Potential crop water requirements of dry season Boro rice under climate change in North-East hydrological region of Bangladesh

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Abstract: In the present study, two districts of North-East region of Bangladesh; a flood prone area with high temperature and maximum precipitation, respectively, were selected along-with two widely cultivated Boro rice varieties in Bangladesh. Reference evapotranspiration (ET_O) during the study period from 1994 to 2010 was estimated with the daily meteorological data utilizing the FAO Penman-Monteith method. A MAKESENS trend model was adopted for the assessment of both Mann-Kendall test and Sen's rate of change over the study period. During the study period, the potential crop water requirement of Bangladesh Rice Research Institute dhan 28 (B28) and BRRI dhan 29 (B29) in Moulvibazar has been declined by −3.953 mm year^{-1} and −5.182 mm year^{-1}, respectively; whereas it has been raised by 2.483 mm year^{-1} and 2.387 mm year^{-1}, respectively in Sylhet. The climatic parameters affecting the observed and projected trends in Potential water requirement differed both significantly and insignificantly over the months of the year. For both varieties, maximum water demand was observed in mid-season stage; whereas the development stage, the water demand was found to be minimum.

Keywords: actual evapotranspiration, climatic effect, MAKESENS trend model, sen's slope, mann-kendall test

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1 Introduction

Climate change has an everlasting pervasive effect on global agriculture (Calzadilla et al., 2013) and irrigation pattern (Puma and Cook, 2010). Only in South Asia, irrigated yield of different crops is experiencing declines (Nelson et al, 2009) and it has pushed countries like Bangladesh in the front line in terms of vulnerability and susceptibility (Huq et al., 2015; IPCC, 2014). As the world's population has tripled in the 20th century, global water use has multiplied six times than the last century (IWMI, 2011). Groundwater withdrawal for irrigation in recent years exhibits a ceiling trend through covering 70% of the total withdrawal (Cosgrove, 2014). In Bangladesh, much greater percentage (88% of the total withdrawal) for irrigation were witnessed (FAO, 2016) because approximately 84% of its people directly or indirectly involved in a wide range of agricultural activities (Rahman, 2004). However, Bangladesh has a high fertility rate of 2.3 and its projected population by 2050 is 202 million (PRB, 2016). On the contrary, only Bangladesh has contributed 7.21% of the world's rice production, i.e. 34.50 million mt (USDA, 2016); and in the future, a substantial percentage of this increased production is likely to come from the extension of irrigation based Boro rice farming (Wahid et al., 2007). During the dry season, ground water level drops down and scarcity of water arises mostly because of increase in groundwater extraction for irrigation from shallow and deep aquifers (Changming et al., 2001; Shahid and Hazarika, 2010), drastic decline of rainfall (Ahmed and Kim, 2003).

Most of the previous researchers (Elgaali et al., 2007; De Silva et al., 2007; Diaz et al., 2007; Allen et al., 2011; and Shen et al., 2013) found that demand for irrigation

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water is mostly sensitive to fluctuations in temperature and precipitation. Schlenker et al. (2007) investigated that irrigation water requirement of crops like rice is utterly sensitive to climate change and higher evapotranspiration as a result of temperature rise will require a higher volume of water for irrigation. On the other hand, Peng et al. (2004) and Hatfield and Prueger (2015) studied that higher temperature will change the crop physiology and shorten the crop growth period, respectively which will eventually reduce the irrigation periods. All these conflicting events will certainly change the irrigation water demand. Savé et al. (2012) outlined that irrigation requirement have changed 40%-250% throughout the last century, depending on the crop requirements. A long-term water resource management and study is necessary to identify how much irrigation water is obligatory to maintain robust yield, agricultural sustainability under current climate change situations (Kousari et al., 2013) and a way to ensure future water security (Holst et al., 2014).

For better management of irrigation water inputs as well as to improve water use efficiency of crops, it is essential to understand the potential crop evapotranspiration (ET_C). Crop evapotranspiration (ET_C) can be obtained from crop coefficient (K_C) and Reference crop evapotranspiration (ET_O) (Allen et al., 1998). Nevertheless, estimation of irrigation water requirement is worth if it subsumes all climatic parameters. Yu et al. (2002) stated that the rise in crop evapotranspiration can be due to changes in relative humidity and temperature in rice fields. Other research by Goyal (2004) shows evidence that ET_C is sensitive to solar radiation, vapor pressure, temperature and wind speed. Thus, study of the changes in potential water requirement of a region of the major crop like Boro rice, involving the relative changes in growth stage days and effective rainfall during growing days is important for a complete understanding of the impacts of climate change. Several researches (Shahid, 2010; Basak et al., 2010; Acharjee et al., 2017) have been conducted in the North-West region, i.e. drought prone area of Bangladesh on irrigation water requirement of Boro rice, but only a handful amount of study has been done in the North-East region (Basak et al., 2010). Although average annual rainfall in Sylhet is highest in Bangladesh, but during the dry season it drastically declines which ultimately affect the groundwater level (Nury et al., 2014). Region based study of different trends of recent climatic parameters is really necessary for better understanding of the basic factors affecting potential crop water requirement. Therefore, the goal of the present study is to understand the change in potential water requirement of dry season Boro rice in the North-East Bangladesh region under prevailing climatic conditions. This study explains a detail, understanding of all of the potential ways to see the effect of climate change in the irrigation water requirements of dry season Boro rice in flood prone areas of Bangladesh.

