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Future Climate Stress on Drinking Water of Kavre Valley: Case of Upper Roshi River

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SUMMARY

This chapter assesses the future climate change impact on the water discharge of the Upper Roshi River (86.2 km^2 catchment area), which is the primary water source for Kavre Valley Integrated Water Supply Project (KVIWSP). The 'abcd'[1] *hydrological model was run under three Representative Concentration Pathway (RCP)*[2] *scenarios- 2.6, 4.5 & 8.5 against the climatic variables projected by the Statistical Downscaling Model (SDSM)*[3] *in the future for the entire period of 21st century. Assessment of the future stream flow shows that there could be a slight increase, to a maximum of 14%, in mean annual discharge by 2050 with reference to the baseline period (1971-2014). Seasonal discharge analysis shows a slight increase in the discharge in winter, monsoon and pre-monsoon, but a very slight decrease in the post-monsoon season throughout the different future time windows under all RCP scenarios. Though there are evidences of climate change, no significant impact of climate change is detected in the future causing a deficit or extreme flows of the water source areas of KVIWSP provided the water infrastructures work properly. However, this study has not considered the changes in land use/land cover, as well as, future water demands resulting from socioeconomic and demographic changes.*

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[1] abcd water balance model is a simple hydrological model for simulating streamflow in response to precipitation and potential evapotranspiration

[2] RCP are newly developed greenhouse gas emission scenarios and adopted in the IPCC's fifth assessment report AR5

[3] SDSM is a decision support tool for assessing local climate change impacts using robust statistical downscaling technique

1. INTRODUCTION

The impact of climate change on water resources is affecting the quality and quantity of water in many regions due to changing precipitation, and altering hydrological cycle (IPCC, 2014). Climate change is likely to worsen current stress on water resources, and one of the challenges is to respond to the uncertainties associated with future climatic conditions and the water need of rapidly growing urban populations (Broto and Bulkeley, 2013). It is estimated that by 2025, almost two-thirds of the world's population is likely to experience some kind of water stress, and for one billion of them, the shortage will be severe and socially disruptive (UNEP, 2004).

A higher rate of rising temperature than the global average (Shrestha and Aryal, 2011; Duncan et al., 2013), erratic rainfall with a greater spatial and temporal variability (SAGUN, 2010; Duncan et al., 2013) and a prolonged drought spell (Karki et al., 2017) have been reported recently in Nepal, which clearly indicate the growing impact of climate change. Consistent with these research findings, Nepal is already considered the 14th most vulnerable country in the world according to the climate change vulnerability index (Eckstein et al., 2017). The effect of water scarcity has already been realized in many villages due to the drying up of local spring sources (Dhakal et al., 2010).

The observed and predicted changes in the climate parameters are likely to alter Nepal's hydrological systems (MoE, 2010) where river discharges are more sensitive to precipitation change than temperature change (WECS, 2011). Climate change affects different aspects of the local hydrology of a river such as the timing of water availability, quantity and quality (Babel et al., 2014; Shrestha and Aryal, 2011; Gautam and Acharya, 2012). Fluctuations in the stream flow affect water availability, which has direct consequences on the livelihood of the people heavily dependent on stream flow for agriculture. It also has a potential impact on the economic development of the country, whose economy largely depend on agriculture and hydropower development. The combination of variability and uncertainty regarding future changes due to climate change is perceived to make water resources planning very challenging (Bharati et al., 2014).

Most of the hydrological studies have been conducted in the larger river basins of Nepal such as the Indrawati (Sijapati et al., 2014), Koshi (Sharma et al., 2000; Agarwal et al., 2014; Bharati et al., 2014; Devkota and Gyawali, 2015; Rajbhandari et al., 2016), Karnali (Pandey et al., 2019) and Bagmati (Sharma and Shakya, 2006). There is limited hydrological study conducted on small rivers like Roshi (Dahal et al., 2019), which limits thorough assessment of the link between changing climate and stream flow. Moreover, there is a notable lack of studies on the projection of future climate change scenarios for the Roshi River.

In this scenario, this chapter presents the findings of a study conducted in an upper Roshi River, with an objective of assessing the projected changes in bulk water resources due to climate change for the entire period of 21st century. The watershed has significant importance for future discharge to meet the objectives of the Kavre Valley Integrated Water Supply Project (KVIWSP). The project, with financial support from the Asian Development Bank (ADB), is under construction for the drinking water supply to the towns namely Banepa, Panauti and Dhulikhel of Kavre Valley. The expected primary source of water for this project is the headwaters of the Roshi River. The project is designed to divert 77.33 liter/sec of fresh water from tributaries of Roshi River: Muldol (35 liter/second), Sisha khani (25 liter/second), Baira Mahadev (7.5 liter/second), Gudgude (5 liter/ second) and Khar (5.23 liter/second). Hence, this river is socio-economically significant for the Kavre Valley. Therefore, it is very important to quantify the climate impacts in order to identify the adaptation options and, thereby, minimize the potential risk of climate change at the local level.

