Projection of the irrigation requirement of potatoes under climate change in Northwest Bangladesh

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Research Article

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Abstract

Climate change not only affect water resources but also water requirement and it is important to quantify the changes in irrigation requirements to ensure water and food security. In this study, CropWat model was used to estimate the crop water and irrigation requirement of potato in Northwest Bangladesh for two future time periods. Climate scenarios were prepared from five global circulation model outputs for moderate (RCP 4.5) and rapid (RCP 8.5) change following downscaling and bias correction techniques. An increase in reference crop evapotranspiration (ET_O) during the potato growing months, especially during the mid-season and late-season stages of potato was observed. The increase in ET_O was higher under rapid climate change. A future possible increase in potential crop water and irrigation requirement of potato under climate change was detected for fixed growth duration of potato. There was much variation among the different model estimates. However, the potential crop water requirement during 2080s was higher than that during the 2050s. Results indicate that rapid climate change in the short-run may cause a relatively smaller increase in the irrigation requirement compared to moderate climate change, but rapid climate change in the long-run would definitely cause a very high increase in irrigation requirement.

1 Introduction

The global climate is changing, and projections have been made that the rate will be extreme by this century (Zhang et al., 2024; Zhang et al., 2023). The global temperature is expected to be higher, which may lead to drought and water scarcity (Shariot-Ullah, 2024; Boehm & Bischel, 2019; UNICEF, 2021). Moreover, extensive utilization of irrigation water for agriculture (approximately 69% of world's freshwater) is pressurizing the limited fresh water resources (Manocha et al., 2024; Sepaskhah & Ahmadi, 2010). Specifically, in arid and semiarid regions, water scarcity threatens socioeconomic and environmental progress, as water plays an important role in the production process of food (Sentlinger & Writer, 2015; Slama et al., 2019). Agriculture is taking the major share (approximately 70%) of freshwater and climate change-induced water scarcity affecting food security and has received global attention in the last few decades. This challenge to food security is a great threat to achieving sustainable development goals (Nouri et al., 2019; UNDESA, 2014; Wu et al., 2021a). Therefore, understanding the changes in irrigation requirements of major crops is important to ensure water and food security under climate change.

The limited land is reducing, and the population is increasing in Bangladesh. Therefore, Bangladesh needs to produce more food in less land to satisfy the food security goal (Jahan et al., 2016). Potato is one of the major crops that requires a short time to grow. It can be one of the substitutes for rice both in terms of nutrition and high carbohydrate contents and can reduce the pressure on rice and wheat as rice production is projected to be reduced (approximately 12.44% yield loss for the 1.5°C scenario) in Bangladesh in the future due to climate change. People of all classes in Bangladesh consume potato as vegetables. Fortunately, potato production has increased significantly over the years. The production of potato increased from 3.281 Metric ton in 1970-71 to 19.647 Metric ton in 2014–2015 (BBS, 2018; Hoque, 2001; Wu et al., 2021b). However, water management in potato cultivation is critical as this plant is one of the most water stress-sensitive plants due to its shallow rooting system.

Tang et al. (2021) simulated the optimization of the water requirement using the combination of irrigation (irrigation requirement 10–100 mm) and nitrogen fertilizer (0-210 kg h⁻1 on potato yield in North China from 1981 to 2010 by using the APSIM-potato model and reported an increase in yield (35.2 t ha^{-1}) for the irrigation requirement of 10 mm, which was obtained under middle APE (agro-pastoral ecotone). Waqas et al. (2021) supplied delayed irrigation to observe the effects on the yield parameters and water productivity of potato under furrow and drip irrigation and observed that 35% of the depleted available plant water gave the highest water productivity, although the control treatment gave the highest yield. Thirty-five percent of plant water depletion increased water productivity by 13.31 kg m^{-3}, saving 40.44% of water compared to the control. As production is increasing, more irrigation and optimization are needed to produce more potato now and in the future. Salam & Al-Mazrooei (2007) carried out an experiment in Kuwait on potatoes in loamy sandy soil by using the CropWat model by using 43 years of meteorological data and found that the annual average reference crop evapotranspiration over the past 43 years was 2882.5 mm and varied from 2.75 mmd-1 to 14.0 mmd-1 in January and June, respectively. They also observed the varied irrigation water requirement and other crop water requirement indexes with the date of planting. Vishnoi et al. (2012) also reported the same finding that water requirements vary with planting date. They estimated the crop water requirement of potato by CropWat at Uttarakhand and Pantnagar and reported the total water requirement at late date (226.7 mm was higher than the earlier date (212.5 mm)). Mojid et al. (2020) estimated crop evapotranspiration and irrigation requirements along with the trend by using CropWat and MAKESENS for the major crops in the northwestern part of Bangladesh (Bogura and Rajshahi districts) from 1985 to 2013 and reported a decreased irrigation requirement for potato cultivation in Bogura, although the scenario started to change after 2000. An increase in total crop evapotranspiration (ETc) was observed for potato, which gives a sign of a shift from wheat to potato.