2 Materials and method

2.1 Study area

The North-East region of Bangladesh comprises of six districts, covering 24,265 sq. km, which is allocated into two discrete sub-regions; the superior Meghna sub-region (83.5%) in the East, and minor Old Brahmaputra sub-region (16.5%) in the West. Out of six districts, only Sylhet and Moulvibazar districts have weather stations to record the climate data. Therefore, this study was focused on the data of these two districts (Figure 1). Geographically the study area extends from 24º08′ to 25º11′ N latitude and from 91º38′ to 92º30′ E longitude. However, frequent flash floods take place in the Meghna sub-region from the adjacent Indian states of Meghalaya, which lies North of the region, and Tripura which lies to the South. In addition, from the Brahmaputra River, flood waters are spilling into the sub-region of the Old Brahmaputra River. The flood-prone areas are mainly suited for Boro rice, since water is available during the dry season and cost of irrigation is low. Like all the other parts of Bangladesh, the hydrological year in the North-East region comprises four distinct seasons as (i) Dry Season from December through March, (ii) Pre-Monsoon from April to May, (iii) Monsoon from June through September and (iv) Post-Monsoon from October and November. Climatically, the study area is characterized by the typical tropical monsoon climate. The mean and standard deviation of monthly rainfall, minimum and maximum temperature, relative humidity, wind speed and sunshine hours of available data series of the two districts for the period of 1994–2010 by the time of study are demonstrated in Figure A1, Appendix A. The periodic distribution of rainfall shows that almost 80% of the annual average rainfall occur between May and September, and the extent of annual rainfall ranges between 4320 mm to 5850 mm. The economy of the study area is completely agriculture based; and therefore, 66% land of the study area is used for agriculture. The major crops of the study area are Boro rice, Aman rice, wheat, pulses, oilseeds, jute, sugarcane, tea, tobacco, spices, vegetables and fruits. However, Boro rice dominants covering more than 42% of these Agro-based lands for Boro cultivation during the dry period from November to April.

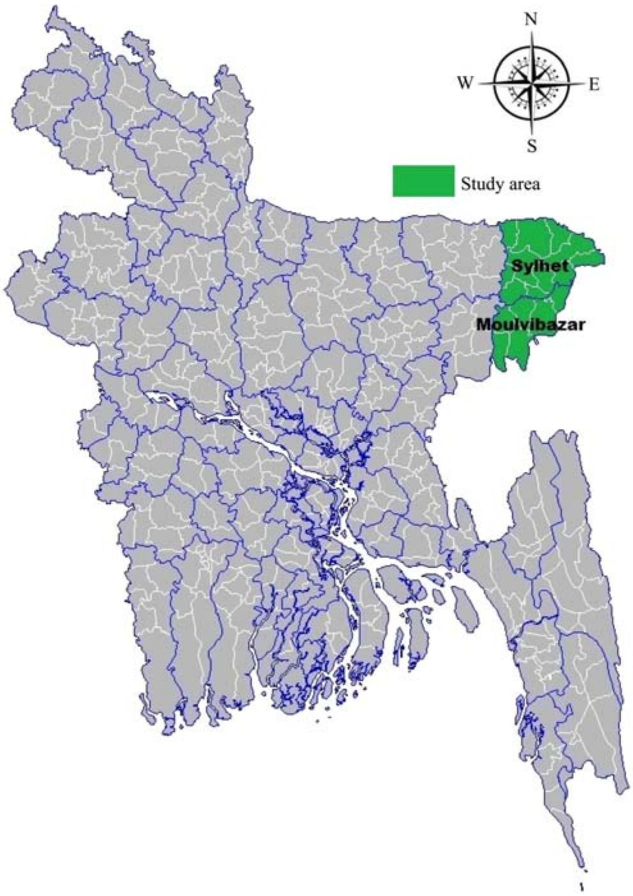


Figure 1 Location of the study area

2.2 Data collection

Two popular varieties of Boro rice, named BRRI dhan28 (B28) and BRRI dhan29 (B29), covering 45.59 and 48.53 percentages of the areas respectively, were selected for this study. These Boro rice varieties were released in the year of 1994. Therefore, the daily meteorological data like the maximum and minimum temperatures, maximum and minimum relative humidity, wind speed, rainfall and sunshine hours for a period of 17 years (1994–2010) were collected from the Bangladesh Meteorological Department (BMD) for both North-East districts. Different crop data like name of the variety, area coverage in percent, release year, growing period of each variety, crop height, harvest time, seed sowing time and length of rice growth stages were collected from Bangladesh Rice Research Institute (BRRI).

2.3 Potential crop water requirement

Under standard conditions, potential crop water requirements/actual evapotranspiration (ET_C) at different growth stages refers to evapotranspiration from well-fertilized crops, disease-free, under optimal soil, water conditions, and achieving full production under given climatic conditions (Allen et al., 1998). The potential crop water requirement (Allen et al., 1998) at different growth stages of Boro rice in North-East districts was calculated as follows:

$$ET_C=K_C\times ET_O \quad (1)$$

where, ET_C is the potential crop water requirements/actual evapotranspiration (mm day^{-1}); K_C is the crop coefficient at different growing stages and ET_O the reference crop evapotranspiration at different growing stages of rice (mm day^{-1})

2.4 Adjustment of crop coefficients

Crop coefficient (K_C) is a ratio of actual evapotranspiration to the reference crop evapotranspiration. There are two approaches for calculating crop coefficient under optimum soil moisture conditions (Allen et al., 1998). These are: single crop coefficient approach and dual crop coefficient approach. The applications related to irrigation scheduling, design and management, single crop coefficient approach is used. Whereas in irrigation scheduling, water applications, water quality modeling and research, dual crop coefficient approach are applicable. In this study, the single crop coefficient approach was applied for adjustments of crop coefficient because single crop coefficient approach deals the applications related to irrigation scheduling, design and management.

