Journal of Hydrology: Regional Studies 3 (2015) 247–264

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Climate change and irrigation demand: Uncertainty and adaptation

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ARTICLE INFO

Article history:
Received 8 January 2014
Received in revised form 12 December 2014
Accepted 17 December 2014
Available online 20 January 2015

Keywords:
Irrigation demand
Climate change
SWAT
Crop yield
Adaptation
Uncertainty

ABSTRACT

Study region: The Kalamazoo River Watershed, southwest Michigan, USA.
Study focus: Climate change is projected to have significant impacts on agricultural production. Therefore, understanding the regional impacts of climate change on irrigation demand for crop production is important for watershed managers and agricultural producers to understand for effective water resources management. In this study, the Soil and Water Assessment Tool was used to assess the impact of climate change on corn and soybean irrigation demand in the Kalamazoo River Watershed. Bias-corrected statistically downscaled climate change data from ten global climate models and four emissions scenarios were used in SWAT to develop projections of irrigation demand and yields for 2020–2039 and 2060–2079. Six adaptation scenarios were developed to shift the planting dates (planting earlier and later in the growing season) to take advantage of periods with greater rainfall or lower temperature increases.
New hydrological insights for the region: Uncertainty in irrigation demand was found to increase moving from 2020–2039 to 2060–2079, with demand generally decreasing moving further into the future for corn and soybean. A shift in timing of peak irrigation demand and increases in temperature lead to corn yield reductions. However, soybean yield increased under these conditions. Finally, the adaptation strategy of planting earlier increased irrigation demand and water available for transpiration, while delaying planting resulted in demand decreases for both crops.

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http://dx.doi.org/10.1016/j.ejrh.2014.12.003

1. Introduction

Population growth and land use change due to agricultural expansion and deforestation have significantly increased pressure on global freshwater resources (Nejadhashemi et al., 2012). As climate change becomes more prevalent globally, the future availability of fresh water for human consumption, agricultural production, and manufacturing becomes more uncertain. By the end of the 21st century, the projected range of global temperature increases relative to 1980–1999 is between 1.1 and 6.4 °C, depending on greenhouse gas emissions (Solomon et al., 2007). Meanwhile, the magnitude of projected precipitation changes varies widely depending on geographic region and spatial scale (Bates et al., 2008), while there is still disagreement regarding the magnitude and sign of potential impacts. On a day-to-day basis, more heavy precipitation events are predicted, even in some regions where mean rainfall is likely to decrease (Solomon et al., 2007). These changes are expected to exert additional pressure on agricultural production, while atmospheric CO_2 has the potential to improve photosynthesis by up to 30% (Long and Ort, 2010).

A number of studies have attempted to understand the effects of climate change on water use in agriculture in the form of changes in net irrigation requirements, demand, and crop water use. This is important because the agricultural industry is the largest user of fresh water–water withdrawals for irrigation account for 70% of all water use globally (Fischer et al., 2007). However, a majority of these studies were performed on large spatial scales (e.g. global, continental, or regional) at low resolution (e.g. monthly temperature and precipitation data), with a few watershed-scale exceptions (Gondim et al., 2012; Save et al., 2012). Save et al. (2012) modeled changes in irrigation requirements in a Spanish watershed using dynamically downscaled daily climate data and the Soil and Water Assessment Tool (SWAT). Depending on the crop (among corn, apples, and alfalfa), irrigation requirements were projected to increase by 40–250% by the end of the 21st century, attributed directly to decreases in growing season water availability, increases in evapotranspiration, and changes in crop phenology. In a Brazilian watershed, Gondim et al. (2012) determined that irrigation water demand will increase by 8–9% by the mid-21st century using monthly climate projections. Demand increases were attributed to projected rainfall decreases (11–18%) and evapotranspiration increases (6.5–8%). Harmsen et al. (2009) used statistically downscaled climate change data to understand changes in monthly cumulative precipitation, reference evapotranspiration (ET_0), and the resulting precipitation deficit between the two in Puerto Rico. Precipitation deficit in February increased up to 90 mm depending on emissions scenario and location, while in September precipitation excess increased by up to 277 mm. Xiong et al. (2010) projected that irrigation demand of three cereal crops in China will slightly decrease in lower emissions scenarios and increase by 44% and 36% in the 2020s and 2040s, respectively for higher emissions scenarios. Thomas (2008) examined irrigation demand across China for the 2030s, projecting both increases and decreases in demand depending on the region. For example, decreasing evapotranspiration in some locations result in demand decreases by 100 mm, while drier regions in western China can expect increases in irrigation demand. Globally, Fischer et al. (2007) projected that by 2080 two-thirds of irrigation requirement increases can be attributed to warming and changes in precipitation patterns, while the remaining third of increases are due to extended growing seasons in temperature and sub-tropical regions. Overall, global net irrigation requirements increase by over 50% in developing regions and 16% in developed regions. Schaldach et al. (2012) examined changes in irrigation water requirements in 2050 in North African and Europe based on climate and land use change. Depending on the region, climate model, and socioeconomic conditions, demand may decrease by up to 30% or increase by up to 264%, indicating large uncertainties in prediction. For example, in Zimbabwe corn irrigation water requirements were projected to increase by 66% by the 2050s and 99% by the 2090s, although there was considerable uncertainty in these projections (Nkomozepi and Chung, 2012) while for paddy rice irrigation requirements in Korea, mean increases by 2050s and 2090s were projected to be 2.4% and 7.9%, respectively (Chung and Nkomozepi, 2012).

Previous studies that determined the impacts of climate change on irrigation demand examined a small number of models and scenarios and therefore could not capture the wide range of climate model predictions. The proposed study is unique in that ten global climate models (GCMs) combined with four emissions scenarios are used to consider the wide range of uncertainty in climate models and their impact on irrigation demand. Using a limited number of GCMs results in a limited view of