In the following section of this chapter, the authors present the brief overview of the study area and methodologies adopted. The findings section include the results obtained from trend analysis of observed data of precipitation and temperature, 'abcd' hydrological model under three RCP scenarios (2.6, 4.5 & 8.5) against the climatic variables projected by the Statistical Downscaling Model (SDSM) in the future for the entire period of this century. Finally, the chapter ends with conclusions and way forward.

2. STUDY AREA AND METHODOLOGY

The study area comprises of the upper Roshi River. The Roshi River as shown in Figure 1 and 2 starts from small tributaries in Kavre and Lalitpur districts and is entirely rain-fed. The required hydro meteorological data for the study was collected from the nearby hydrological and meteorological stations of the Department of Hydrology and Meteorology (DHM, 2017) as described in Table 1. The overall methodology consists of downscaling of the temperature and precipitation data with the help of Statistical Downscaling Model (SDSM), then SDSM again was applied for the projection of the future temperature and precipitation data under different RCP scenarios. The 'abcd' hydrological model was used for the hydrological analysis and calculation of the future discharge with the help of projected temperature and precipitation data. RClimDex[4] was used to assess the climate stress through the trend analysis of the observed temperature and precipitation data taken from the DHM.

The hydro meteorological data required for the study was collected from different stations of the Department of Hydrology and Meteorology (DHM, 2017) as described in Table 1.

Table 1
Meteorological and hydrological data station of the study area

Station Name	Type	DHM Index No.	Altitude in meter	Latitude	Longitude	Data Availability
Roshikhola, Panauti	Hydrological (Daily)	640	1480	27°34'50" N	85°30'50" E	1964-1987
Godawori	(Temperature, precipitation) (Daily)	1022	1400	27°21'N	85°14'45" E	1971-2014
Khopasi	Precipitation (Daily)	1049	1517	27°21' N	85°18'36" E	1971-2014

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[4] RClimDex is a software package designed to provide a user friendly interface to calculate indices of climate extremes for monitoring and detecting climate change

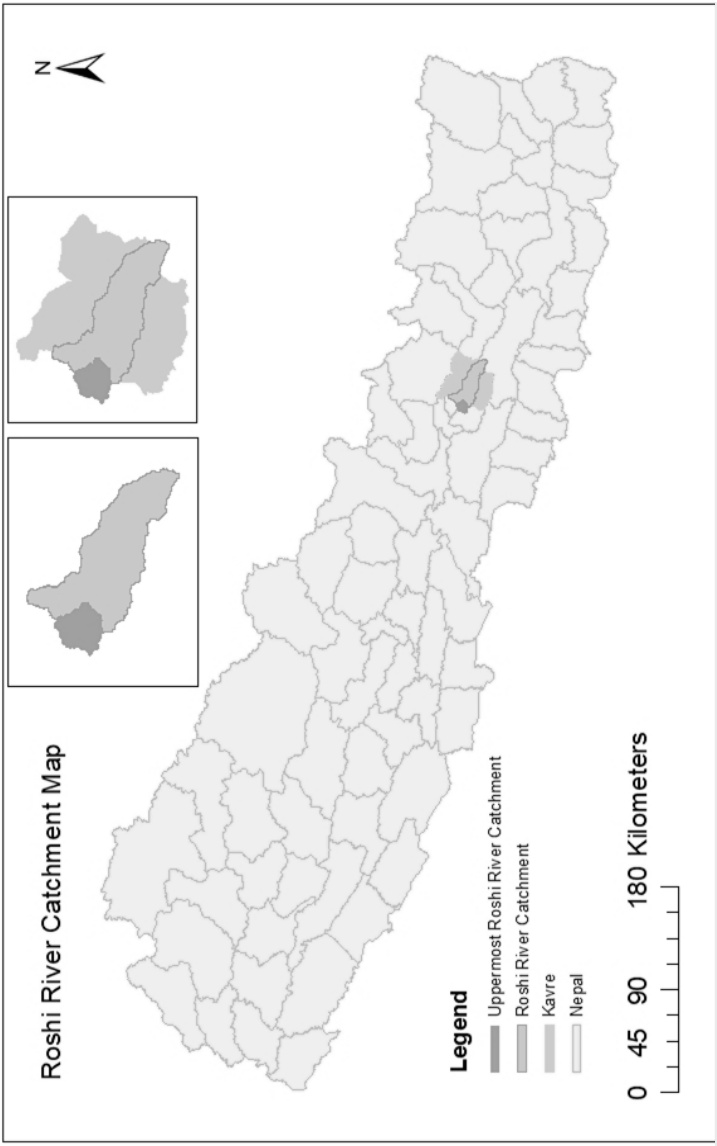


Figure 1 Study Area, Upper Roshi River in Kavre District, Nepal.