The yield and quality of potatoes depend on the water availability and shortage and vary with the texture of the soil. For commercialized potato cultivation, maintaining optimum irrigation is essential, as it is water sensitive, and this practice is practiced globally. The yield may start to decrease if the water deviates even from the optimum. Therefore, to maximize the yield of potato, it is a prerequisite to quantitatively manage irrigation (King et al., 2020).

Future projection depicting that agriculture will have to face the severe adversity of climate change in upcoming years and will impact significantly on agricultural water management, especially in the climate change hotspot in southern Europe and semiarid regions since the water for irrigation is approximately 80% and 25% in Europe and in some of the Mediterranean countries, respectively, which is a great threat to food security (Masia et al., 2021). The excessive use of water threatens this essential resource and becomes crucial to address the pathways for the proper planning and management of irrigation. To support optimized planning for proper irrigation water management, a crop-growth model is a powerful tool and is being used worldwide (Kelly & Foster, 2021). One of the major ways to estimate and optimize irrigation water management is crop water modelling in the future to provide guidelines for policymakers and farmers to adopt necessary strategies to cope with future climate-induced challenges in water sectors (Vishnoi et al., 2012).

Although this is important to address the scenario for the future, research in this field is scarce in the water-scarce northwestern part of Bangladesh. Thus, this study aimed to understand the changes in irrigation requirements for sustainable potato production under climate change to ensure water and food security goals.

2 Materials and methods

2.1 Study area

The northwest zone of Bangladesh was selected for this study. The study area includes Bogura, Rajshahi, Pabna and Dinajpur districts and extends from 23°47´N to 25°50´N latitude and from 88°01´E to 89°48´E longitude. This region is characterized as a subhumid agroclimatic class. The mean annual temperature distribution for the period of 1981–2016 reveals that temperature ranges from about 24.5 ºC in the north and 25.2 ºC in the south over northwest Bangladesh (Karmakar, 2019). The average annual rainfall distribution for the period of 1981–2016 reveals a 1500–2300 mm annual rainfall in northwest Bangladesh, and annual evapotranspiration in some places is equal to annual rainfall (Shahid et al., 2005). Hence, drought is very prominent in this region, especially in pre-monsoon season. *Boro* rice is the predominant dry season crop, but wheat, maize, potato and vegetables are also cultivated. The cultivation area of potato during the 2019–2020 season was 58058, 36490, 834 and 46836 hectares in Bogura, Rajshahi, Pabna and Dinajpur, respectively (BBS, 2021).

2.2 Data collection

Historical climate data for each study districts were collected from the Bangladesh Meteorological Department. Crop coefficient values, growth stage duration, rooting depth, crop height and critical depletion factor of potato were collected from Bangladesh Agricultural Research Institute (BARI). The maximum infiltration rate, initial soil moisture depletion and available soil moisture, drainable porosity, critical depletion for puddle cracking, maximum percolation rate after puddling, maximum rooting depth, water availability at planting, and maximum water depth were standardized for the study region for a medium average soil from the FAO standard values.

2.3 Prediction of climate change

Future climate scenarios were constructed by five general circulation models (GCMs), namely, (i) the CNRM-CM5 model, (ii) the EC-Earth model, (iii) the HadGEM2-ES model, (iv) the IPSL-CM5A-LR model, and (v) the MPI-ESM-LR model. These five models were previously used for estimation of irrigation requirement of rice by Acharjee et al. (2017) in Northwest Bangladesh. These five models were selected because of their important criteria in evaluating the impacts of climate change. The climate scenarios were constructed under two emission scenarios, RCP 4.5 and RCP 8.5, because they represent realistically low and high future emission scenarios. Minimum and maximum temperatures, wind speed, rainfall and solar radiation for the 2050s (time series of 2035–2065) and 2080s (time series of 2065–2095) were prepared. Statistical downscaling and bias correction were followed to generate the future climate data.

