Application of CORDEX Ensemble to Simulate Climate Change Impacts on Flow Regime in the Upper Chamkhar Catchment, Bhutan

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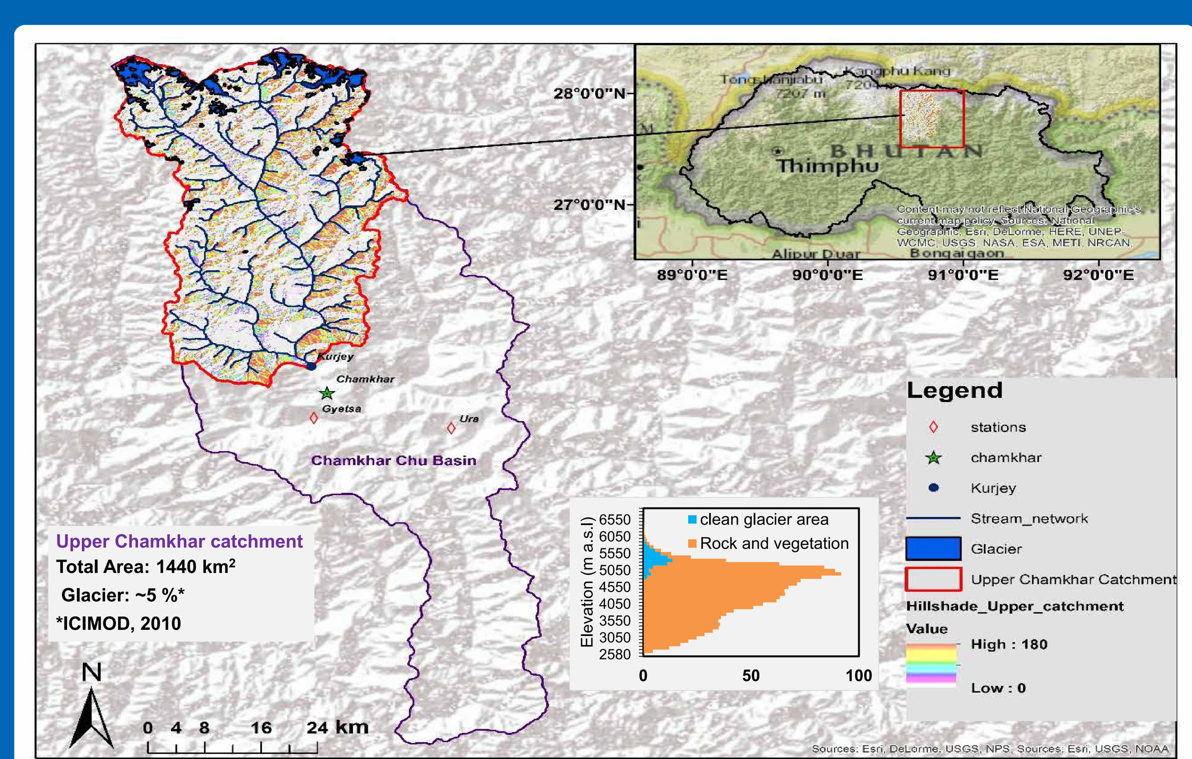
Background

- Snow and ice melt dominate the Bhutanese headwater catchments.
- Changes in temperature and precipitation are likely to affect the cryospheric processes and hydrology of these catchments (Cruz et al. 2007; Immerzeel et al. 2009).
- An assessment of glacio-hydrological response to changing climate using appropriate modelling tools is necessary for estimating future water supply in these catchments.
- A number of studies have used the temperature index model in data sparse Himalayan basins to estimate snow ice melt contribution in river discharge at different temporal scales. This method has been chosen due to its relatively easy interpolation and forecasting possibilities, and generally good model performance and computational simplicity (Braithwaite, 1995; Kayastha et al. 2000a; Hock, 2003).

Objective

- Simulation of climate change impacts on flow regime in the Upper Chamkhar Catchment under different climate change scenarios.