Daily precipitation data for the period 1971 to 2014 were collected from the Godawori and Khopasi stations, which were later extrapolated using the Thiessen Polygon method. Daily temperature data for the same period of 1971-2014 from the Godawori station, and the daily discharge data for the period 1964-1987 were collected from the Roshi Khola, and Panauti hydrological stations. Figure 2 describes the upper Roshi River with meteorological and hydrological stations.

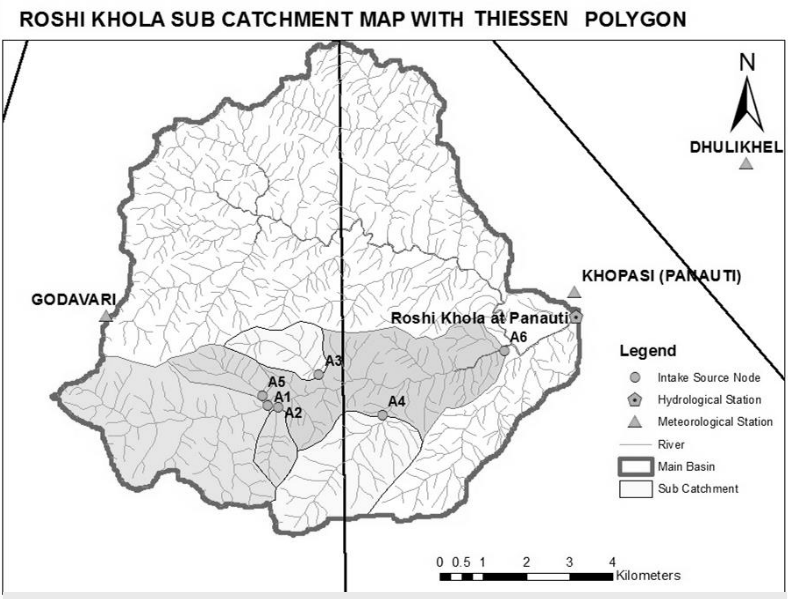


Figure 2 Upper Roshi River (total catchment area = 86.2 km^2) with locations of the meteorological and hydrological stations.

The available observed historical data sets of precipitation and temperature (1971-2005) were divided into two groups. The data sets from 1971-1995 (25 years) were taken for the calibration and 1996-2005 (10 Years) were taken for the validation for both temperature and precipitation.

Using downscaled results, projected changes in maximum/ minimum temperature and precipitation for three periods; 2011-2040, 2041-2070 and 2071-2100 (addressed as 2020s', 2050s', and

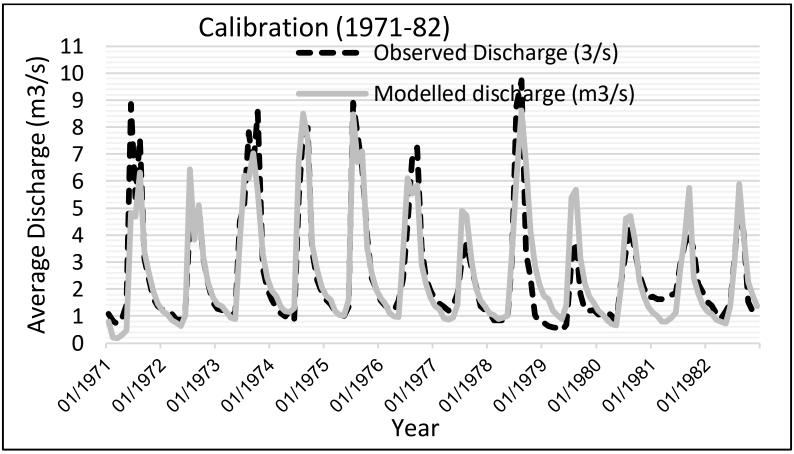
2080s'), relative to the baseline period 1971-2014 were calculated for all the stations under three RCP scenarios. After calibration and validation of the 'abcd' hydrological model, it was run to calculate the future discharge of the river for three different RCP scenarios RCP 2.6, RCP 4.5, RCP 8.5 for the period 2006-2100. The period of 1964-1987 was taken as the baseline and the future discharge for three periods: 2011-2040, 2041-2070, and 2071-2100 (addressed as 2020s', 2050s', and 2080s'), were calculated for all the stations under three RCP scenarios.

