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Research Paper

Predicting design water requirement of winter paddy under climate change condition using frequency analysis in Bangladesh

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ABSTRACT

The effects of climate change on the agricultural sector are tremendous. Thus, it is essential to determine its impacts on agricultural water resources and to minimize adverse effects on crop production. The present study aims to simulate climate data based on SRES A1B scenario from the outputs of three General Circulation Models (GCMs) namely, FGOAL, HADCM3 and IPCM4 and examine the design water requirement (DWR) of winter paddy using frequency analysis under climate change condition in Bangladesh. The average change rates of DWR in four climatic zones were compared to baseline and the results were −12.16% (2020s), −0.28% (2055s), and 1.25% (2090s) for the FGOAL, −4.44% (2020s), 0.57% (2055s) and 1.25% (2090s) for the HADCM3, and −1.12% (2020s), 2.22% (2055s) and 6.69% (2090s) for the IPCM4. The change rates of gross paddy water demand (GPWD) for three GCMs ranged from −3.01% to 11.16%. In both cases of the DWR and GPWD, the change rates were above 3%, indicating a warning signal to the future winter paddy water management. The outcomes of this study can be used as basic data for the development of agricultural water resource management, which will help to minimize the drought-risk and to implement future agricultural water resource policies in Bangladesh.

1. Introduction

Nowadays, climate change is one of the greatest threats that our planet faces. Climate change directly affects global and regional agriculture and irrigation systems (Puma and Cook, 2010; Hong et al., 2016). It is generally accepted that the agricultural sector of developing countries are more vulnerable to climate change than developed countries, mostly because of low capacity and infrastructure to adapt to changing climate. Being a developing country, Bangladesh is also facing tremendous challenges from climate change, particularly for its agricultural based economy. Consequently, irrigation water requirements in Bangladesh will increase in the upcoming decades due to the rises in temperature, changes in rainfall pattern and solar radiation. In addition, agricultural sector of Bangladesh is expected to face rising competition for water resources from other sectors. According to the Ministry of Water Resources of Bangladesh, 86% of total water usage is attributed to the agricultural sector, and 70% is consumed to paddy rice cultivation (Chowdhury, 2010). The design water requirement of paddy rice is vital to the optimal design and operation of agricultural water resources systems. However, profound knowledge regarding the change rates of design rice water requirement at regional and national levels in Bangladesh is still significant for the better understanding of climate change and its multidimensional impacts.

Bangladesh has now become a self-sufficient rice producing country because irrigation has intensified rice production. Winter rice is one of the main dry season crops of Bangladesh, which fully depends on irrigation. The total amount of water used for winter rice has increased considerably over the last three decades because of intensive irrigated agriculture in Bangladesh. Intensive irrigated agriculture is the outcome of water shortages during dry seasons from January to April (Shahid, 2008). Additionally, groundwater is heavily used for irrigated agriculture due to shortage of surface water resources, and this has led to decline of groundwater levels during the dry season. Any change of rice water requirement as affected by climate change, and then, needs to be thorough studied and the results require managing rice water requirement. Drought risk (Shahid and Behrawan, 2008), groundwater sustainability (Kirby et al., 2015), and future climate change impacts (Mainuddin et al., 2015; Kirby et al., 2016) are considered serious challenges for irrigation water management, and they

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have recently received the significant attention in Bangladesh. Hence, irrigation water management in Bangladesh has concentrated mainly on protecting the paddy rice areas from the possible risk of drought under climate change, because sustaining food security and further increasing paddy rice production in Bangladesh is considered a top priority.

The present study has focused solely on one of the most critical factors, namely the effects of future climate change on design water requirement of paddy rice. In order to be able to adapt to the changing climate, a clear understanding of water requirement changes in response to the variations in the climate variables can help in the planning and management of agricultural water resources (IPCC, 2014; Wang et al., 2015). As the agricultural sector is a climate-sensitive, it is necessary to understand how climate change affects agricultural water resources for sustainable agriculture, particularly paddy rice production in Bangladesh. Future water security depends on climate change and water requirements for irrigation (Hong et al., 2016). It is essential to know how much water is required for irrigation to help agricultural sustainability and food security under current and future climate change scenarios.

Bangladesh is already recognized as one of the worst victims of climate change (IPCC, 2007). The IPCC (2007) predicts that climate patterns in Bangladesh will change due to the rising global temperature. The rainfall, temperature and solar radiation vary with season to season and location wise. Each year Bangladesh face mild to severe drought, for instance, northwestern area has been known as drought prone regions of the country (Islam et al., 2017). Drought is very sensitive to climate and varies in year to year. One of the important problem in drought analysis deals with past record of an events in terms of future probabilities of occurrence. The procedure for estimating frequency of occurrence of a drought event is usually done by frequency analysis. Though rainfall is erratic in nature, temperature varies season with time and space, it is possible to predict design water requirement (DWR) under climate change condition using frequency analysis. In fact, drought frequency analysis is a basic tool for safe and economic planning and design of future agricultural water management. Hosking and Wallis (1997) reported that planning for water related management, design of irrigation structure; all rely on knowledge of the frequency of the extreme events such as drought, storm and flood. There is no widely accepted procedure to predict the DWR under climate change condition. This is why the evaluation of design water requirement as embodied with probability distribution function (PDF) relationship has been a major focus of both theoretical and applied agricultural water resources management. Anticipating the effects of climate change and adapting to them is one of the ways to reduce vulnerability to the potential adverse impacts (Prodanovic and Simonovic, 2007). So, a frequency analysis has an application for predicting the design water requirement on probability basis that is irreplaceable.