Study Area



Model Description

- Temperature index models are based on a relationship between melt rates and air temperature usually expressed in the form of positive temperature sums (Braithwaite and Olesen, 1989; Hock, 2003) (Eq. 1).

$$M = \begin{cases} DDF_{snow/ice} \times T & \text{if } T > 0°C \\ 0 & \text{if } T \leq 0°C \end{cases} \quad \ldots\ldots (1)$$

where, M is the snow or ice melt (mm/d), T is the air temperature (°C) and DDF is the positive degree day factor for snow or ice (mm/d/°C).

Model Setup

- Snow/ice melt (mm/d) at each zone is calculated (Eq. 1)
- Discharge (m³/s) 'Q_z' from each zone is calculated using ....(Eq. 2)

$$Q_z = Q_r * C_r + Q_s * C_s + Q_b \quad \ldots\ldots(2)$$

where, Q_r and Q_s = Discharges (m³/s) from direct rainfall (r) and snow - ice melt (s)
C : Runoff coefficient for rain (r) and snow and ice melt (s) (Martinec, 1975)
Q_b : Base flow (m³/s), which is calculated in R with inbuilt package 'EcoHydRology' version 0.4.12
Q_z is summed to get the total discharge from entire basin (Q) (Eq. 3)

- Q is routed to the basin outlet as per the recession equation given by Martinec (1975) (Eq. 4)

$$Q = \sum_{z=1}^{z=44} Q_z \quad \ldots\ldots(3) \qquad Q_n = Q * (1-k) + Q_{n-1} * k \quad \ldots\ldots(4)$$

where, Q_n : River discharge (m³/s) at the basin outlet on n^{th} day
k : Recession coefficient obtained by solving Eq 5 (Martinec and Rango, 1986)

$$k_{n+1} = x\, Q_n^{-y} \quad \ldots\ldots(5)$$

Table 1: **List of parameters**

Parameter	Description	Value
DDF	Degree day factor	3.5 – 6.5 mm d^{-1} °C^{-1} (Snow) 6.5 – 10.5 mm d^{-1} °C^{-1} (Ice) (Kayastha et al. 2000 a)
C_r and C_s	Runoff coefficients for rain and snow ice melt	0.3 – 0.75
x and y	Constants for the recession coefficient	0.996 and 0.0112, respectively
Q_b	Base flow	5.1 – 14.6 m³/s

Hydro-meteorological input data

- ***Observed data:*** Department of Hydro-Met Services, Bhutan
- ***Future Projected data***: Six RCMs along with their ensemble of CISRO-CCAM driven by different GCM boundary conditions for the CORDEX South Asia domain with 0.440 (~50 km) spatial and daily temporal resolutions are chosen. The RCM output for different experiments is bias corrected using the methods given by Sperna Weiland et al. (2010) for temperature (Eq. 6) and precipitation (Eq. 7).
- $$T_{corrected\_MOD} = T_{MOD} + (\bar{T}_{OBS} - \bar{T}_{MOD}) \ldots\ldots(6) \qquad P_{corrected\_MOD} = P_{MOD}\,\frac{\bar{P}_{OBS}}{\bar{P}_{MOD}} \ldots(7)$$

where, T is the daily temperature (°C), P is the daily precipitation (mm), and $\bar{T}$ and $\bar{P}$ the N - year average monthly temperature and precipitation respectively, with N representing the number of observed years.