2.1. Evaluation of the 'abcd' model performance

The accurate performance of the 'abcd' hydrological model was assured with the help of calibration and validation of the modeled discharge with respect to the observed data. The 17 years available data set of discharge from 1971 to 1987 was divided into two parts. The first 12 years data from 1971 to 1982 was taken for the calibration and the latter 5 years of data from 1983 to 1987 was taken for the validation of the model. The evaluation of the model with the statistical parameters: Root Mean Square Error (RMSE), Nash-Sutcliffe Efficiency (NSE), Pearsons' Correlation coefficient (r), Coefficient of Determination (R^2), and RMSE- observations Standard Deviation Ratio (RSR) was found to be in the acceptable range of performance for the model. The NSE of the model was noted to be 82% and 74% for the calibration and validation periods, respectively. Likewise, R^2 was found to be 0.83 and 0.79, respectively, showing the goodness of fit for the observed and simulated data. The results are tabulated as below in Table 2:

Table 2
'abcd' model calibration and validation

	NSE	RMSE	r	R^2	RSR
Calibration 1971-1982	0.82	0.89	0.91	0.83	0.42
Validation 1983-1987	0.74	1.13	0.89	0.79	0.51



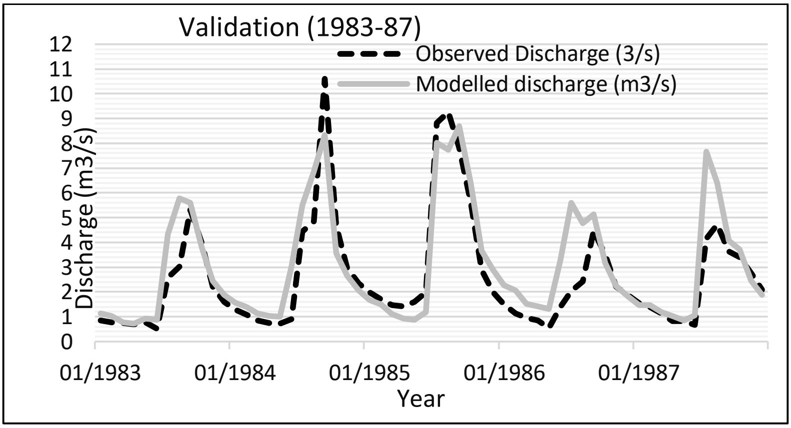


Figure 3 Observed and modeled monthly hydrograph of upper Roshi River for the calibration and validation periods respectively

2.2. Evaluation of the performance of SDSM

The first set of data for 25 years (1971-1995) was considered for the calibration and remaining set of data for 10 years (1996-2005) was considered for the validation as the observed data sets were taken from climate stations monitored by DHM; the simulated data sets were generated by the model SDSM. The statistical results are shown in Table 3, namely, Root Mean Square Error (RMSE), Nash-Sutcliffe Efficiency (NSE), Pearsons' Correlation coefficient (r), Coefficient of Determination (R^{2}), and RMSE- observations Standard Deviation Ratio (RSR). The efficiency was observed to be 94% and 88% for maximum temperature, 97% and 98% for minimum temperature, and 76% and 79% for precipitation for the calibration and validation periods, respectively. The goodness of fit was found 0.94 and 0.93 for maximum temperature, 0.97 and 0.98 for minimum temperature, and 0.77 and 0.79 for precipitation for the calibration and validation periods, respectively, indicating reasonable performance of the model.

Table 3
Statistical evaluation of SDSM performance for calibration and validation periods with NCEP/NCAR

Maximum Temperature (TMax)									
RMSE		NSE		r		R^2		RSR	
1971-1995	1996-2005	1971-1995	1996-2005	1971-1995	1996-2005	1971-1995	1996-2005	1971-1995	1996-2005
1.05	1.32	0.94	0.88	0.97	0.96	0.94	0.93	0.25	0.35
Minimum Temperature (TMin)									
0.99	0.79	0.97	0.98	0.98	0.99	0.97	0.98	0.18	0.14
Precipitation (PPT)									
78.93	79.15	0.76	0.79	0.88	0.89	0.77	0.79	0.49	0.46