It is generally acknowledged that General Circulation Models (GCMs) are the key tools to assess future climate change at large scale (Xu, 1999). The main limitation of GCMs is the coarse horizontal resolution, which limits their capability to resolve processes at local scale (Wilby and Wigley, 1997). To resolve this problem, it is of necessary to adjust the changes of large-scale predictions of GCMs to the changes of local-scale climate variables. The technique used to convert GCM outputs into local climate variables are generally done by downscaling methods. There are various methods for downscaling GCMs outputs which fall into two categories e.g. (i) dynamic and (ii) statistical downscaling (Fowler et al., 2007). Among several downscaling methods, LARS-WG (Long Ashton Research Station Weather Generator) (Semenov et al., 1998) model has the advantage of less data require and has been extensively used in the climate change impact studies (Islam et al., 2017; Kumar et al., 2014). Another advantage is that 15 GCMs outputs with various scenarios have been included in the LARS-WG model to better dealing with GCMs uncertainties.

Several studies have been carried out on future water requirements of paddy rice affected by climate change at local and global scales, which can be found in literature. For example, De Silva et al. (2007) assessed the paddy irrigation water requirement (IWR) in Sri Lanka and the IWR predicted by 13–23% increase under SRESB2 and A2 scenarios using datasets from the HADCM3outputs. Rodriguez Diaz et al. (2007) studied in the Guadalquivir Basin in Spain and found that the seasonal IWR would be increased between 15% and 20% by the 2050s underA2 and B2 scenarios. Elgaali et al. (2007) modeled in the Arkansas Basin in Colorado and projected irrigation water demand an increase of 5% (2050s) and 9% (2090s) when using the HadCM2 GCMs outputs. Chung et al. (2011) projected the total volumetric decreases of 4% (2050s) and 10% (2080s) of the IWR in South Korea based on the HadCM3 outputs for the A2 and B2 scenarios. Yoo et al. (2012) also projected the average change rates of the design water requirement (DWR) of wet season paddy below 3% under SRES A1B, A2 and B1 scenarios in South Korea when using climate datasets from the CGCM 3.1 GCMs outputs. Gondim et al. (2012) in the Jaguaribe River Basin, Brazil and Rehana and Mujumdar (2013) in Bhadra reservoir area in India found the impacts of climate change to be increased of paddy rice IWR and a change in crop evapotranspiration (ETc). Lee and Huang (2014) predicted an increase of 7% (2050s) of IWR of paddy rice in Taiwan. Hadinia et al. (2016) studied climate change impacts on rice water requirement in Iran and found that average rice water requirement will increase for the upcoming periods. Most of the previous studies predicted that rice water requirement will increase under climate change scenarios, even though the effect of projected changes in rainfall on the IWR is offsetting by the effect of projected changes in other climate variables such as temperature, solar radiation.

In Bangladesh, Shahid (2011) predicted the changes of the IWR in the dry season *Boro* rice field in northwest Bangladesh under SRES B2 scenario. Mainuddin et al. (2015) estimated the impact of climate change on the IWR of dry season crops in Bangladesh and confirmed to increase by a maximum of 3% of the *Boro* paddy IWR for the 2050s dry condition using the A1B scenario based on the HADCM3 and FGOALS GCM outputs. Recently, Acharjee et al. (2017) investigated the future impacts of climate change on the IWR of dry season Boro rice in north-west Bangladesh and found that net irrigation requirement of Boro rice will decrease by 1.6% in 2050s and 7.4% in 2080s using the RCP 8.5 scenario based on five GCM models. These earlier studies in Bangladesh have focused on the changes of crop evapotranspiration (ETc) and the net irrigation requirement (NIR). However, the study of design water requirement for paddy rice under climate change condition has not been undertaken in Bangladesh. Therefore, the research of climate change impacts on the DWR for winter paddy rice in Bangladesh, which accounts for a maximum agricultural water usage, need to be introduced as a matter of concern.

Motivated by the above-mentioned facts, the main objective of this study is to predict design water requirement and gross water demand for winter paddy rice in the major climatic zones of Bangladesh under climate change. We simulated a database of future climate data (2011–2099) using the three GCMs outputs and downscaled by the LARS-WG model under SRES A1Bscanario. This study focuses on changes in the spatial and temporal trends in the DWR of winter paddy in Bangladesh. However, for the first time in Bangladesh, a study of climate change-predicting design water requirement using frequency analysis for winter paddy rice has been carried out. It is anticipated that this study will be guideline for regional water managers, agriculturalists and decision makers in understanding the impacts of future climate change and also