Agricultural Systems ■■ (2014) ■■–■■

Contents lists available at ScienceDirect

Agricultural Systems

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

Impact of prospective climate change on water resources and crop yields in the Indrawati basin, Nepal

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ARTICLE INFO

Article history:
Received 19 April 2014
Received in revised form 7 October 2014
Accepted 21 October 2014
Available online

Keywords:
Climate change impacts
Water balance dynamics
Crop yield
Nepal
Himalaya
SWAT

ABSTRACT

The study aimed at developing a tool to investigate the effect of prospective climate change (until 2100) on hydrology and productivity of rain-fed crops (wheat *Triticum* L., maize *Zea Mais* L., and rice *Oryza* L.) in the Indrawati river basin, Nepal, Himalaya.

Climate scenarios from 3 climate models (GCMs), namely CCSM4, EC-Earth and ECHAM6, each one under 3 different representative concentration pathways (RCPs) were fed to Soil and Water Assessment Tool (SWAT) and hydrological fluxes and crop yields were estimated for two time windows, i.e. half century (2045–2054) and end of century (2085–2094) against control run decade (1995–2004). The results foresee considerable potential changes of hydrological fluxes (from −26% to +37% yearly, with large difference seasonally and between models and RCPs), and potential changes of crop production (−36% to +18% for wheat, −17% to +4% for maize, and −17% to +12% for rice, again with differences between models and RCPs), also in term of yearly variability, potentially affecting food security. The CCSM4T model projected larger changes in hydrology and reduction in crop yields than other models. Wheat was found to be more vulnerable than maize and rice to climate change.

1. Introduction

Agriculture is heavily impacted by climate change, and yield reduction may result in the decline of *food security* worldwide, especially in mountainous areas (Bhatt et al., 2013; Malla, 2008; Olesen and Bindi, 2002; Parry et al., 2004). Agriculture requires much water for irrigation, and worldwide roughly 70% of the water is used by agriculture (Fader et al., 2011; Rost et al., 2008; *e.g.* Konar et al., 2011), and increasingly so under population growth pressure. Most relevant crops for food security are cereals, especially wheat, *Triticum* L., maize *Zea Mais* L, and rice *Oryza* L (Confalonieri et al., 2009; Supit et al., 2010; Torriani et al., 2007; Tubiello et al., 2000), requiring significant amounts of water for production, *i.e.* rainfall and often irrigation during summer or dry season (Bocchiola et al., 2013; Nana et al., 2014). Under climate change the need of water for cropping may increase, requiring adaptation strategies (*e.g.* Bocchiola et al., 2013; Torriani et al., 2007). Effects of climate on agriculture may include (i) effect of CO_2 increase on plant respiration cycle, especially for plants of type C3, and less for type C4 (Jarvis et al., 1999; Leuning, 1995; Morison, 1999), (ii) effects of temperature and rainfall changes (Brouwer, 1988), and (iii) effect of sea level rise, and reduction of cultivable lands (*e.g.* Zanoni and Duce, 2003). Climate change as projected for the 21st century may significantly alter crop production (FAO, 2009; Rosenzweig and Hillel, 1998). The recently issued assessment report 5 AR5 of the Intergovernmental Panel on Climate Change (IPCC) states that negative impacts of climate trends have been more common than positive ones worldwide (IPCC, 2013), and there are between 5 and 200 million additional people at risk of hunger within 2100 (Olesen and Bindi, 2002; Olesen et al., 2007).

This study focused on the Indrawati river basin, Nepal, Himalayas. Nepal's varied topography and social vulnerability make the country particularly susceptible to climate change (Agarwal et al., 2014; Awasthi et al., 2002; Eriksson et al., 2009; Karki and Gurung, 2012; Maskey et al., 2011; Nyaupanea and Chhetrib, 2009; Rai, 2007; Shrestha and Aryal, 2011). In turn, Nepal has low adaptive capacity to respond to the variability due to climate change (Dulal et al., 2010). Small scale (average 0.7 ha), subsistence agriculture is the mainstay of Nepal's economy, employing 78% of the workforce, and contributing nearly 36% of Nepal's GDP (World Bank, 2012). Only 27% of agricultural land has access to irrigation, and it is located above all in the Terai zone (the southern belt along the

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http://dx.doi.org/10.1016/j.agsy.2014.10.016
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Nepal–India boarder), whereas the great part of arable land is rainfed. The effect of recent climate change in Nepal includes rapid temperature increase (Eriksson et al., 2009; Malla, 2008; Rupa Kumar et al., 2006), erratic rainfall pattern, decreased length of Winter, and increased frequency and length of droughts (Sharma and Dahal, 2011). Therefore, the question arises whether present and perspective climate change may impact (negatively) on cropping, and food security locally. Even further, one needs a tool able to provide conjectures on future crop production, usable to develop (i) potential adaptation to climate change, (ii) modified cropping strategies including irrigation, and (iii) assessment and optimization of crop yield, and water usage under prospective climate change.

The objectives of this study were therefore (i) to set up a tool able to accurately mimic the hydrological cycle of the high altitude, topographically complex Indrawati river catchment, based upon climate inputs, (ii) to model accurately crop yield in the area for three key cereal species (wheat *Triticum* L., maize *Zea Mais* L., and rice *Oryza* L.), based upon little available agronomic information, and (iii) to investigate quantitatively the potential effect of prospective climate change scenarios (until 2100) on hydrology and crop production.

We used the Soil and Water Assessment Tool SWAT (Arnold et al., 2010) coupled with climate scenarios from 3 general circulation climate models (GCMs) included within the IPCC (Intergovernmental Panel for Climate Change) fifth assessment report 5AR, to obtain a range of hydrological and crop projections possibly providing a reference for initial assessment of future conditions in the area, and of potential adaptation strategies.