3. DATA ANALYSIS AND RESULT

3.1. Precipitation

The trend analysis for the precipitation daily data of the Godawori (1022) and Khopasi (1049) weather stations for the period of 1971-2014 was done. For this data period, the analysis showed that RX1day (24-hour precipitation) was decreasing in both Godawari and Khopasi stations at rates of 0.18 to 0.69 mm per year respectively. The values were not statistically significant as both the stations have partial p-values not less than 0.05. Similarly, consecutive dry days (CDD) showed an increasing trend at the rates 0.62 and 0.63 days per year, for Godawori and Khopasi respectively, mostly with mild trend, which was statistically significant for the station 1022 only. The analysis of the consecutive wet days (CWD) shows decreasing trends at both the stations at rates of 0.04 to 0.12 days per year, respectively, with statistically significant value for the station 1022. The index R95p (very wet days) shows decreasing trends for both the stations from 3.23 to 4.38 mm per year, respectively. The result was not found to be statistically significant at both the stations. Similarly, R99p (extremely wet days) values also has the gentle decreasing trend from 1.82 to 3.42 mm per year, respectively, for both the stations. The result was observed to be statistically significant only for the station 1022. Likewise, PRCPTOT showed a decreasing trend in both the stations at the rates of 6.45 mm and 10.12 mm per year, respectively with a statistically significant result for the station 1022.

Hence, the precipitation trend was observed to be similar at both the stations with most of the indices showing a decreasing trend with gentle slope, resulting in low statistical significances which represents the change in climate.

3.2. Temperature

The trend for the monthly maximum value of the daily maximum temperature (TXx) was observed to show a statistically significant increasing trend at the rate 0.05 ℃ per year. Similarly, the monthly minimum value of the maximum temperature (TNx) was also found to be increasing at a rate of 0.03 ℃ per year, which was also statistically significant. Likewise, monthly maximum value of the daily minimum temperature (TXn) was also seen to increase at the rate of 0.06 ℃ per year, which was statistically significant. Besides the above mentioned temperature indices, the monthly minimum value of daily minimum temperature (TNn) was found to be decreasing at a rate of 0.02 ℃ per year with no statistical significance. The monthly mean difference between maximum and minimum temperature (DTR) was, however, observed to show a statistically significant increasing trend at a rate of 0.07 ℃ per year.

Hence, most of temperature indices were noted to have an increasing trend with statistically significant results, with the exception of monthly minimum value of the daily minimum temperature (TNn), which suggests that the rates of change actually represent a changing climate.

3.3. Future climatic variables projection

Downscaling of the future maximum temperature, minimum temperature and the precipitation under RCP 2.6, RCP 4.5 and RCP 8.5 scenario was done for the period of the 2006 to 2100 by SDSM. The future trend analysis of the climate variables was carried out in three time windows 2011-2040, 2041-2070 and 2071-2100 which are considered as the 2020's, 2050's and 2080's, respectively, from here onwards. The observed datasets of temperature and precipitation for the period 1971-2014 and of discharge for the period 1964-1987 are referred to the baseline.

3.3.1. Future Maximum Temperature (TMax)

The simulated future maximum temperature shows a slight increase in all the scenarios and time windows except a very slight decrease in the maximum temperature in 2020's for RCP 2.6 and RCP 4.5 by 0.05 and 0.07 ℃ respectively compared to the baseline. The highest increase in the TMax was found in RCP 8.5 in 2080's of 0.67 ℃. The overall trend of the maximum temperature was found to be increasing in the RCP 4.5 and RCP 8.5, but almost normal trend in the RCP 2.6 by 2100 as shown in Table 4 and Figure 4 below.

Table 4
Future change in average annual maximum temperature (TMax) under RCP 2.6, 4.5 and 8.5 scenario with respect to baseline

Annual Average TMax (C)									
Baseline	RCP 2.6			RCP 4.5			RCP 8.5		
	2020s'	2050s'	2080s'	2020s'	2050s'	2080s'	2020s'	2050s'	2080s'
22.01	21.96	22.07	22.02	21.95	22.14	22.23	22.02	22.31	22.68
Change(C)	-0.05	0.06	0.01	-0.07	0.12	0.22	0.01	0.30	0.67

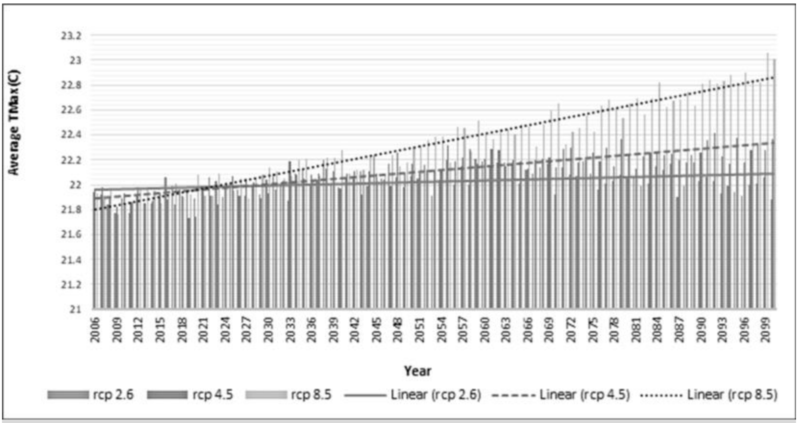


Figure 4 Annual Average Maximum Temperature distribution over the period 2006-2100

