Executive summary

Three largest perennial rivers of Nepal, which originate from the Himalayas, are fed from snow melt-water. Many studies have shown that the temperature is going to increase due to increase in greenhouse gas emissions. Climate change will contribute to increased variability of river runoff due to changes in timing and intensity of precipitation as well as melting of glaciers. In this context, the main objective of the study is to study the impact of climate change on discharge of major rivers of Nepal: Koshi, Narayani, Karnali.

The methodology of the study consists of two parts. The first part consists of developing a hydrological model for the basins for assessing the impact of climate change. The second part is the climate modeling. For hydrological modeling, HEC-HMS model was selected as it is freely available, user friendly, widely applied in Nepal and has many modules. The model was calibrated and validated using historical rainfall and discharge data at selected stations. For climate change analysis, CANESM2 general circulation model (GCM) was selected as data from this model is easily downloadable from this model and predictors are readily available for downscaling. This model is one of the models applied in IPCC Fifth Assessment Report (AR5). SDSM (Statistical Downscaling Model) was applied for downscaling grid data to station data. A bias correction equation was applied to correct any bias in downscaled data. The bias corrected precipitation was fed to obtain the projected discharge due to the climate change. Decadal trend analysis of the historical climate data including temperature and rainfall was carried out using the software RClimDex. Comparison of current and future flows at major outlets of the study basin was carried out using Indicators of Hydrologic Alteration (IHA) software. Both these softwares are available freely. Trend analysis of past climate data did not show any particular pattern or trend of climate change, although natural climatic variability was clearly observed. Similar nature of results was observed in all the three study basins.

The basin characteristics were derived from freely available SRTM DEM. Historical rainfall data was prepared for 1980-2010 time period. Rainfall stations having continuous record during this period and possibility of filling few missing values were selected in the study. Many rainfall stations were discarded due to the unavailability of continuous data. The basin average precipitation was prepared by Thiessen polygon method. Discharge stations were also selected based on the availability of quality data. The latest available data after 1990 was used for the hydrological model calibration and validation. A basin was divided into a number of subbasins and parameters were calibrated manually and automatically using the historical discharge data available at outlet stations. The performance of the model is satisfactory in terms of statistical performance measures as well as visual plots.

Basin	**Data**	**Hydrological stations data used**	**No. of rainfall stations used**
Koshi	Calibration: 1990-1999 Validation: 2000-2005	Pachuwarghat, Rabuwa, Hampachuwar, Turkeghat, Majhitar, Chatara	34
Narayani	Calibration: 1990-1999 Validation: 2000-2006	Betrawati, Arughat, Shisaghat, Kotagau, Narayanghat	21
Karnali	Calibration: 1990-1999 Validation: 2000-2006	Benighat, Banga, Jamu, Chisapani	14

Three RCP (Representative Concentration Pathways) scenarios of CANESM2 model were considered: RCP2.6 (very low greenhouse gas concentration levels), RCP4.5 (stabilization scenario), RCP8.5 (high greenhouse gas concentration levels). RCPs are based on radiative forcing, which consider the change in the balance between incoming and outgoing radiation to the atmosphere. Subbasinwise downscaled and bias corrected precipitation for the three scenarios were prepared for assessing the impact of climate change on flow. The climate change analysis was carried out for three future time windows – immediate/near future (2011-2040), mid-term future (2041-2070) and long-term future (2071-2100). CanESM2 GCM AR5 data was found to represent the climate of Nepalese basins well. Performance of SDSM in downscaling the GCM precipitation was also found to be satisfactory. Calibrated SDSM model was found to successfully capture the average monthly precipitation trend and also able to match the peak values. But it was found to relatively over estimate the dry season precipitation. Bias correction and calibration and validation at the monthly level were also satisfactory.

Comparison of future discharge with the baseline period showed consistent increase for all the selected stations, the maximum values being predicted in the long-term future towards the end of the century. The magnitudes of the increase were found to be varying with station and an early shift in the onset of monsoon could be predicted in future for all the stations analyzed. Daily hydrographs thus generated showed increase in the magnitude and frequency of peaks could be expected in the future. However, no particular trend or pattern of correlation between the precipitation and discharge or temperature and discharge was observed in the selected stations of the three study basins.

The current study of climate change was based on data from only one GCM. Although downscaling and bias correction were carried out satisfactorily, the results that are presented in this report are obtained from the use of a single GCM data. Therefore, it is recommended that similar study needs to be carried out using an ensemble of a number of other GCM datasets in order to quantify with confidence the impacts of climate change on the study basins.