The typical values of crop coefficient were taken as 1.05, 1.20 and 0.90 for the initial stage, mid-season stage and for late season stage, respectively (Allen et al., 1998). Following Allen et al. (1998), K_C for initial stage was considered as 1.05. The typical values of crop coefficient during mid-season and late season stage, $K_{C\text{-}mid}$ and $K_{C\text{-}late}$, were adjusted with climatic conditions and height of crop above ground surface by (Allen et al., 1998; Pereira et al., 1999)

$$K_{C-mid} = 1.20 + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (2)$$

$$K_{C-late} = 0.90 + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (3)$$

where, $K_{C\text{-}mid}$ and $K_{C\text{-}late}$ are the crop coefficient during the mid-season and late season stage, respectively; u_2 is the mean daily wind speed at 2 m height over grass during the growth stage (m s^{-1}); RH_{min} is the mean daily minimum relative humidity during the growth stage (%) and h is the mean plant height during the growth stage (m).

The crop coefficient for the development stage of rice was derived by the empirical equation considering the initial and mid-season stages (Allen et al., 1998; Rahman et al., 2015). The empirical equation is as follows:

$$K_{C-dev} = K_{C-prev} + \left[\frac{i - \sum(L_{prev})}{L_{stage}}\right] \times (K_{C-next} - K_{C-prev}) \quad (4)$$

where, $K_{C\text{-}dev}$ is the crop coefficient of rice at the crop development stage, i the day number within the growing season; L_{stage} is length of the stage under consideration (day); $\Sigma(L_{prev})$ is sum of lengths of all previous stages (day); $K_{C\text{-}next}$ is crop coefficient at the beginning of the next stage and $K_{C\text{-}prev}$ is crop coefficient at the end of the previous stage.

2.5 Estimation of reference crop evapotranspiration

The Penman-Monteith method is recommended as a sole standard technique by FAO (Allen et al., 1998). Evapotranspiration is directed upon by the interrelationship of weather, plant and soil states. The influence of only weather can be described by reference crop evapotranspiration. For computing ET_O, The FAO Penman-Monteith equation requires some basic data like maximum, minimum and mean air temperatures, solar radiation, wind speed and air humidity data. Reference crop evapotranspiration on a daily basis (mm day^{-1}), was calculated as follows (Allen et al., 1998):

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma(900/(T+273))u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (5)$$

where, ET_O is the reference crop (mm day^{-1}); R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}); G is the soil heat flux density (MJ m^{-2} day^{-1}); T is the mean daily air temperature at 2 m height (°C); u_2 is the wind speed at 2 m height (m s^{-1}); e_s is the saturation vapor pressure (kPa); e_a is the actual vapor pressure (kPa); $(e_s - e_a)$ is the saturation vapor pressure deficit (kPa); Δ is the slope of vapor pressure curve (kPa $°C^{-1}$) and γ is the psychrometric constant (kPa $°C^{-1}$).

2.6 Trend analysis

For trend analysis, a number of approaches were applied for both meteorological and hydrological data, including both parametric (linear regression) and non-parametric approaches (Mann, 1945). MAKESENS trend model (Salmi et al., 2002) has been widely used to detect and estimate different meteorological and hydrological trends (Ali et al., 2012) that comprise the non-parametric Mann-Kendall test for trends along with Sen's methods for the degree of the trend. In our study, different trends of potential crop water requirements of Boro rice were detected and estimated by the MAKESENS trend model. It first tests any presence of monotonic increasing or decreasing trend with the nonparametric Mann-Kendall test and then estimates slope of a linear trend with the nonparametric Sen's method (Gilbert, 1987). To examine how change of different climatic parameters is affecting the potential crop water requirement components, trend analysis was also performed for climatic parameters, i.e. for average monthly maximum and minimum temperature, rainfall, wind speed, relative humidity and sunshine hours (Table A1, Table A2, Appendix A).

The potential crop water requirement, condition (Ali et al., 2012) for the future is projected as follows:

$$X = B + Q\ (\text{Simulation year} - \text{Base year}) \quad (6)$$

where, X is the potential crop water requirement/actual evapotranspiration of Boro rice of different varieties; B is the intercept and Q is the slope of the trend line, which were found from the MAKESENS model output. The simulation years were selected as 2010, 2015, 2020, 2025, 2030 and 2035, whereas the year 1994 was considered as a base year (being the first year of the data set).