Result

Figure 2: Annual temperature and precipitation at Chamkhar met. station

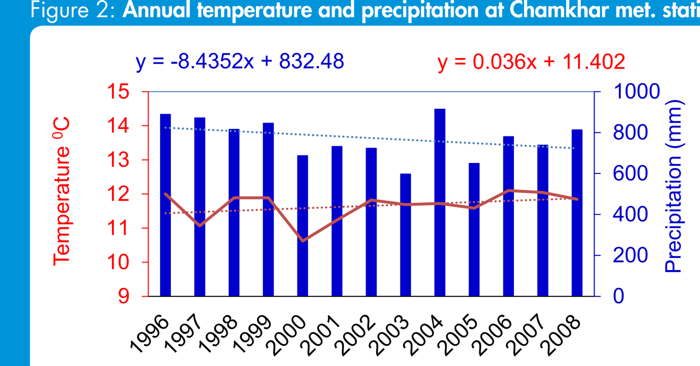


Table 2: **Model performance and average discharge**

Model	Model Efficiency		Average Discharge (m³/s)
	Nash Sutcliffe	Volume Difference	
Calibration	0.81	-3.57	59.65
Validation	0.76	-2.82	56.17

Figure 3: Observed vs simulated discharge for a calibration (1996–2000) and validation (2001–2008)

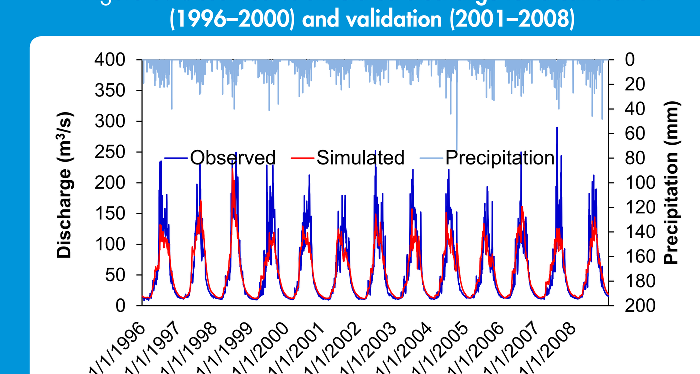


Figure 4: Monthly partitioning of runoff components

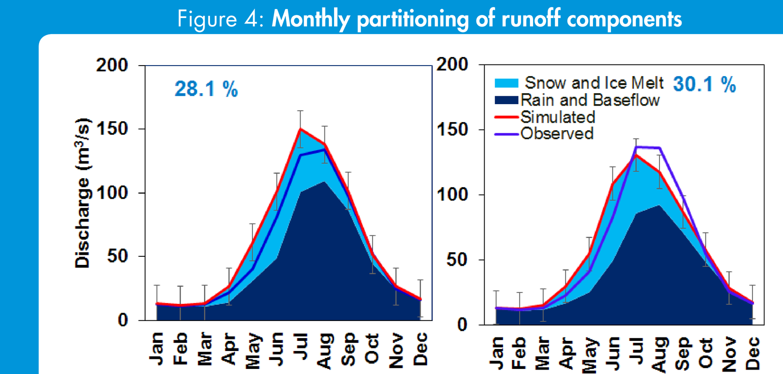


Figure 5: Five-year moving average of annual precipitation and temperature of Chamkhar Station under RCP 4.5 and RCP 8.5 scenarios.