3.3.2. Future Minimum Temperature (TMin)

The simulated future minimum temperature (TMin) follows the increasing trend in all the time windows under all RCP scenarios with reference to the baseline. The increment in the mean annual temperature ranges from 0.64 ℃ (RCP 4.5, 2020's) to 1.91 ℃ (RCP 8.5, 2080's). Though there was no distinct increasing trend for RCP 2.6, there was a higher slope for an increase in the future temperature for scenarios RCP 4.5 and RCP 8.5 by the end of this century.

Table 5
Future change in average annual minimum temperature (TMin)
under RCP 2.6, 4.5 and 8.5 Scenario with respect to baseline (1971 to 2100)

Annual Average TMin (C)									
Baseline	**RCP 2.6 (C)**			**RCP 4.5 (C)**			**RCP 8.5 (C)**		
	2020s'	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**
11.44001	12.12	12.33	12.29	12.08	12.34	12.50	12.17	12.71	13.35
Change	0.68	0.89	0.85	0.64	0.90	1.06	0.73	1.27	1.91

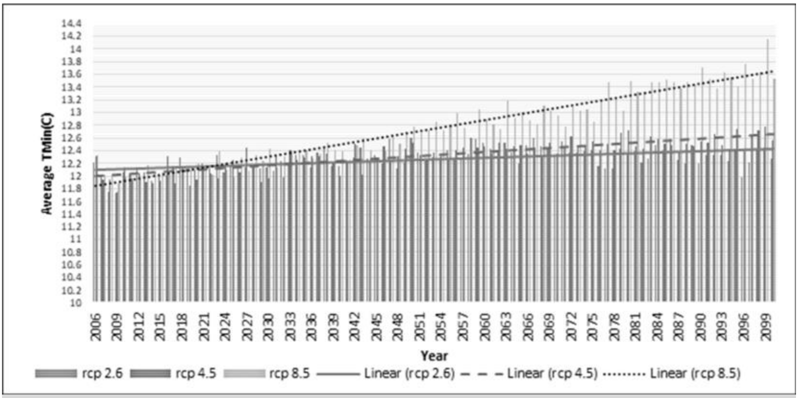


Figure 5 Future Average Annual Minimum Temperature (TMin) projection over the period 2006-2100

3.3.3. Future Precipitation (PPT)

The projection of the future precipitation does not show any specific trend explicitly under all RCP scenarios by the end of this century. Though, the trend line shows very slightly decreasing trend for the mean annual precipitation in most of the time windows under the RCP scenarios, there is increase in the mean annual precipitation with reference to the baseline. While moving from 2020's to 2080's, a slight decrease was found in the annual mean precipitation in most of the time windows and RCP scenarios, with the exception of a slight increasing trend from 2020's to 2050's under RCP 2.6. The highest precipitation was found in July and the lowest precipitation value occurred in November.

Table 6
Future change in average annual precipitation (PPT) under RCP 2.6, 4.5 and 8.5 Scenario with respect to baseline (1971 to 2100).

Sum of PPT, annual average(mm)									
Baseline	**RCP 2.6 (mm)**			**RCP 4.5 (mm)**			**RCP 8.5 (mm)**		
	2020s'	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**
1597	1737.04	1764.39	1720.63	1743.27	1730.10	1718.98	1721.22	1661.54	1662.02
Change	140.04	167.39	123.63	146.27	133.10	121.98	124.22	64.54	65.02