3 Results and discussion

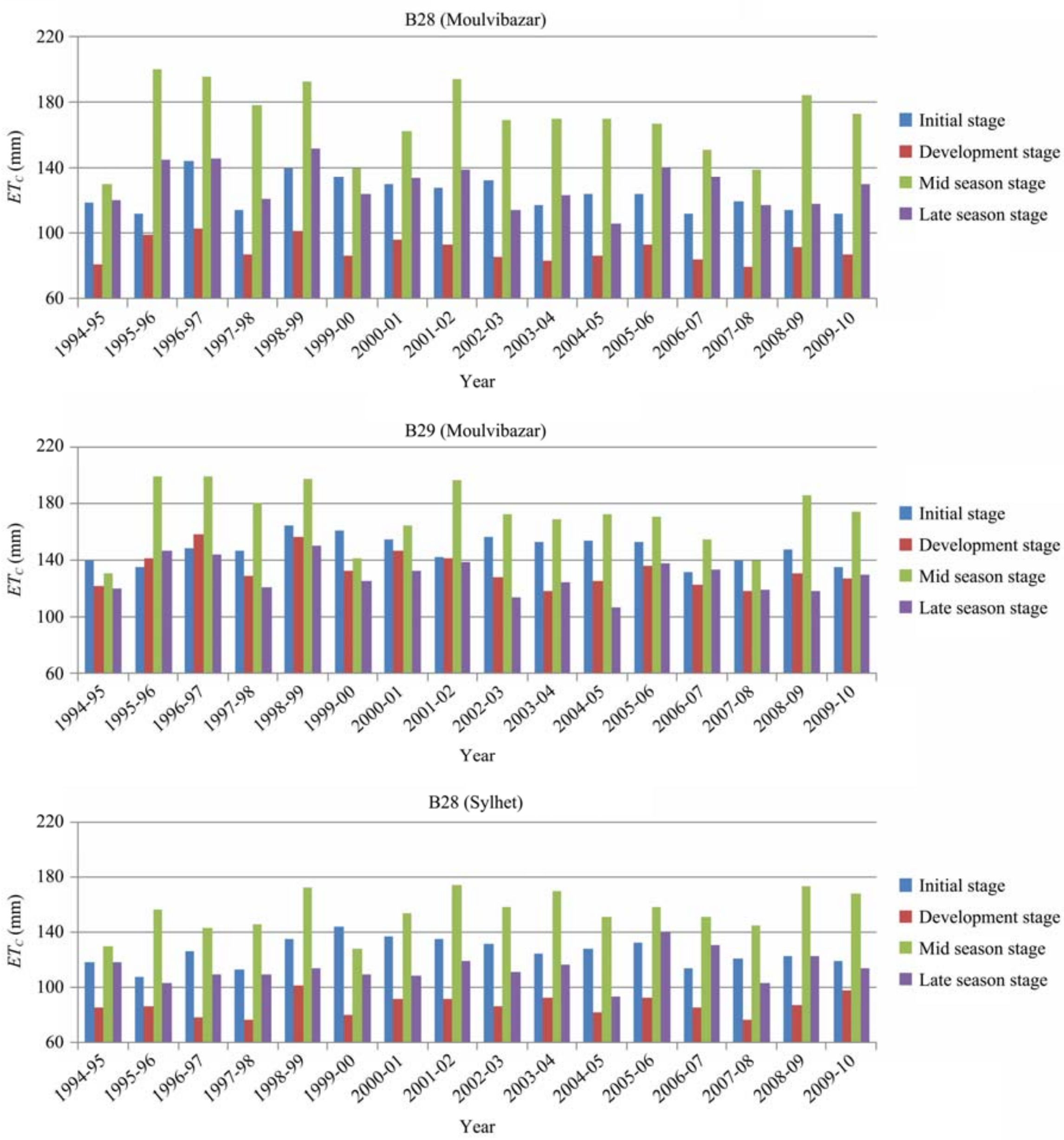
3.1 Potential crop water requirement (PWR)

The Mann-Kendall test values of actual crop evapotranspiration (ET_C) showed significant declining trends in the initial stage of B28 as well as the development stage of B29 varieties in the case of Moulvibazar district (Table 1). However, unlike initial stage of B28, an upward trend in the case of Sylhet district was observed for the both varieties in all stages. Apart from development stage of B28 and initial stage of B29, Sen's values of both rice varieties showed decreasing tendencies in two locations (Table 1). Stage-wise potential water requirement was peresnted in Figure 2.

Table 1 Mann-Kendall test value and Sen's rate of change of stage-wise potential crop water requirement by Boro rice varieties in two North-East districts for the period of 1994-95 to 2009-10

District	Varity	Mann-Kendall test value				Sen's rate of change, mm year^{-1}			
		Initial	Development	Mid	Late	Initial	Development	Mid	Late
Moulvi-bazar	BRRI dhan 28	–1.76^{+}	–1.40	–0.95	–1.04	–1.71	–0.64	–1.35	–0.94
	BRRI dhan 29	–0.72	–1.76^{+}	–0.95	–1.31	–0.69	–1.48	–1.14	–1.11
Sylhet	BRRI dhan 28	–0.41	0.95	1.40	1.22	–0.41	0.35	1.34	0.45
	BRRI dhan 29	0.23	0.00	1.31	0.95	0.15	–0.01	1.30	0.49

Note: + Sign indicate significant at 0.10 level of significance.



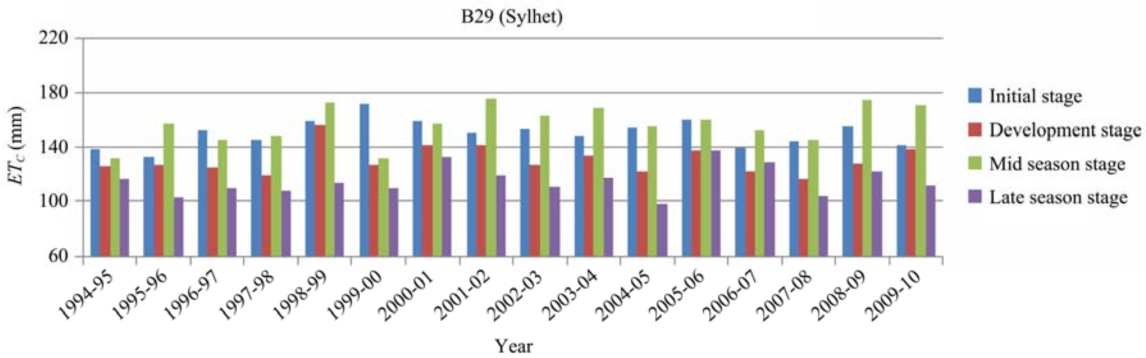


Figure 2 Stage-wise potential water requirement of Boro rice varieties at North-East districts of Bangladesh

In Moulvibazar district the Mann-Kendall value of crop coefficients in three different stages of both rice varieties demonstrated an insignificant decreasing trend. Conversely, in Sylhet district, a significant increasing trend was noticed in mid-season stage for both varieties as well as the development stage of B28. However, the insignificant increasing trend in late-season stage of both varieties and decreasing trends in development stage of B29 were also observed (Table 2).