2.4 Estimation of irrigation requirement

The Penman–Monteith equation was followed to calculate the reference crop evapotranspiration (ET_O). FAO developed CropWat model was used to estimate the irrigation requirement of potato. This model has been widely used as a decision support tool to estimate irrigation requirements (Clarke et al., 2000). Water requirement components, namely potential crop water requirement (PCWR), effective rainfall (ER) and potential irrigation requirement (PIR) were estimated for the 2050s and 2080s for five climate scenarios and two RCPs for four northwest districts of Bangladesh. The modelling of potato growth was performed under a standardized irrigation schedule in CropWat to exclude any effect of change in management practices over the time period and therefore assess the impact of only climate change. The criteria of scheduling was to provide irrigation at 80% of critical depletion with a refill soil moisture content to 100% field capacity. The crop coefficient values of potato for the initial, mid-season and at harvest were 0.40, 1.05 and 0.70, respectively. Fixed growth duration was considered for all estimations. The date of planting of potato was 15th October and duration of growth stages were 20, 30, 20 20 for initial, development, mid-season and late-season, respectively. The date of harvest was 12th January.

3 Results and discussion

3.1 Changes in reference crop evapotranspiration (ET_O)

Figure 1 presents the monthly average reference crop evapotranspiration (ET_O) during the base period, 2050s and 2080s and the percent increase in ET_O during the 2050s and 2080s compared to the base period during potato growing months (October–January). The results indicate an increase in ET_O in the future time periods for both moderate and rapid climate change scenarios. The monthly average ET_O was found to be higher during October and November, i.e., during the early stages of potato. However, the percent increase in the monthly average ET_O was found to be higher during December and January. Therefore, the later stages of potato may experience a higher increase in water requirements than the early stages. The results indicate a higher average and percent increase in ET_O during the 2080s compared to those during the 2050s. During the 2050s, the percent increase in ET_O was almost similar for both moderate (RCP 4.5) and rapid (RCP 8.5) climate change. During the 2080s, the percent increase in ET_O under rapid climate change was much higher than that under moderate climate change. An experiment over a 43-year period on the water requirement of potato cultivation in Kuwait estimated a significant increase in monthly ET_O and supported this study (Salam & Al-Mazrooei, 2007). Farag et al. (2015) also projected an increase in ET_O under the RCP 3.0, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios for different time series. They reported a highly variable higher increase in the long term than in the short or mid-term. The study by Ayub & Miah (2011) also reported similar findings.

3.2 Changes in the potential crop water requirement of potato

Figure 2 presents the potential crop water requirement (PCWR) of potato under five climate scenarios and two RCPs during the 2050s and 2080s in four northwest districts of Bangladesh. The potential crop water requirement was highest in Pabna district and lowest in Dinajpur district for all climate models under both RCP 4.5 and RCP 8.5. Results indicate the highest potential crop water requirement during the 2080s under rapid climate change, except for the CNRM-CM5 and EC-Earth models. Although there were many variations among the different model estimates, the potential crop water requirement during the 2080s was higher than that during the 2050s. The potential crop water requirement was highest under the HadGEM2-ES model outputs and lowest under the CNRM-CM5 model outputs. Farag et al. (2015) projected a similar increase in the total water requirement under RCP 3.0, RCP 4.5, RCP 6.0 and RCP 8.5 for 3 different time series (2011–2040, 2041–2070, and 2071–2100) compared to the present situation.

3.3 Changes in effective rainfall during the potato growing season

Figure 3 presents the effective rainfall (ER) during the potato growing period under five climate scenarios and two RCPs during the 2050s and 2080s in four northwest districts of Bangladesh. None of the five models show any specific trend. The highest effective rainfall event was found (74 mm) under the EC-Earth model estimates for the RCP 8.5 scenario during the 2050s and under MPI-ESM-LR for the RCP 4.5 scenario during the 2080s in the Pabna district. There was huge variation in effective rainfall among the different model estimates. The average effective rainfall showed the maximum value for RCP 8.5 during the 2050s in Pabna and the lowest under the same scenarios and time period in Dinajpur.

The increase in variable effective rainfall is projected to be 10.5–14.4%, 13.3–14.4% and 9.4–11.2% for the 2030s, 2040s, and 2050s and 12.4–14.9%, 13.4–15.0%, and 11.3–12.5% for the 2060s, 2070s, and 2080s, respectively, during potato and other major crop growing seasons in Tajikistan under three different scenarios, RCPs 2.6, 4.5 and 8.5 (Kobuliev et al., 2021a).

3.4 Changes in the potential irrigation requirement of potato

Figure 4 presents the potential irrigation requirement (PIR) of potato under five climate scenarios and two RCPs during the 2050s and 2080s in four northwest districts of Bangladesh. The highest potential irrigation requirement was found in Pabna district and lowest in Dinajpur district for most of the climate models. There was a huge variation in the potential irrigation requirement among the different climate models. The HadGEM2-ES model showed the highest and the CNRM-CM5 model showed the lowest potential irrigation requirement. The highest average potential irrigation requirement was found under rapid climate change (RCP 8.5) during the 2080s in the Pabna district. The lowest average potential irrigation requirement was found under moderate climate change (RCP 4.5) during the 2050s in the Dinajpur district.