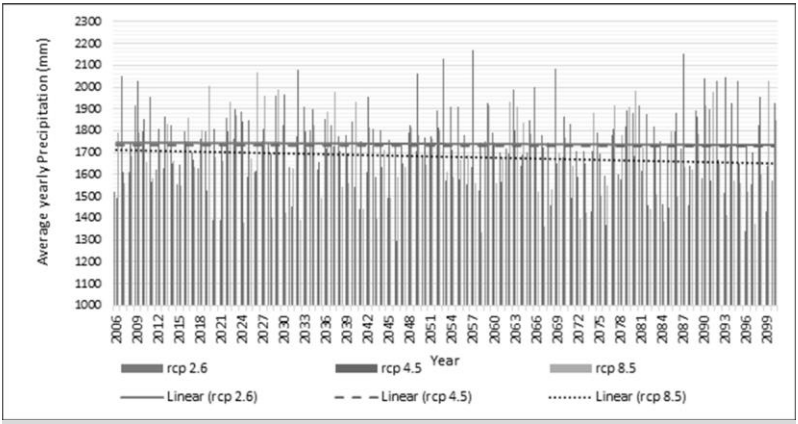


Figure 6 Future Average Precipitation (PPT) projection over the period 2006-2100

3.4. Impact of future climatic change on stream flow

The main objective of this study was to project the future stream flow of the upper Roshi River based on the future downscaled precipitation and temperature data under the different RCP scenarios for chosen time windows. No significant increasing or decreasing trends in stream flow were observed, but a slight increase in the mean annual discharge in the future with reference to the baseline was predicted as shown in the table and figures below. Though, there is no distinct projected change in the discharge of the future stream flow under different RCP scenarios with reference to the baseline, a slight increase in the mean annual discharge was noted, with highest discharge (2.81 m^3/s) projected in 2050's RCP 2.6 and the lowest discharge (2.54 m^3/s) is projected in 2050's, RCP 8.5 (Table 7 and Figure 7).

Table 7
Percentage change in mean annual discharge with respect to baseline period

% Change in average annual discharge with respect to baseline										
Discharge	**Baseline**	**RCP 2.6 (m^3/s)**			**RCP 4.5 (m^3/s)**			**RCP 8.5 (m^3/s)**		
		2020s'	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**
Mean (m^3/s)	2.458	2.689	2.810	2.675	2.733	2.683	2.687	2.649	2.547	2.553
Change	-	0.231	0.352	0.217	0.275	0.225	0.229	0.191	0.089	0.095
% Change	-	9.39%	14.32%	8.81%	11.18%	9.13%	9.33%	7.78%	3.63%	3.85%

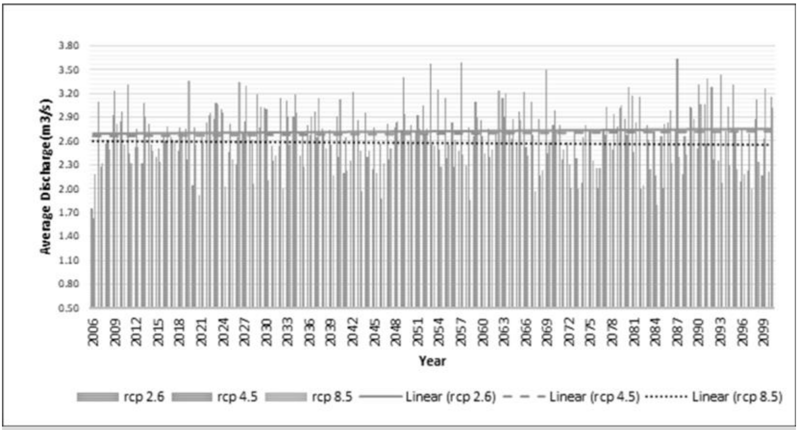


Figure 7 Future Average Discharge projection over the period 2006-2100.

3.5. Impact of future climatic change on seasonal stream flow

As climatic variations are more likely supposed to affect the seasonal flow, the analysis of the future stream flow was done for four seasons. The result showed an increase in the stream flow during the pre-monsoon (March–May), monsoon (June–September) and winter (December–February) seasons, and a decrease in the post-monsoon (October–November) season throughout the various future time windows under all RCP scenarios (Tables 8 & 9). The highest increase (21.28%) in the discharge is seen in winter in 2050's, RCP 2.6, and the highest decrease (3.74%) is seen in the post-monsoon for the time window 2050's, RCP 8.5 with reference to the baseline (which is 1971-2014). The pre-monsoon season has a lower rate of increase in the discharge in comparison to the monsoon and winter season has the higher rate of increase in the future discharge under all RCP scenarios.

Table 8
Mean seasonal flows of Roshi River.

Average Seasonal Discharge (m3/s)										
Seasons	**Baseline**	**RCP 2.6**			**RCP 4.5**			**RCP 8.5**		
		2020s'	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**
Pre-monsoon	0.966	1.017	1.012	1.024	1.002	1.015	0.979	1.002	0.947	0.978
Monsoon	4.313	4.865	5.037	4.763	4.965	4.804	4.828	4.750	4.536	4.427
Post-monsoon	2.671	2.613	2.855	2.667	2.653	2.669	2.681	2.627	2.571	2.719
Winter	1.327	1.509	1.609	1.546	1.540	1.531	1.545	1.510	1.480	1.517

Table 9
Percentage change in mean seasonal discharge with respect to baseline.

