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Declining trends of water requirements of dry season *Boro* rice in the north-west Bangladesh

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ABSTRACT

The drought prone North-West Bangladesh is vulnerable to the impacts of climate change, particularly because of less water availability in the dry period and high water requirement for crop production. Improved understanding of recent changes in crop water demand in the dry season is important for the water resources management in the region. A study was carried out to determine the potential impacts of recent climate change during last three decades on trends of water requirements of *Boro* rice. The reference crop evapotranspiration (ET_o), potential crop water requirement ($\sum ET_C$), effective rainfall during the crop growing period (ER), potential irrigation requirement for crop evapotranspiration ($\sum ET_C - ER$) and net irrigation requirement of *Boro* rice were estimated using observed daily climate data in the CropWat model for the period of 1980 to 2013 for four North-West districts. Significant decreasing trends of ET_o were observed in most of the dry months due to increasing relative humidity and decreasing wind-speed and sun-shine hours. The results showed decreasing trends of potential crop water requirement, i.e. the total crop evapotranspiration ($\sum ET_C$), of *Boro* rice due to decreasing reference crop evapotranspiration and shorter crop growing periods. The variations in trends of potential irrigation requirement for crop evapotranspiration ($\sum ET_C - ER$) found among different districts, are mainly linked to variations in trends of changes in effective rainfall. The net irrigation requirement of *Boro* rice has decreased, by 11% during the last three decades at an average rate of $-4.4\,mm\,year^{-1}$, instead of decreasing effective rainfall, mainly because of high rate of decrease of crop evapotranspiration ($-5.9\,mm\,year^{-1}$). Results indicate that a warming climate does not always result in higher agricultural water use and that climate change can also result in reduced water demands because of changes in humidity, wind-speed and sun-shine hours.

1. Introduction

Irrigation requirement for crop production is the highest water demand sector in Bangladesh. The total water withdrawal in 1990 was estimated at about $14.64\,km^3$, of which about 86% for agriculture (FAO, 2016). Irrigation requirement is highly related to the climatic condition of a region. The world climate is changing, and Bangladesh is considered as one of the most vulnerable countries due to the impacts of anthropogenic climate change (Intergovernmental Panel on Climate Change, 2007). Water related impacts of climate change will likely be the most critical for Bangladesh, including enhanced possibility of dry season drought (Agrawala et al., 2003). An investigation of potential impacts of recent climate change on water demand by crops is important for water resources management of the region. Globally, the amount of water for irrigated agriculture accounts for 70% of the fresh water withdrawal (Fischer et al., 2007). Hence, studies on impacts of climate change on water demand for agriculture is important. Such studies which are performed on large spatial scales (e.g. global, continental, or basin) are not detailed enough for understanding the consequences of climate change on regional water management. The regional studies on impacts of recent climate change, involving the major crop of that region, is important from local water management perspective (Woznicki et al., 2015). Moreover, trends of water requirement, estimated from observed recent long-term daily climate data (which is already affected by anthropogenic impacts) and comparison with the trends of local climatic parameters could provide a better insight of climate change induced

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changes in water demand and related recent water management situations.

The rainfall distribution pattern is very seasonal in Bangladesh. The country receives almost 90% of the total rainfall during May to October (Shahid, 2009). *Boro* is the dry season rice in Bangladesh, which needs irrigation during January to April. The annual average rainfall in North-West Bangladesh ranges from 1400 to 2000 mm, with 93% of the rainfall occurring during May to October, and only about 6% during *Boro* rice growing months (Shahid, 2010). Hence, dry season crops that require water during November to April, fully dependent on irrigation. As the surface water flows during the dry period in the North-West Bangladesh are not adequate to support crop cultivation, the irrigation systems mostly depend on groundwater resources. Several studies indicate that groundwater levels in drought prone regions of Bangladesh are declining because of over-exploitation for irrigating dry period *Boro* rice and reduced recharge potentiality due to urbanization. The groundwater table in the North-West Bangladesh has declined between 2.3 to 11.5 m from 1981 to 2011 (Dey et al., 2013). About 85% of the area in Rajshahi district has low recharge potentiality and only 8.6% of total average annual rainfall percolates into subsurface to recharge groundwater (Adham et al., 2010). Analyses of groundwater hydrographs and rainfall time-series by Shahid and Hazarika (2010) indicate that, groundwater level is declining in the North-Western districts, because of increasing groundwater extraction for irrigation in the dry season and recurrent droughts. The amount of water extracted in any region for cultivating crops depends on net irrigation requirement of cultivating crops, cultivation area and irrigation efficiency. The potential change in water extraction due to change in net irrigation requirement of cultivating crops can distinctly vary from region to region considering the regional changes in climatic condition. Because, changes in climatic conditions can impact differently in different regions of the world depending on different present existing climate condition and different rate of changes in various climatic parameters that affect water demand by crops.