Figure 5 presents the percent increase in the future potential irrigation requirement compared to the base period. The highest percent increase in future potential irrigation requirements was found under rapid climate change during the 2080s. The lowest increase in the future potential irrigation requirement was found under rapid climate change during the 2050s. Therefore, rapid climate change in the short run may cause a smaller increase in irrigation demand than moderate climate change, but rapid climate change in the long run would cause a very high increase in irrigation demand. The change in potential irrigation demand from the 2050s to the 2080s under moderate climate change is negligible. A very high increase in potential irrigation demands from the 2050s to the 2080s was detected under rapid climate change. The findings of this study is consistent with the study by Acharjee & Mojid (2023). They found that the average irrigation requirement of wheat in Northwest Bangladesh would be 5.7% and 13.9% higher during 2050s and 2080s, respectively, compared to the base period under moderate climate change. However, the percent increase in irrigation requirement of potato is comparatively higher than wheat.

For potato cultivation, the groundwater for irrigation water requirements has been projected to increase by 5.3%, 6.9%, and 7.4% during the 2030s, 2040s, 2050s, and by 9.6%, 10.1%, and 7.5% during the 2060s, 2070s, 2080s under RCP 2.6, RCP 4.5, and RCP 8.5, respectively, in southern Tajikistan. The projection explains a stable increase in effective rainfall, which may lead to a possible reduction in the irrigation water requirement for potato and some other major crops (Kobuliev et al., 2021b). Zhuo et al. (2016) also reported the same stable growth in the water footprints of major crops, including potato, in the arid and semiarid regions of Ningxia and Xinjiang, China, under the RCP 4.5, RCP 8.5, and CanEsm2 scenarios. Moreover, specific crop phenology is also an influencing factor for irrigation requirements (Parry et al., 2005).

3.5 Implications and limitations of the study

Agricultural adaptation to climate change should be planned based on the prediction of crop water requirements and irrigation requirements of major crops. Sustainable potato cultivation should apply knowledge of possible changes in the irrigation requirements of potato under climate change. The study of the irrigation requirements of potatoes under different planting dates and irrigation management practices could be an interesting topic for future research. Although it is important to consider the changes in growth duration of potato while estimating the irrigation demand, the growth duration has not been estimated due to a lack of phenological data on potato cultivation in Bangladesh. This is a major limitation of our irrigation demand estimations. Therefore, this study suggests conducting research on the phenological aspects of potato in Bangladesh.

Conclusions

This study investigated the future water demand of potato under climate change. The findings of this study indicate an increase in reference crop evapotranspiration in the future for both moderate and rapid climate change scenarios. The potential crop water requirement during the 2080s was higher than that during the 2050s. There was huge variation in effective rainfall among the different model estimates. The highest average potential irrigation requirement was found under rapid climate change (RCP 8.5) during the 2080s, and the lowest average potential irrigation requirement was found under moderate climate change (RCP 4.5) during the 2050s.

Declarations

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Author Contribution The first author collected data, done all analysis, and prepared tables and figures. All authors wrote and reviewed the manuscript.

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Conflicts of interest/Competing interests The authors have declared that no competing interests exist.

Data availability (data transparency) The datasets generated during and/or analysed during the current study are available on reasonable request.

