Impact assessment of climate change on snowmelt runoff of a snow-dominated mountainous watershed in the western Hindukush-Himalaya region

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1. Introduction

The hydrology and cryosphere of mountainous river basins are expected to be affected by climate change (Wijngaard 2019). The climate change will impact the frequency and intensity of natural hazards, and also surface and groundwater availability will likely be affected (Wijngaard 2019). Temperature increases in high mountain Asia projected towards the end of the 21st century between 1.7 ºC and 6.3 ºC (Lutz et al. 2016). Temperature rise will have a significant impact on human society. The rise in temperature will decline snow and glacier-covered areas, due to the increased melting of snow and ice pack as well as because of lowered accumulation of snowfall in total precipitation (Khadka et al. 2014). Advanced models which have a good representation of mountain hydrological processes can be very useful to solve many of these problems (Wijngaard 2019). Such models need to be calibrated and validated on remotely sensed data or ground observation data and need to apply with downscaled climate change projection scenarios.

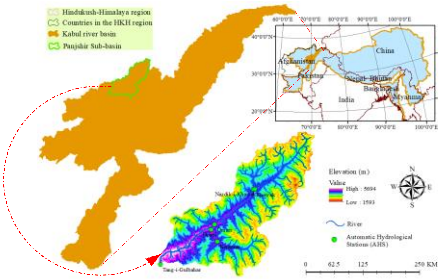

Figure 1. Map of Panjshir sub-basin including Kabul river basin and Hindukush-Himalaya region.

The purpose of this study is to simulate the future distribution of snow and runoff under projected climate scenarios. Previously, the snow model was developed, calibrated and validated with the integration of remote sensing and field observation data and estimated the distribution of snowfall, snowmelt and snow water equivalent in the Panjshir sub-basin (Azizi and Asaoka 2019a). Moreover, this model was combined with the snowmelt runoff model to simulate daily runoff to decrease uncertainties in the parameters for runoff simulation. Runoff simulated and validated using observed and simulated snow cover area (Azizi and Asaoka 2019b). To simulate the future snowfall distribution and water availability, in the present study the developed models were forced by applying climate change scenarios.

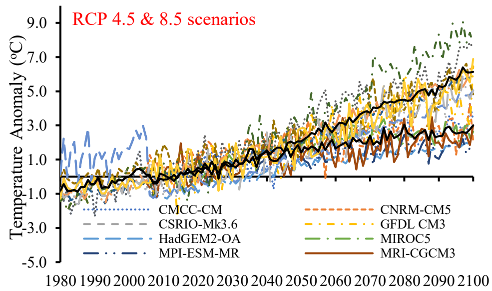

Figure 2. Projected annual temperature from different GCMs and the average of multiple GCMs.

2. Study area

This study is conducted in Panjshir sub-basin having catchment area of approximately 3540 km^2, located in high altitude (ranges from 1593 m to 5694 m) mountainous region of Hindukush, in the upper north part of the Kabul river basin (Figure 1). Snowfall and snowmelt from this watershed provide water to most of the important irrigated lands in the Kabul river basin and supports the life of the people living in the valleys and downstream areas.

3. Datasets and methods

3.1. Data

To calibrate and validate Snow Model (SM) and Snowmelt Runoff Model (SRM), daily temperature, precipitation, and discharge data observed at the hydro-meteorological stations including remotely sensed (MODIS 8-day) snow cover product were used over the period (2009-2015) in the previous studies. In the present study, we used different GCMs (CCDM4, CMCC-CM, CSRIO-Mk3.6, GFDL CM3, HadGEM2-AO, MIROC5, MPI-ESM-MR, and MRI-CGCM3) under RCP 4.5 and 8.5 to assess the impact of climate change in the study area.

Table 1. Mean annual temperature and precipitation in future periods for multiple GCMs and scenarios.