Table 2 Mann-Kendall test value of stage-wise adjusted crop coefficient of Boro rice varieties for the period of 1994-95 to 2009-10 for the North-East districts

District	Variety	Development	Mid	Late
Moulvibazar	BRRI dhan 28	–0.34	–1.16	–1.06
	BRRI dhan 29	–0.34	–1.28	–1.51
Sylhet	BRRI dhan 28	1.74^{+}	2.31*	1.10
	BRRI dhan 29	–0.34	2.04*	1.11

Note: + and * signs indicate significant at 0.10 and 0.05 level of significance, respectively.

It was observed from the study that the Mann-Kendall value of reference crop evapotranspiration (ET_O) decreases significantly in case of initial and late stage of B28 and development stage of B29 varieties in Moulvibazar district (Table 3). However, other than initial stage of B28 and development stage B29 an insignificant increasing trend of the values was observed in case of Sylhet city (Table 3). The values of PWR/ET_C are influenced by the crop coefficient (K_C), and ET_O (as $ET_C = K_C \times ET_O$), period of growing stages as well as for the variability of sowing times during the boro season. ET_C of B28 ranges from 450.23 to 588.47 mm in Moulvibazar and 444.72 to 523.54 mm in Sylhet district was observed over the study period. In case of B29 variety, the corresponding deviations range from 511.31 to 666.65 mm and 520.41 to 601.9 mm were observed.

Table 3 Mann-Kendall value of reference crop evapotranspiration of Boro rice varieties for the period of 1994-95 to 2009-10 in North-East districts

District	Varity	Mann-Kendall test value			
		Initial	Development	Mid	Late
Moulvibazar	BRRI dhan 28	**–1.85**$^{+}$	–1.22	–0.41	**–1.89**$^{+}$
	BRRI dhan 29	–0.72	**–1.67**$^{+}$	–1.04	–1.31
Sylhet	BRRI dhan 28	–0.41	0.68	1.13	0.95
	BRRI dhan 29	0.23	–0.32	1.49	0.86

Note: + Sign indicate significant at 0.10 level of significance.

Pirmoradian et al. (2002) revealed that water requirement of rice was 560 and 757 mm in Shiraj and Iran respectively. Kar and Verma (2005) studied that PWR of rice in different standard precipitation year using CROPWAT 4.0 model and witnessed 775-875 mm for summer rice, 450-550 mm for autumn rice and 600-720 mm for winter rice. Another research done by Shahid (2010) indicated that PWR varied from 423 to 483 mm with a mean value of 452 mm in the North-West districts of Bangladesh. In the North-East part of the Haihe River basin, Gao et al. (2011) recorded maximum value of PWR for rice was 572.7 mm while in the east and south region PWR ranged from 460 to 540 mm. Furthermore, he also reported that in northern and western Hilly regions of the Haihe River basin, a gradual dropdown of actual evapotranspiration occurred which leads to a minimum value of 345.7 mm PWR. As life cycle of crop continued, at different stages of its growth, water demand directly affected by the crop coefficient and reference crop evapotranspiration. B29 is usually transplanted in early December while B28 is in early January. During the course of the study, it was observed that in North-East region of Bangladesh, the PWR at the initial stage of Boro rice was usually affected by an insignificant fall of minimum and maximum temperature particularly in the month of December and January. From February and onwards, the subsequent stages were mostly affected by the small variation of minimum and maximum temperature (Table A1, Appendix A). Mínguez et al. (2005) indicated that increase in temperature are the most likely reasons to augment crop water requirements and therefore much more irrigation water is required. Moreover, present study unveiled that both significant and minor variation of wind speed affects ET demands (Table A2, Appendix A). A research carried out by Goyal (2004) disclosed that ET demand increases up to 14% with the rising in temperature by 20% and wind speed by 7% over a study period of 32 years in Rajasthan, India. One of the significant outcomes of this study was, the highest quantity of water is required in the mid-season stage whereas the lowest quantity in the development season stage. A similar pattern was discovered by Brouwer et al. (1986) and Rahman et al. (2015). It was observed that actual crop evapotranspiration in the North-East region starts to exceed in the month of November and persists till April. This means that soil moistness scarcity starts to accumulate in November. The variation of ET_C was obtained for boro rice varieties due to higher and lower governing parameters of ET_O and K_C (Table A1, Table A2, Appendix A).

3.2 Trends of potential crop water requirement

The trends of estimated PWR, i.e. ET_C of B28 and B29 increased in Sylhet but decreased in Moulvibazar district (Figure 3). According to the Sen's method, in Moulvibazar the rate of decrease of PWR was –3.953 mm year^{-1} for B28 and –5.182 mm year^{-1} for B29 (Table 4). Conversely in Sylhet, the annual PWR was increased at a rate of 2.483 mm and 2.387 mm for both varieties (Table 4). Cumulative trends (except initial stage of B28 and development stage of B29) in Sylhet district and declining trends in Moulvibazar district were also observed (Table 5) for the ET_O of both rice varieties in separate season.