Code availability (software application or custom code) Not Applicable

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Figures

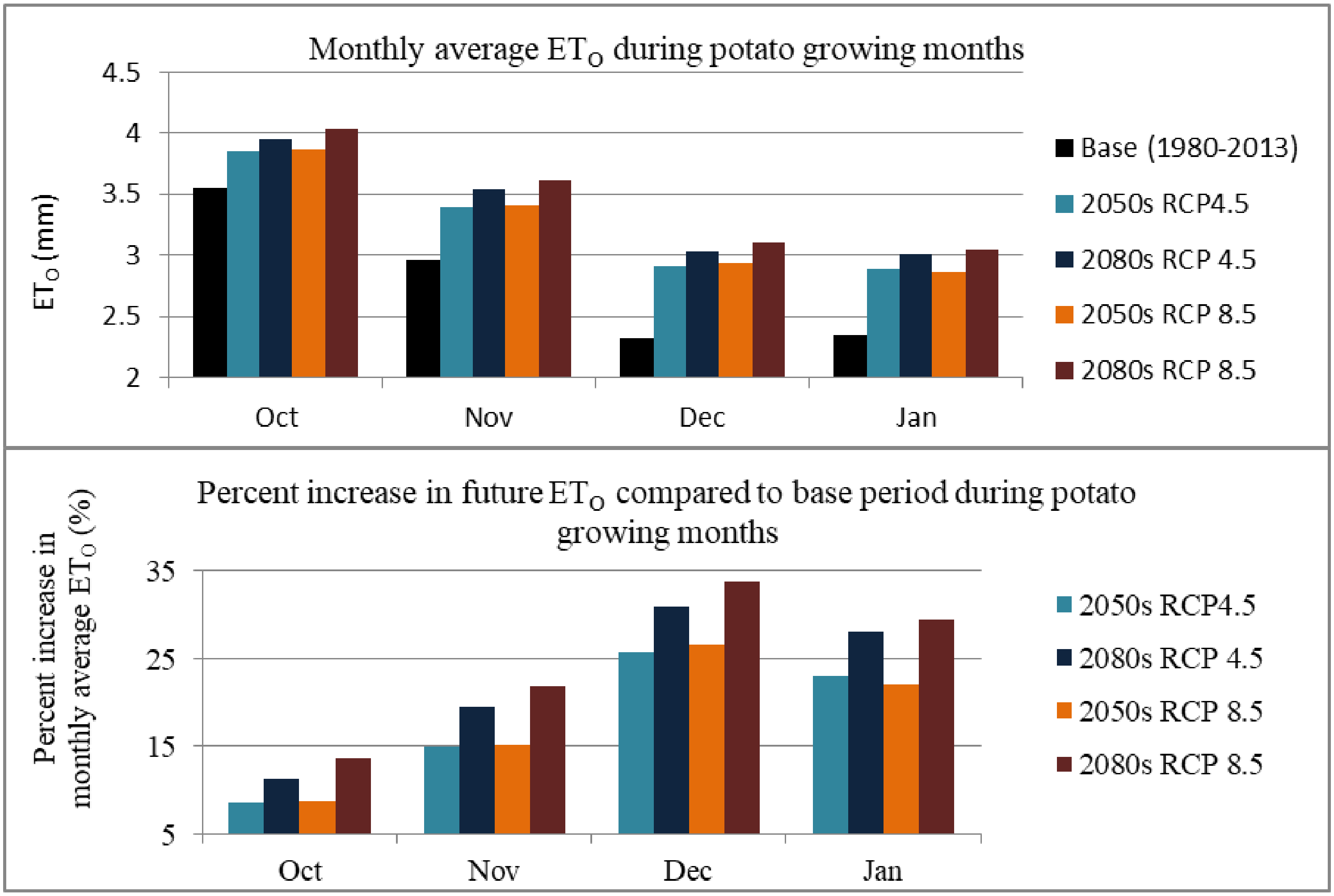

Figure 1

Monthly average reference crop evapotranspiration (ET_O) and percent increase in ET_O during potato growing months.

