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Climate change impact assessment on the hydrological regime of the Kaligandaki Basin, Nepal

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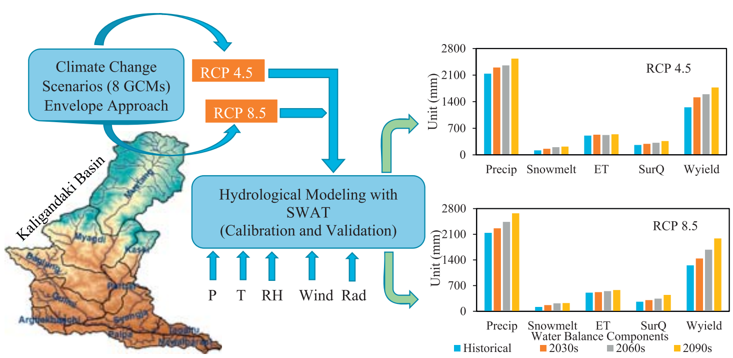
HIGHLIGHTS

- The rise in temperature and increase in precipitation is projected in future in Kaligandaki River basin.
- The water availability in the basin is not likely to decrease during this century.
- The change in water balance in the upper sub-basins of Kaligandaki River is higher.
- The output from this research could be beneficial for water resources management.

GRAPHICAL ABSTRACT



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ABSTRACT

The Hindu Kush-Himalayan region is an important global freshwater resource. The hydrological regime of the region is vulnerable to climatic variations, especially precipitation and temperature. In our study, we modelled the impact of climate change on the water balance and hydrological regime of the snow dominated Kaligandaki Basin. The Soil and Water Assessment Tool (SWAT) was used for a future projection of changes in the hydrological regime of the Kaligandaki basin based on Representative Concentration Pathways Scenarios (RCP 4.5 and RCP 8.5) of ensemble downscaled Coupled Model Intercomparison Project's (CMIP5) General Circulation Model (GCM) outputs. It is predicted to be a rise in the average annual temperature of over 4 °C, and an increase in the average annual precipitation of over 26% by the end of the 21st century under RCP 8.5 scenario. Modeling results show these will lead to significant changes in the basin's water balance and hydrological regime. In particular, a 50% increase in discharge is expected at the outlet of the basin. Snowmelt contribution will largely be affected by climate change, and it is projected to increase by 90% by 2090.Water availability in the basin is not likely to decrease during the 21st century. The study demonstrates that the important water balance components of snowmelt, evapotranspiration, and water yield at higher elevations in the upper and middle sub-basins of the Kaligandaki Basin will be most affected by the increasing temperatures and precipitation.

1. Introduction

The impact of climate change and adaptation measures is perceived as a major contemporary global concern (IPCC, 2014). Increases in global

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surface temperatures, variability of rainfall patterns both spatially and over time, as well changes in the predictability of this variance are all likely to occur over the next century (Trenberth et al., 2003; Alexander et al., 2006; Kharin et al., 2013). The Intergovernmental Panel on Climate Change has defined a series of Representative Concentration Pathways (RCP) scenarios for future climate projection, based on the Coupled Model Intercomparison Project (CMIP5) (van Vuuren et al., 2011). These suggest an average global rise in surface temperature of over 2 °C by the end of the century, compared to the reference period of 30 years from 1986 to 2005. More specifically, the average temperature is projected to increase over 1 °C under a low-emission scenario (RCP 2.6), and over 4 °C under an extreme scenario (RCP 8.5) (Knutti and Sedlácek, 2013). Increase in temperature and precipitation changes can alter regional water balances and hydrological regimes (Poitras et al., 2011; Bolch et al., 2012).

The potential impact of climate change will be more evident in the Himalayan region, where the runoff is dominated, largely, by glacier melt and snowmelt (Viviroli et al., 2007; Immerzeel et al., 2013; Lutz et al., 2014). The average contribution of snowmelt to the annual stream flow across the Hindu Kush-Himalayan region is nearly 20%, with a maximum contribution of >65% in the Indus catchment (Bookhagen and Burbank, 2010). In addition, glacier melt in the Upper Indus region is approximately 32% (Immerzeel et al., 2009). Whereas mean temperatures in the Indus, Ganges, and Brahmaputra (IGB) basin are projected to rise up to 3.5 °C for an RCP 4.5 scenario and 6.3 °C for an RCP 8.5 scenario. Similarly, the projected precipitation of this region is expected to vary between 3% to 37% under RCP 4.5, and RCP 8.5 scenario respectively (Lutz et al., 2016).