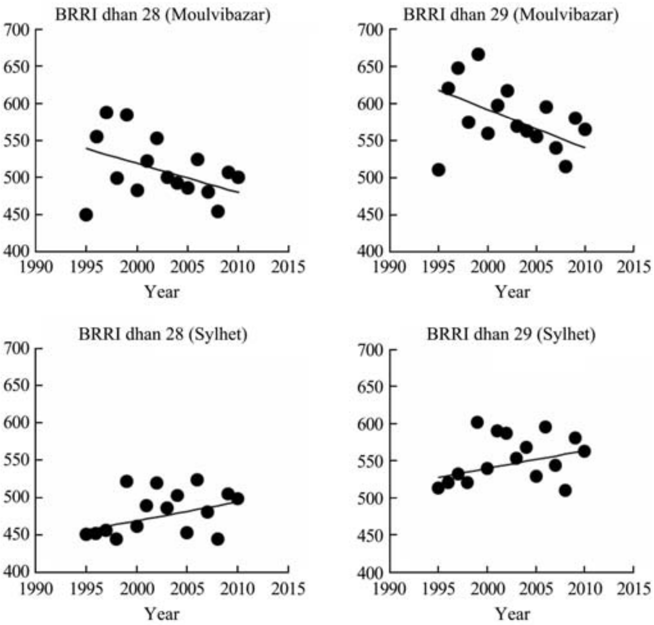


Figure 3 Sen's slope of potential crop water requirement, ET_C (mm), of Boro rice varieties at North-East districts of Bangladesh

Table 4 Statistics of potential crop water requirement by Boro rice varieties in two North-East districts for the period of 1994-95 to 2009-10

District	Variety	Mann-Kendall test	Sen's rate of change (mm year^{-1})	Mean Sen's estimate (mm)	Value at first year, from Sen's line (mm)	Mean Residual
Moulvibazar	BRRI dhan 28	–1.13	–3.953	509.22	538.87	2.29
	BRRI dhan 29	–1.49	–5.182	579.38	618.25	0.75
Sylhet	BRRI dhan 28	1.31	2.483	475.12	456.49	5.55
	BRRI dhan 29	1.04	2.387	545.74	527.84	7.38

Table 5 Shen's slope of reference crop evapotranspiration of Boro rice varieties for the period of 1994-95 to 2009-10 for the North-East districts

District	Varity	Sen's rate of change (mm day^{-1} year^{-1})			
		Initial	Development	Mid	Late
Moulvibazar	BRRI dhan 28	–0.034	–0.020	–0.022	–0.027
	BRRI dhan 29	–0.013	–0.028	–0.021	–0.033
Sylhet	BRRI dhan 28	–0.009	0.012	0.026	0.011
	BRRI dhan 29	0.003	–0.002	0.027	0.013

The mean Sen's estimate for B29 was found higher than the B28 of both districts. Furthermore, the mean residual was found higher in Sylhet compared to Moulvibazar district. The two major governing factors of

ET_C are water as well as climactic factors. Other factors , for instance, crop factor includes the type of crop, variety, plant density, growth stages can influence the crop development due to the reduction of crop evapotranspiration. Management and environmental conditions such as the factors like soil salinity, poor land fertility, the presence of hard soil horizons and poor soil management can limit the crop development with reduction of crop evapotranspiration. The ET_O redirects energy, existing for evapotranspiration and used to represent the mutual effect of climatic factors, including air temperature, net solar radiation, wind speed and relative humidity. The soil, water content is directly linked to water supply as well as rainfall. These factors collectively lead role to the variations of actual crop evapotranspiration of rice. Yu et al. (2002) estimated the climate change effects on evapotranspiration based on linear interpolation of the meteorological variables trend and the predictions of different GCMs separately where two different climatic scenarios were used for investigation. In China, at the Kao-Hsiung area the evapotranspiration from rice fields for the two crop seasons, increased by 4.95% and 3.09%, respectively, whereas in the other season, the increased percentages were 5.50% and 3.20%, in that order. After a long-term assessment in most areas of the Haihe River basin located in China, Gao et al. (2012) showed a decreasing trend for the annual ET_C and the changing rate ranges from –5 mm/10a to –30 mm/10a. This present study also unveiled insignificant trend which was corroborated by several other researchers (Gao et al., 2007). An investigation done by Acharjee et al. (2017) claims that in Bogra, Dinajpur, Pabna and Rajshahi district (North western part of Bangladesh) the PWR decreases in the rates of −2.75, −6.15, −9.48 and −5.38 mm $year^{-1}$, respectively. Additionally, a highly significant (p<0.001) decreasing trends in the estimated values of PWR demonstrated in these drought prone areas of Bangladesh. However, the present study site is not only a flood prone area of Bangladesh but also a place where maximum annual rainfall and daily average temperature (Figure A1, Appendix A) collectively has an impact on actual evapotranspiration. Therefore, the reason for the variation in significance might be due to the cause of the climatic condition of the study areas.

3.3 Prediction of potential crop water requirement

PWR, ET_C, of B28 and B29 rice varieties would decrease over time in Moulvibazar district while the increase in Sylhet district (Figure 4). The yearly decrease would be 0.824% and 0.958% for B28 and of B29 varieties in case of Moulvibazar district. Conversely, in case of Sylhet district, the annual increment would be 0.503% and 0.423% for both rice varieties. By the year 2035 potential crop water requirement will be 380.75 and 555.81 for both boro rice varieties in Moulvibazar district (Figure 4). On the other hand, in Sylhet district, the corresponding values are 410.97 and 623.32 for B28 and B29, respectively.