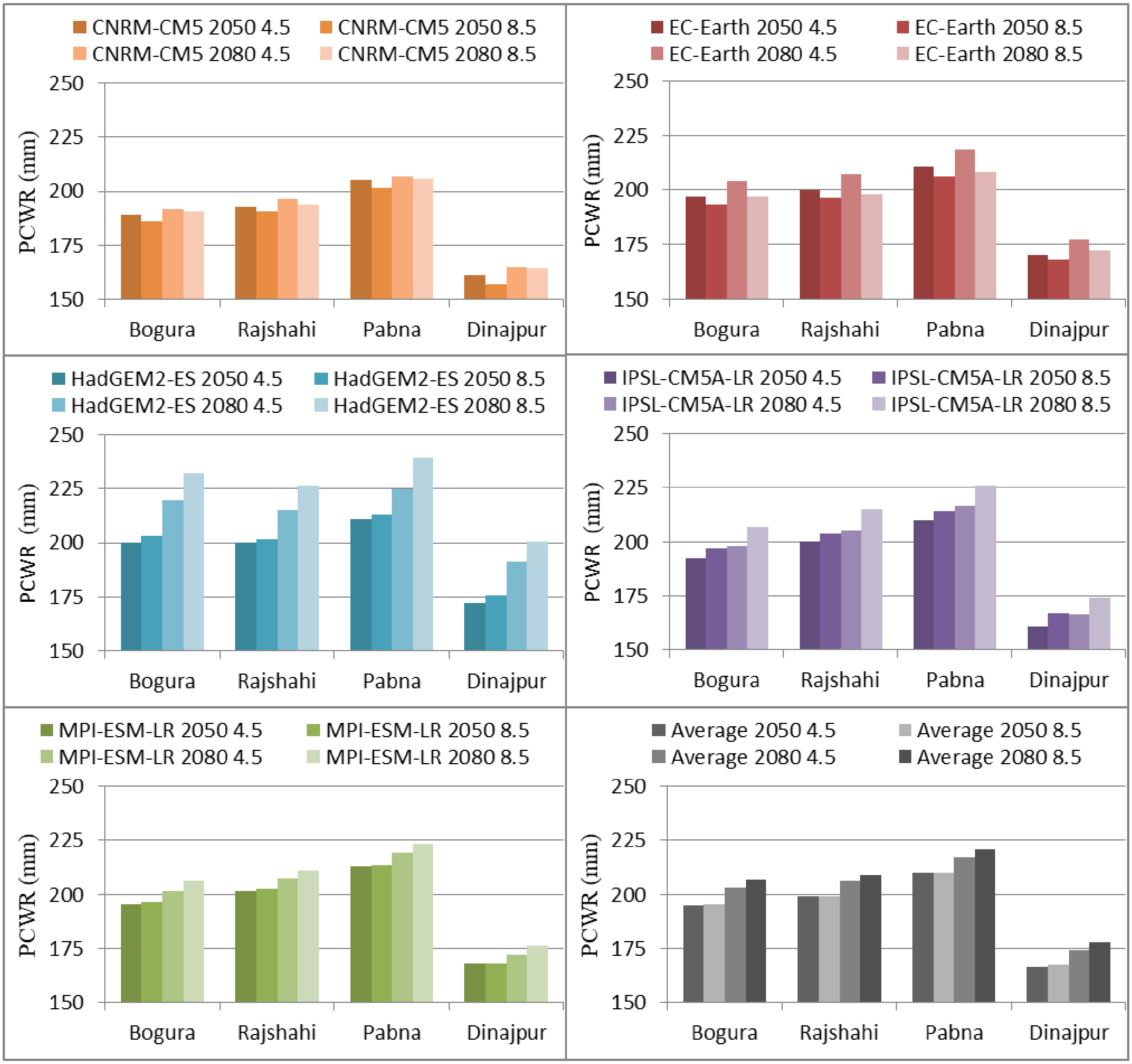

Figure 2

Potential crop water requirement (PCWR) of potato in four northwest districts of Bangladesh.

