denotes sequential Mann-Kendall test for change point.

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