Some studies indicate a decrease in climatic water requirement (ET_o) of crops in the North-West districts of Bangladesh due to change in climatic conditions during last few decades. A study by Mojid et al. (2015) indicates a decreasing trend of ET_o in most of the months in Dinajpur and Bogra due to changes in climatic conditions from 1990 to 2010. Irrigation water requirement is very sensitive to climate change (Schlenker et al., 2007). Demand for irrigation water is particularly sensitive to changes in precipitation, and temperature (Frederick and Major, 1997). An investigation based on an irrigation model by McCabe and Wolock (1992) indicates a change in annual mean water requirement is strongly associated with the change in temperature. Most of the studies regarding the effects of climate change on crop water requirement have treated evapotranspiration as a function of temperature or as a function of the impact of elevated CO_2 on stomatal conductance (Gleick, 1987). However, not only temperature, but also humidity, wind speed and solar radiation affect evapotranspiration. A sensitivity analysis by Eslamian et al. (2011) indicates that evapotranspiration estimation using *Penman–Monteith* formula is very sensitive to temperature and humidity than compared to wind speed and sunshine duration. Findings by Yu et al. (2002) indicated that, solar radiation is the most sensitive variables of the modified Penman formula and wind-speed the least sensitive. However, estimation of irrigation requirements involving all climatic parameters as input could provide a better insight of consequences of climate change on water demand.

To completely understand the impacts of climate change on agricultural water requirements, only studying changes in ET_o is not sufficient. Changes in temperature not only affect evapotranspiration but also affect the length of the growing season. Higher temperatures results in more rapid plant development and thus shorten the growing season and total seasonal plant water use. Further, changes in the length of growing season of a crop could change the total percolation loss during that crop growing season. Also, changes in rainfall amount and distribution patterns, especially the changes in effective rainfall affect irrigation requirements. Thus, analysis of the changes in irrigation requirement of the major crop of a region, 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.

Boro rice is the economically most important and most cultivated dry period crop of Bangladesh. High yielding variety of *Boro* rice is cultivated on more than 70% of the total cultivable area during December to May. Out of 33.83 million metric tons of total rice production in 2012–13, 18.78 million metric ton was from *Boro* rice. During the past few decades, the area under *Boro* rice cultivation has been increased by almost tenfold in the North-West districts of Bangladesh. *Boro* rice needs large amounts of irrigation during the dry season. According to Parvin and Rahman (2009), the overall irrigated area in Bangladesh increased from 16 to 56% from 1981 to 82 to 2006–07, due to rapid expansion of groundwater dependent *Boro* rice cultivation which alone consumes 73% of total irrigation. Increased groundwater withdrawal for irrigating dry period crops and frequent drought events are causing prolonged absence of groundwater within the operating range of shallow tube-wells during dry season in some North-West districts (Shahid and Hazarika, 2010).

Climatic water requirement is the reference crop evapotranspiration (ET_o), which represents the environmental demand for evapotranspiration, defined as the evapotranspiration rate from a reference surface, which is a surface of short grass-like cover, completely shading the ground, of uniform height and with adequate water status in the soil profile. The crop evapotranspiration (ET_C) differs distinctly from the ET_o as the ground cover, canopy properties and aerodynamic resistance of the actual field crop are different from the reference grass. The effects of those characteristics that distinguish field crops from reference grass are integrated into the crop coefficient (Kc). In the crop coefficient approach, ET_C is calculated by multiplying ET_o by Kc. The *potential crop water requirement* is the total crop evapotranspiration ($\sum ET_C$) during the crop growing period. Actual evapotranspiration (ET_A) takes into account both climatic water demand of the field crop and soil water stress in the root zone. Hence, ET_A differs from ET_C in situation of water stress in the soil root-zone. *Potential irrigation requirement for crop evapotranspiration* is the total crop evapotranspiration amount in excess of effective rainfall, i.e. $\sum ET_C - ER$. Here, effective rainfall is the amount of rainfall that is effectively added and stored in the soil for later use by the crop. *Net irrigation requirement* takes into account the irrigation needed for crop evapotranspiration, percolation loss (PL) and water required for nursery and land preparation (N&LP), i.e. $\sum ET_C - ER + PL + N\&LP$.

A regional study on trends of recent climatic parameters, reference crop evapotranspiration, potential crop water requirement or crop evapotranspiration, potential irrigation requirement for crop evapotranspiration and net irrigation requirement, involving the changes in growing days that affects the crop water requirement and the changes in effective rainfall during the crop growing period that affects the potential irrigation requirement, and the changes in overall net irrigation of the major crop, is required for a better understanding of the impacts of recent climate change on water requirement for agriculture. Thus, this study, with an objective to quantify the impacts of recent climate change, i.e. changes in maximum and minimum temperature, relative humidity, wind-speed, sun-shine hour and rainfall, on trends of water requirements of *Boro* rice, has applied CropWat model using observed daily meteorological data as input for the period of 1979-80 to 2012-13 for