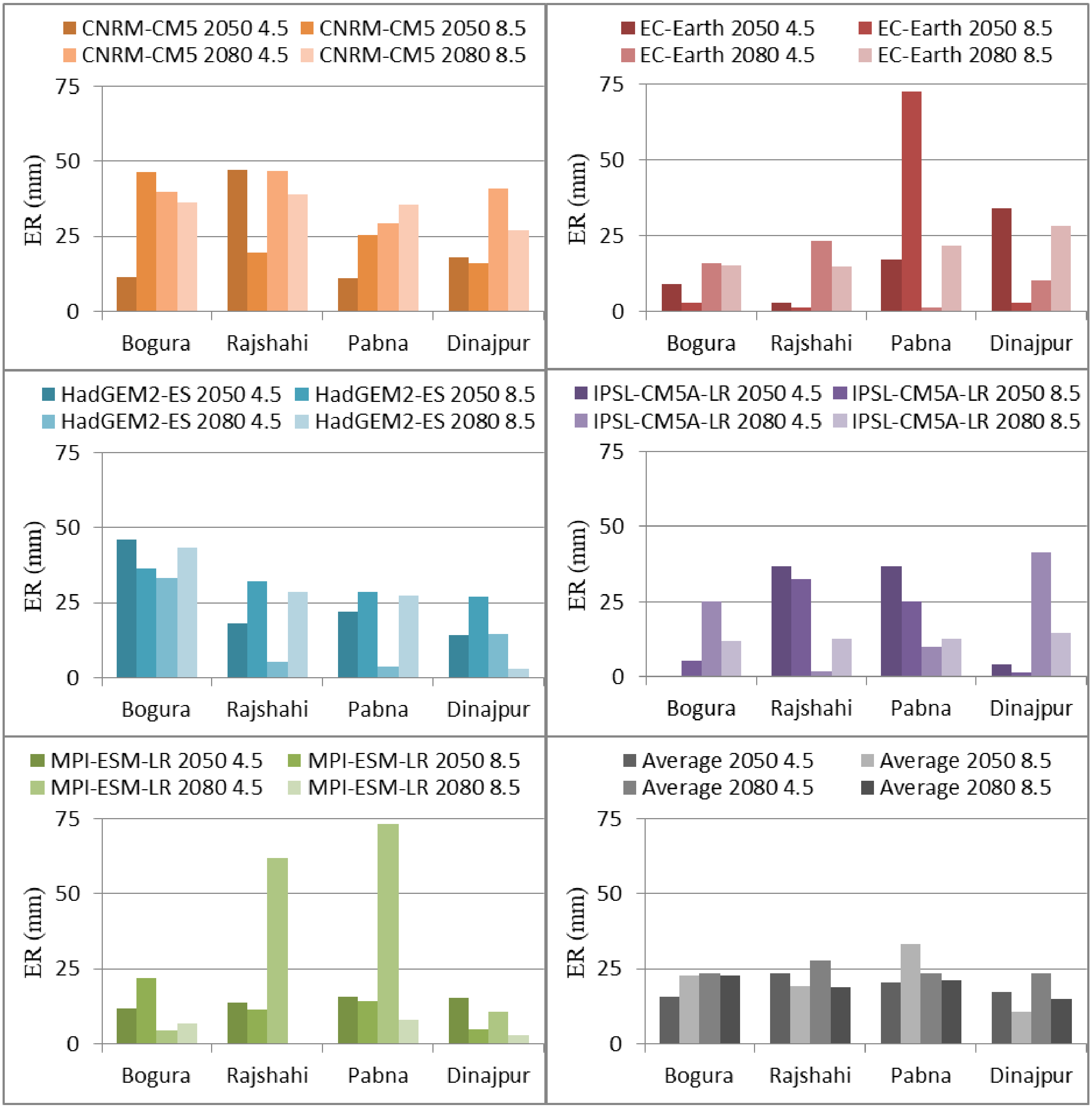

Figure 3

Effective rainfall (ER) during the potato growing period in four northwest districts of Bangladesh