Percentage change in average seasonal discharge with respect to baseline									
Seasons	**RCP 2.6**			**RCP 4.5**			**RCP 8.5**		
	2020s'	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**	**2020s'**	**2050s'**	**2080s'**
Pre-monsoon	5.29%	4.74%	5.98%	3.72%	5.04%	1.37%	3.74%	-1.93%	1.29%
Monsoon	12.80%	16.78%	10.43%	15.13%	11.38%	11.94%	10.13%	5.17%	2.64%
Post-monsoon	-2.16%	6.89%	-0.14%	-0.68%	-0.08%	0.37%	-1.63%	-3.74%	1.79%
Winter	13.68%	21.28%	16.50%	16.06%	15.38%	16.45%	13.78%	11.54%	14.33%

3.6. Future discharge analysis of the Kavre Valley Integrated Water Supply Project (KVIWSP)

The designed water discharge for KVIWSP is 77.73 lps from five different nodes at Roshi River, while the dry season measured discharge (2014 March) was 160 lps (KVIWSP, 2014). The analysis of the future discharge in the 5 different source nodes of the project was conducted comparing the result of available discharge measured with the designed discharge as explained in the table below.

Table 10
Node-wise water discharge of KVIWSP.

S.N	Stream/River	Sub-basin	Designed water discharge for KVIWSP (lps)	Measured discharge in March 2014 (lps)
1	Muldole/Roshi	A1	35	76
2	Baira Mahadev	A2	7.5	20
3	Gudgude	A3	5	13
4	Kharkhola	A4	5.23	24
5	Sishakhani	A5	25	27
Total			77.73	160

Source: KVIWSP, EMP 2014

As the projected discharge of the watershed in the future under different RCP scenarios is projected to have a trend of slight increase in the discharge during the winter, pre-monsoon and monsoon seasons, there is no significant climate change impact causing a deficit or extreme flows of water at the source nodes. However, there could be some stress in water availability at the source nodes during the post-monsoon season. Hence, the Sishakhani source node is more likely to be sensitive in post-monsoon as this source node has only a 2 lps surplus discharge compared to the designed discharge.

4. CONCLUSION AND WAY FORWARD

Future discharge of the upper Roshi River was assessed with respect to the future climatic variables (temperature, precipitation) using 'abcd' hydrological model and SDSM climate models. Assessment of the future stream flow of the Roshi River shows that there will be slight increase up to maximum of 14% in mean annual discharge in 2050's. Seasonal discharge analysis shows slight increase in the discharge in winter, monsoon and pre-monsoon but a very slight decrease during the post-monsoon season would occur. This indicates that if water supply infrastructure is in place to store and transfer water, then the problem of water deficit due to any changes in seasonal flow over time could be managed (Bharati et al., 2014). Moreover, such change in stream flow will increase the intensity of floods and droughts with substantial impacts on the water resources at local and regional levels (Barnett et al., 2005). A recent study conducted by Joshi et al. (2019) indicates that the community of the Roshi River had already experienced heavy flooding during the monsoon which destroyed the lives and livelihoods of the local people. The risks associated with such extreme events will also affect the development of water supply infrastructure. Therefore, changes in flow volumes or water balance components from climate change might not affect development plans, if managed properly. Hence, increases in variability, including extreme events such as flood risk needs to be taken into consideration while planning water related initiatives.

Since the Kavre Valley Integrated Water Supply Project (KVIWSP) has a designed discharge of 77.3 lps of total water from all the 5 source nodes, the measured discharge for those source nodes during the dry season (i.e., March of 2014) was 160 lps leaving about 80 lps of water surplus at the source. Based on this analysis, no significant future climate stress is likely to occur on most of the source nodes, but the source node of Sishakhani could be affected during the post-monsoon in future as this source node has only marginal surplus discharge as per the design discharge by KVIWSP. However, this analysis does not resonate with Dahal et al. (2019), where the authors, through trend analysis conclude that the decline of streamflow of Roshi would cause a shortage of water for domestic, agricultural, and industrial uses in the downstream.

However, this study has not considered the changes in land use/land cover, as well as changes in water demand of the communities due to population growth and socioeconomic development in the future. Therefore, a comprehensive research considering the uncertainties in future climate affecting the water availability as well as predicting the future land use/land cover and demand for water by various economic sectors including ecological demand is recommended. Furthermore, while planning any water project in climate vulnerable countries like Nepal, there is a need to assess the impacts of projected climate changes as this helps to build resilience against its possible impacts through enhanced institutional flexibility and the consideration of climate-related risks in the planning process.

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