The Hindu Kush Himalayan region is one of the most vulnerable regions in the worlds with respect to climate change because of its highly diverse climatic and topographical variations (IPCC, 2007; Kundzewicz et al., 2007). Climate changes are expected to influence millions of people living in the region (Immerzeel et al., 2010). Many researchers have quantified the impact of climate change on the water availability in the snow and glacier dominated catchment of the Himalayan region in Nepal using hydrological and glacier mass balance models (Bharati et al., 2014; Khadka et al., 2014; Shea et al., 2014). Most of this research has used coarse-resolution, General Circulation Model (GCM) or Regional Circulation Model (RCM) based data. GCM resolutions may vary from 300 to 400 km and are not preferred for hydrological modeling in a mountainous catchment (Babel et al., 2014). However, the GCM data can be downscaled to catchment level using observed meteorological data. The downscaled GCM climate data can be used as a forcing data for hydrological models to project stream flow. A fine resolution data-set can significantly improve the projection of stream flow, thereby providing more reliable results.

In this study, we used 10-km resolution data-set developed by Lutz et al. (2016) for the IGB basin, constructed with a particular focus on the improved representation of high-altitude precipitation and temperature. The climate data were then used in a SWAT model to generate future outflows in the basin. The SWAT model was well tested and implemented for different catchments in the Himalayan region yielding good simulation (Bharati et al., 2012; Palazzoli et al., 2015; Dahal et al., 2016).

This study considers the individual contribution of precipitation, snowmelt, evapotranspiration and water yield within the water balance for the Kaligandaki basin, which could help to understand future hydro-climate variability. Previous research had mainly focused on a time-based stream flow in the basin only, often missing out on the other water balance components for instance water yield and evapotranspiration. This paper outlines the impacts of projected temperature and precipitation on different components of water balance in the Kaligandaki Basin in Nepal.

2. Materials and methods

2.1. Study area

The Kaligandaki Basin (Fig. 1) is an important sub-basin of the Narayani Basin in Nepal, which is a major tributary of the Ganges River Basin. It has a catchment area of approximately 11,830 km^2 and is located between 27° 43′N to 29° 19′N and 82° 53′E to 84° 26′E. Elevations within the Kaligandaki Basin varies from 188 to 8143 m, thus marked topographic variations is a feature. The upper region of the Kaligandaki Basin is characterized by high altitudes, low temperatures, and some glacier coverage. Permanent snow covers about 33% of the basin, while over 50% of this snow cover occurs above 5200 m (Mishra et al., 2014). The middle region of the basin is mostly hilly with high altitude terrain; the plains in the South have a sub-tropical climate and high precipitation.

Climate data (precipitation, relative humidity, solar radiation, wind speed, and temperature) collected at Department of Hydrology and Meteorology (DHM) stations throughout the basin were used as input to the SWAT model. In addition, land use data at a 300-m resolution were obtained from the European Space Agency. Global land cover data for 2000, 2005, and 2010 periods were also used in developing the hydrological model. The Soil and Terrain Database Programme (SOTER) provided a soil map at 1:1 million scale for Nepal and China. Separate soil maps were merged for the soil map of the Kaligandaki basin.

2.2. Hydro-meteorological stations in the Kaligandaki basin

The network of hydrological, precipitation and temperature stations used in the SWAT model are given in Fig. 1. Overall, daily data from 14 precipitations, 9 temperature, and 1 hydrological station were used in this analysis from 1995 to 2004.The hydro-meteorological station data for the Kaligandaki Basin were obtained from the Department of Hydrology and Meteorology, Nepal.

2.3. Climate change data for the basin

Lutz et al. (2016)'s climate dataset for the entire IGB basin was based on selected CMIP5 GCMs with a 10 × 10 km spatial resolution and daily time steps. In the IGB dataset, the best GCMs were selected for the region using the 'Envelope' approach, and downscaled by Quantile mapping. In the envelope approach, suitable GCMs are selected from the universal sets of GCMs available covering different range of temperature and precipitation projection. Since the Kaligandaki basin is part of the Ganges basin, their dataset was used for our climate change analysis. Table 1 shows the selected climate model used for this study.

SWAT is a semi-distributed model that does not allow the use of meteorological data in a grid format, hence these were converted to point data in SWAT format. For this purpose, climate data located at the centroid of the unit grid were extracted (Price et al., 2014). To simplify the analysis, only virtual points representing the climatology of the basin were used for the model. Since the stations measuring precipitation and temperature adequately represent the spatial and topographical variation of the basin, only the gridded pixel stations were used for our analysis. This method enabled us also to compare the climate datasets with observed historical datasets for validation. We used GCM climate dataset 1990s (1981–2010) as a reference data and 2030s (Present-2040), 2060s (2041–2070), and 2090s (2071–2100) as a projected future data to see the change in climate between the reference and future projection in the Kaligandaki River Basin.

2.4. Hydrological modeling

Hydrological modeling plays an important role in the analysis of water resources subjected to climate change, especially when attempting to understand its consequences (Praskievicz and Chang, 2009). The hydrological model SWAT was used in this study to simulate future discharge and assess different water balance components in the context of climate change.