2. Material and methods

2.1. Description of study area

The Indrawati river basin (Fig. 1) extends from latitude 27°37′11″N to 28°10′12″N and longitude 85°45′21″E to 85°26′36″E, nested in the mid-hills of the central region of Nepal, and located about 50 km North-East of Kathmandu (capital city of Nepal). It is one of the seven sub basins of the larger Sapta Koshi basin.

The Indrawati river originates from the Himalayas (over 5850 meters above sea level [masl]), and flows southwards to meet the Sun Koshi River (at 623 masl), which then drains into the Sapta Koshi. Indrawati river is 59 km in length, and has a catchment area of 1228 km^2. The landscape is mostly made of rugged mountains, with occasional plateaus where farming is done, and covers a climatic range from subtropical to polar (Peel et al., 2007). Climate is governed by South Asian monsoon (carrying ca. 93% of total precipitation), and rainfall and snow melt are major sources of inflow. The rest of the year is considerably dry, with roughly 7% of the annual precipitation from November to April. Despite the little precipitation, Winter and Spring flow in the river are noticeable, due to snow melting. Temperatures range from 5 °C to 32.5 °C, and the

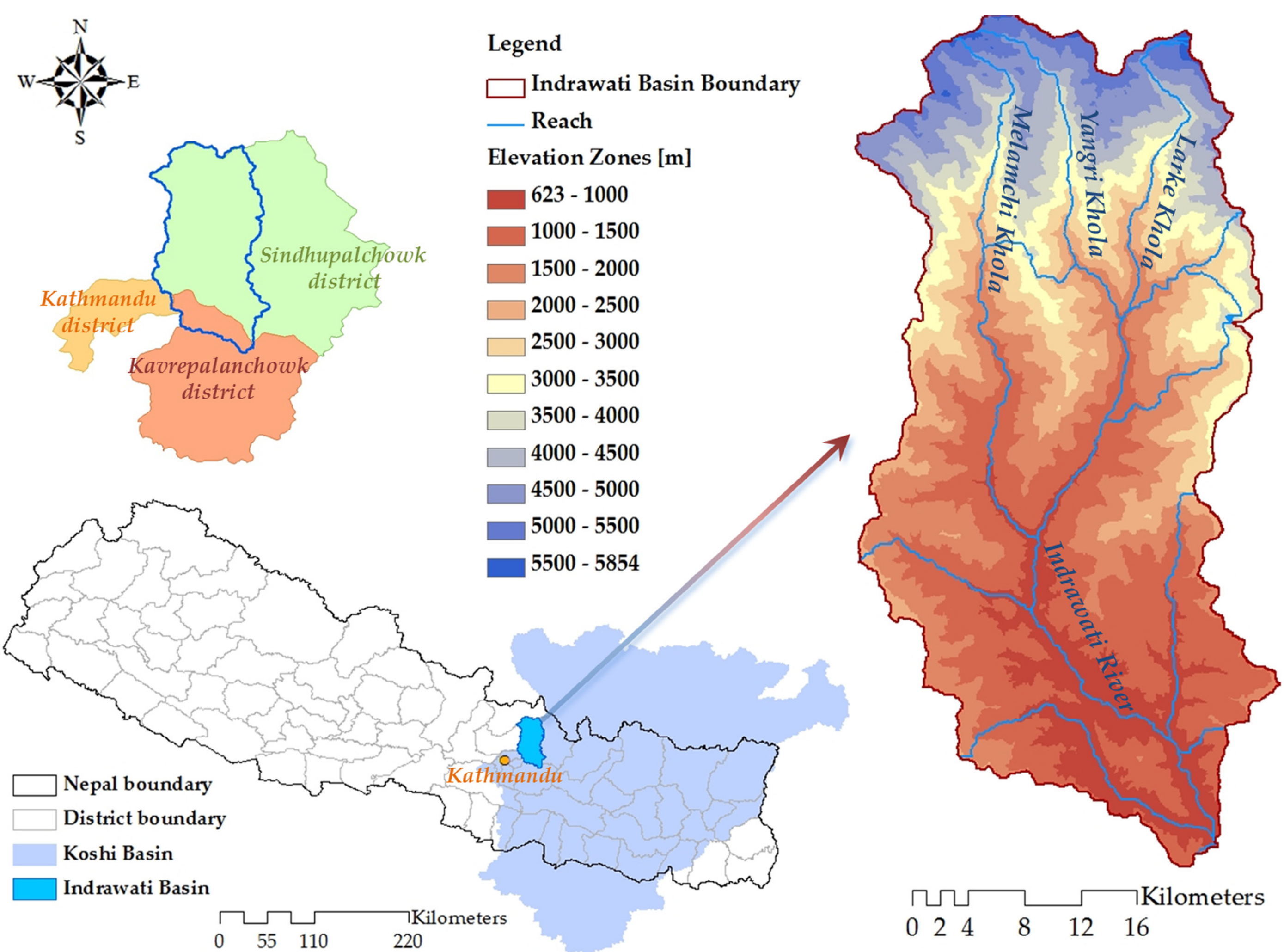

Fig. 1. Case study area. Indrawati basin location and elevation zones.

Please cite this article in press as: I. Palazzoli, S. Maskey, S. Uhlenbrook, E. Nana, D. Bocchiola, Impact of prospective climate change on water resources and crop yields in the Indrawati basin, Nepal, Agricultural Systems (2014), doi: 10.1016/j.agsy.2014.10.016