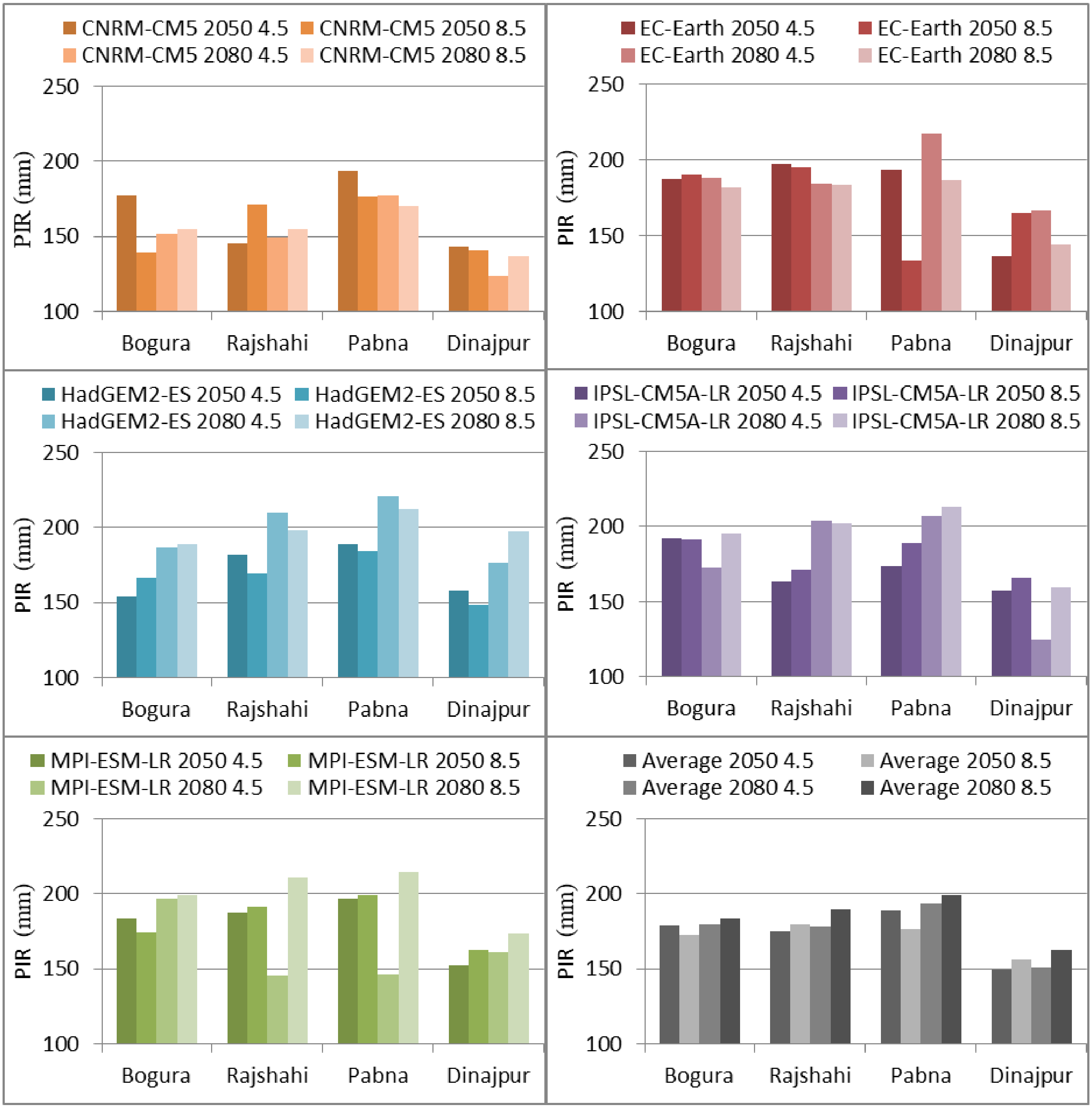

Figure 4

Potential irrigation requirement (PIR) of potato in four northwest districts of Bangladesh.

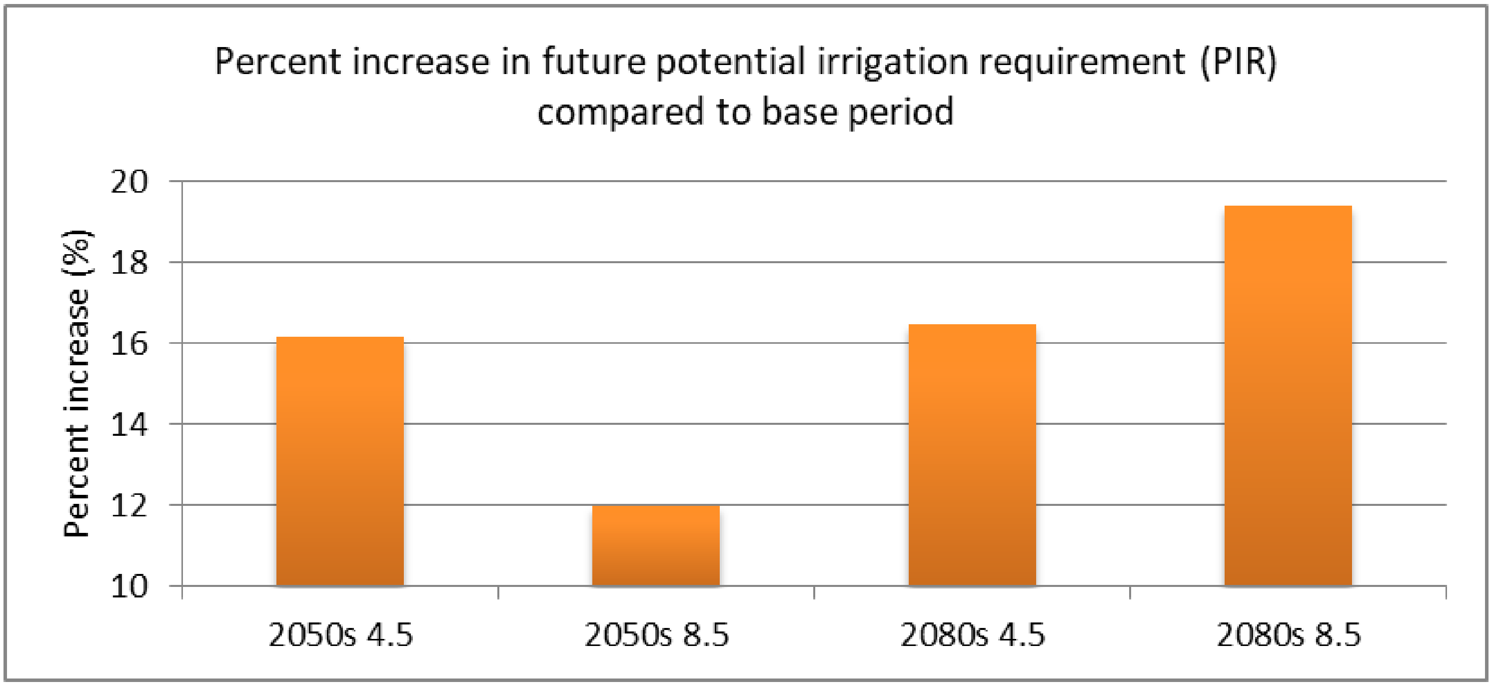

Figure 5

Percent increase in thefuture potential irrigation requirement of potato in Bogura compared to the base period.