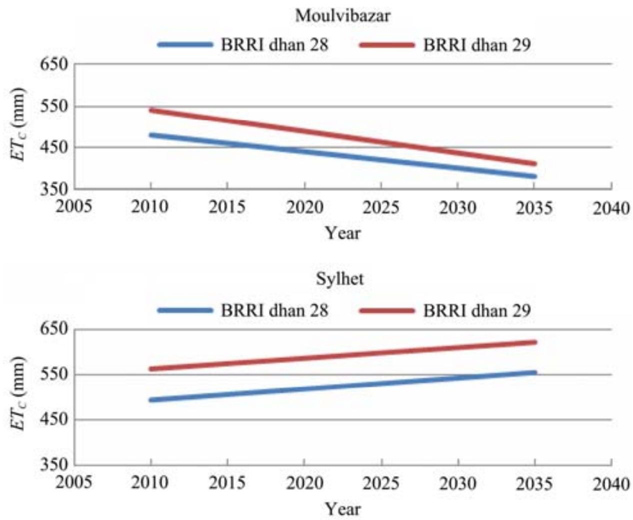


Figure 4 Predicted water demand of Boro rice varieties during 2010–2035 in Moulvibazar (up) and Sylhet (down) districts of Bangladesh

Nielsen et al. (2001) anticipated that crop water demand would upsurge by 37% between the present day and the scenarios of 2070–2099. They also specified that water withdrawal from the main channel and lake system would likely have sufficient water to meet increased demand, but some districts using tributary water may not meet the demand. Similar results were outlined by Yu et al. (2002) who studied, the mean values of evapotranspiration for the first and second crop season from 1993 to 1997 respectively, by using the prediction of general circulation model. They discovered that rises in evapotranspiration of approximately 25 mm and 24 mm might happen in the first and second crop/growing season over the 50 year study period. Especially because of the temperature rising, the current estimated crop evapotranspiration might increase in both crop growing seasons in the future. (Lee and Huang, 2014). They observed that the calculated crop water requirement might increase up to 36.0% and 15.2% in the first and second seasons respectively. Diaz et al. (2007) also accused climate change for the additional 20% increase in the crop water requirements as a prediction for the year of around 20% and 16% (scenarios 2050_A2 and 2050_B2) are predicted by the 2050. Tao et al. (2015) compared with the reference period (1961-1990), crop evapotranspiration increases by 10.2%, 19.1%, and 27.3% under the RCP85 scenario and 9.8%, 12.6%, and 15.6% under the RCP45 scenario throughout the time frames from 2011 to 2040, from 2041 to 2070, and from 2071 to 2100, respectively. Also, an analysis by Shahid (2010) claims that the amount of irrigation water will be about 8.8, 8.9, 9.1 and 9.3 mm day^{-1} in the year of 2025, 2050 and 2100 in the North-West districts of Bangladesh. The interesting finding of the study is that the climate change will increase the daily use of water for irrigation by an amount of 0.8 mm day^{-1} at the end of this century.

For leading a worthy prediction of future climatic parameters proper investigation of the impacts of future climate change on crop water demand is necessary, which includes important parameters like temperature, solar radiation, sunshine hours, wind speed and humidity. Otherwise, the management decision based on the future scenarios of crop water demand could be seriously misleading.

Our research has not inspected the changes in crop water requirements as affected by the changes in atmospheric CO_2 concentration. Tans and Keeling (2016) reported that the global CO_2 concentration had amplified from 339 ppm to 396 ppm during 1980 to 2013. Several investigations claim that evapotranspiration decreases with the elevation in CO_2 concentration and therefore it increases water use efficiency (Baker and Allen, 1993; Goyal, 2004). Since PWR by Boro rice in the North-East districts of Bangladesh are showing both decreasing and increasing trends without considering the influences of rising CO_2 concentration in the atmosphere therefore acknowledging its impacts could possibly strengthen the conclusion of this study through revealing more sophisticated relationship between the variables.

4 Conclusion

A study has been carried out to evaluate the recent trends of potential crop water requirement (PWR) or the actual crop evapotranspiration of two different Boro rice varieties during the dry season in order to experience the consequences of regional climate change. In the study period, PWR of BRRI dhan 28 ranged between 450.23 to 588.47 mm in Moulvibazar district, and 444.72 to 523.54 mm in Sylhet district. Likewise, for BRRI dhan 29, the corresponding deviations were observed between 511.31 to 666.65 mm and 520.41 to 601.9 mm, respectively. During 1994 to 2010, the PWR of BRRI dhan 28 and BRRI dhan 29 have been declined at an average rate of −3.953 mm $year^{-1}$ and −5.182 mm $year^{-1}$, respectively in Moulvibazar; whereas in Sylhet, it has been amplified at an average rate of 2.483 mm $year^{-1}$ and 2.387 mm $year^{-1}$, respectively. The outcomes also demonstrate that the yearly decrease in PWR of Boro rice varieties will be 0.824% and 0.958% in Moulvibazar district; whereas in Sylhet district, the yearly increase will be 0.503% and 0.423%, respectively by the year of 2035. Both declining and rising trends of PWR directly play a substantial effect on the existing energy and water supply, respectively. However, the decline in groundwater level might induce an increase in irrigation budget and might not be cost-effective for the marginal growers of Sylhet. Under recent climatic circumstances during the study period, climate change not only prompts variability in the PWR, but also in the net irrigation water demand of Boro rice. Positive utilization of PWR change is necessary for innovative management policies related to agriculture after proper consideration of such changes.

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Appendix:

Table A1 Mann-Kendall test for monthly average minimum, maximum temperature and relative humidity for the period of 1994–2010 for two North-East districts of Bangladesh

Month	Minimum Temperature		Maximum Temperature		Relative humidity	
	Moulvibazar	Sylhet	Moulvibazar	Sylhet	Moulvibazar	Sylhet
January	0.25	0.82	1.61	1.08	**1.93**+	–0.21
February	–0.37	1.16	1.36	**1.77**+	0.51	–1.38
March	0.70	**2.06***	1.11	1.11	–0.54	**–1.78**+
April	0.29	0.92	0.29	–0.41	0.25	0.21
May	**1.74**+	1.03	–1.63	0.75	0.00	–1.01
June	0.41	0.66	**–2.29***	–1.08	1.17	–0.08
July	**1.70**+	**1.66**+	0.46	0.17	–0.50	–1.01
August	0.58	0.50	1.08	0.50	0.35	–0.13
September	1.37	1.09	–0.17	0.54	–0.04	–0.54
October	–0.58	–1.03	1.08	**2.27***	0.90	–0.55
November	**–1.69**+	0.12	–0.68	–0.13	0.43	–1.58
December	–0.78	–0.25	0.66	1.16	1.43	0.25

Note: + and * signs indicate significant at 0.10 and 0.05 level of significance, respectively.