Time Period	RCP Scenarios	Mean Annual Temperature	Mean Annual Precipitation
2040-2060	4.5	+1.45	-4.7%
	8.5	+2.05	-1.7%
2080-2100	4.5	+2.51	-5.4%
	8.5	+5.18	-4.4%

Key Words: GCMs, Panjshir sub-basin, global warming, snowmelt runoff model, snow cover area, water resources management

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3.2. Methodology

Future climate GCMs data for the RCP4.5 and RCP8.5 scenarios were used as shown in Figure 2. First, we subtracted the mean monthly temperature data of the near future (2040-2060) and future (2080-2100) periods from the reference (2009-2019) period, respectively, to bias correct the temperature data. Secondly, the mean monthly precipitation of the reference period was divided into mean monthly precipitation data of near future and future periods, respectively, to bias correct the precipitation data. Finally, the mean monthly temperature and precipitation values for the future periods were obtained. The mean monthly temperature and precipitation values were added and multiplied on daily observed data of temperature and precipitation over the period (2009-2015) as a means of daily data for the near future and future periods. The provided data for these periods were used as inputs in the SM and SRM to simulate the SCA and streamflows in the near future and future periods.

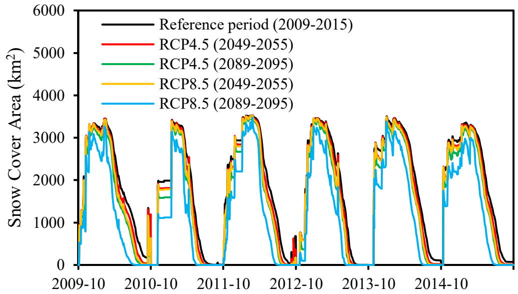

Figure 3. Projected SCA during (2009-2015) and under climate RCP4.5 and 8.5 scenarios over the future periods.

4. Results and discussions

4.1. Projected Snow Cover Area (SCA) and streamflows

The change in mean annual temperature and precipitation shown in Table 1. The effect of climate change on the SCA was estimated from the SM by applying the RCP scenarios for (2049-2055) and 2089-2095) periods and compared to reference period (2009-2015) to evaluate the changes. The results showed that there was approximately 7% and 12% decrease under RCP4.5 and 8.5 in the mean annual SCA, respectively over the period (2049-2055). Similarly, under the same RCP scenarios mean annual SCA showed a decrease of 15% and 34% during (2089-2095). In the same way, the daily discharge was simulated from the SRM by applying climate change scenarios. The results obtained after applying RCP4.5 and 8.5 for (2049-2055), showed a decline of 7% and 13% in the mean discharge, respectively. The results found after applying RCP4.5 and 8.5 for (2089-2095), showed a decline of 25% and 43% in the mean discharge, respectively.

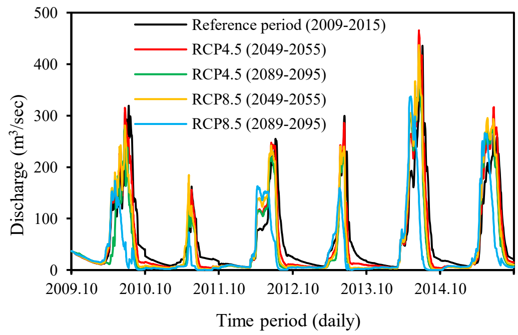

Figure 4. Projected runoff during (2009-2015) and under climate RCP4.5 and 8.5 scenarios over the future periods.

5. Conclusion

Application of SM under climate change projections suggested a decrease of 7% to 34% and 7% to 43% SCA and discharge, respectively for mid to late 21st century under different RCP scenarios in the Panjshir sub-basin. Climate model data suggest that the average annual temperature will increase from 1.45 to 5.18 ºC and precipitation will decrease by 1.7% to 5.4%. The snowfall is likely to decrease and also the increase in temperature both resulted in decreased snow storage capacity and runoff in the basin.

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