Table A2 Mann–Kendall test for monthly average wind speed, rainfall and sun shine hours for the period of 1994–2010 for two North-East districts of Bangladesh

Month	Wind speed		Rainfall		Sun shine hours	
	Moulvibazar	Sylhet	Moulvibazar	Sylhet	Moulvibazar	Sylhet
January	**1.89**+	0.30	–1.30	**–1.80**+	**–2.32***	**–1.90**+
February	**2.86****	–0.08	–1.25	–0.66	–0.45	–0.95
March	**2.66****	–0.66	–1.48	–1.36	**–2.24***	–0.21
April	1.12	1.04	1.28	1.28	–0.12	–0.83
May	1.35	0.17	1.48	**1.85**+	–0.21	0.91
June	**2.67****	0.88	0.78	0.00	**–2.35***	–0.12
July	**2.94****	0.58	–0.70	–0.95	0.00	0.50
August	**3.40*****	0.42	0.78	0.29	1.45	0.00
September	**3.57*****	0.50	0.78	0.21	–0.33	0.45
October	**2.04***	0.75	0.29	0.00	–1.31	–0.58
November	**2.17***	0.04	–0.21	–0.39	–0.45	0.37
December	1.00	**–1.68**+	0.41	0.98	**–2.17***	–1.16

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

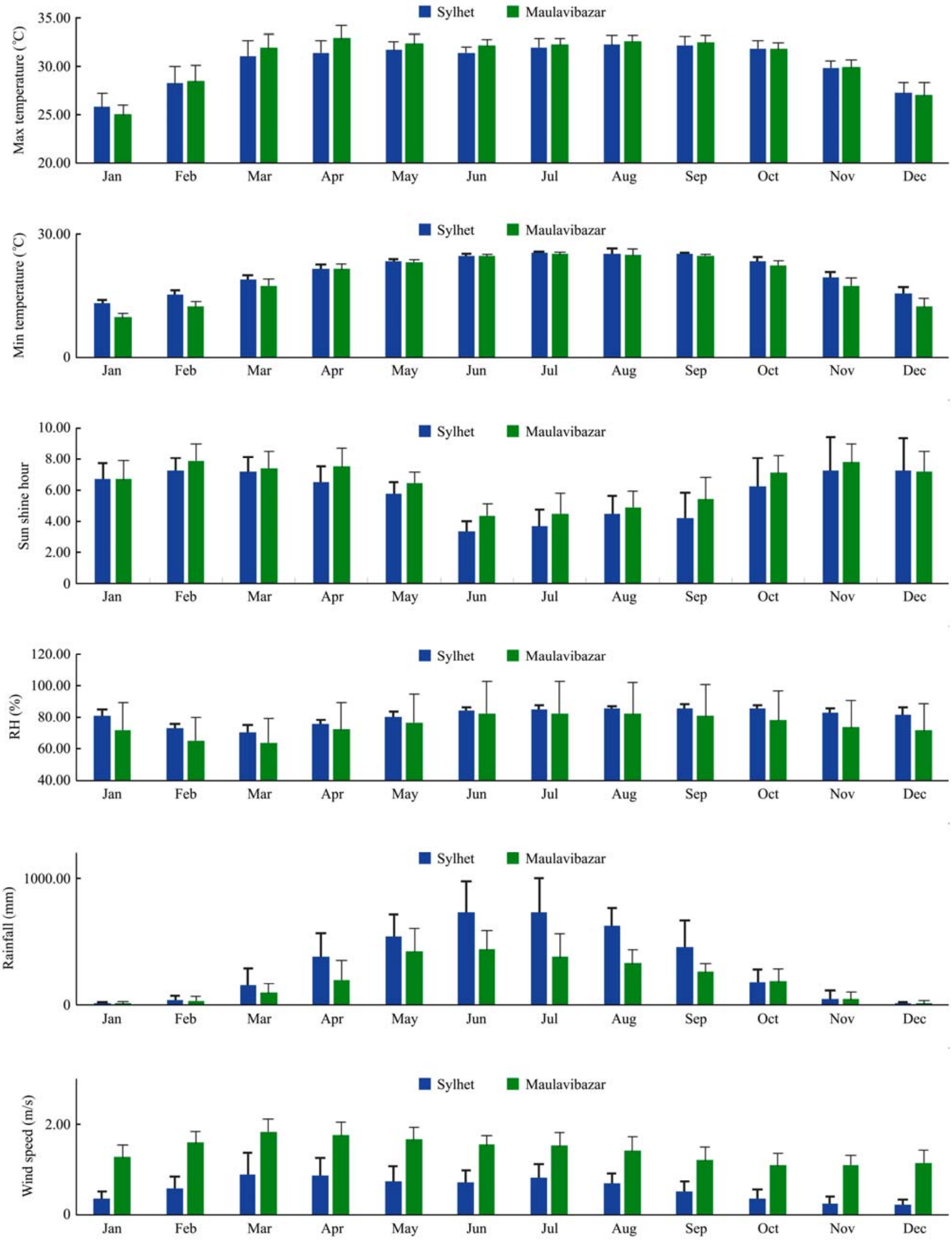

Figure A1 Average and standard deviation of different meteorological parameters for the period from 1994 to 2010 in North-East Districts