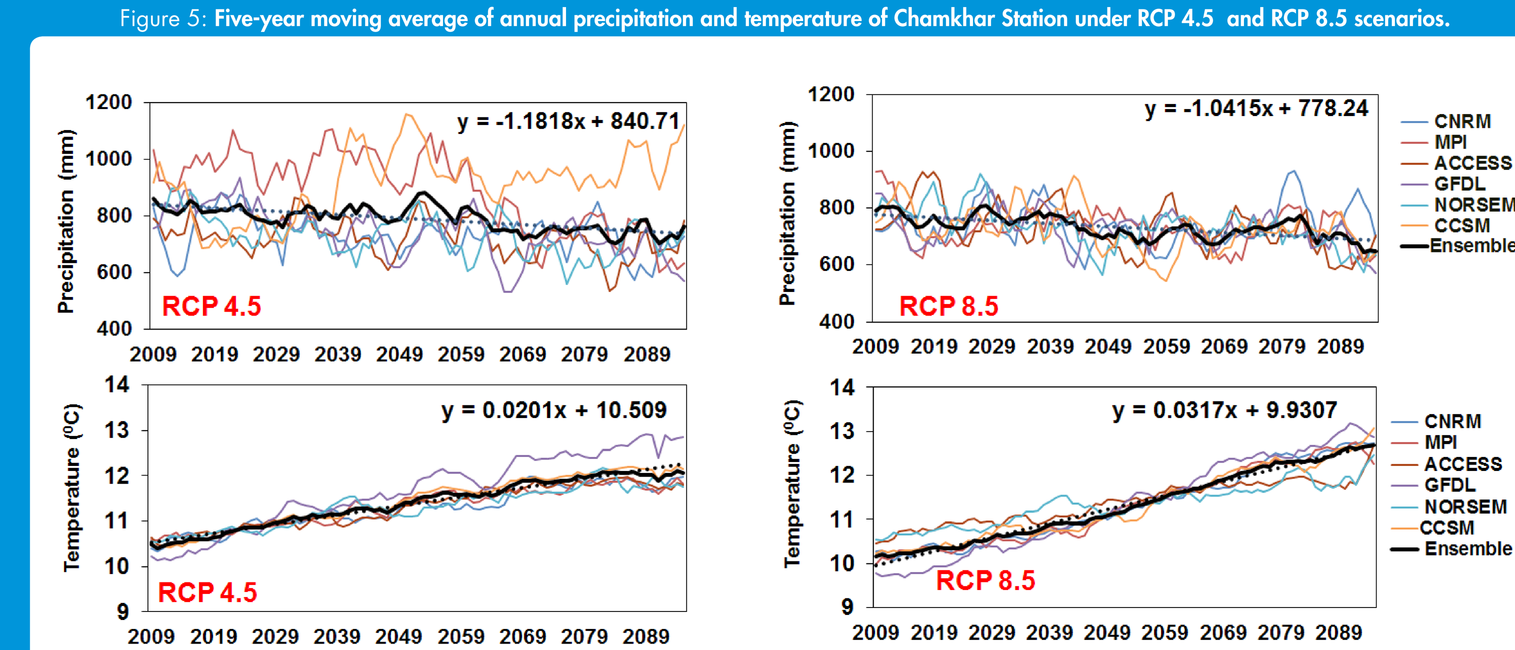
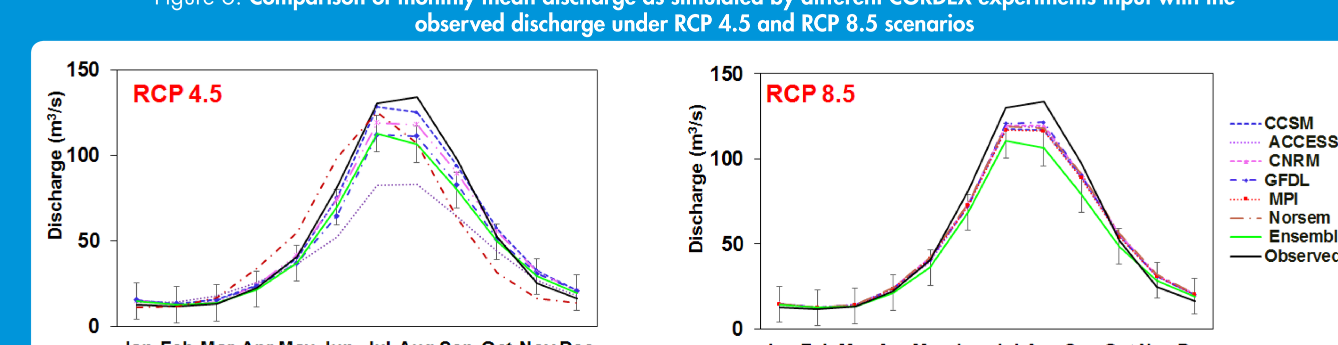


Figure 6: Comparison of monthly mean discharge as simulated by different CORDEX experiments input with the observed discharge under RCP 4.5 and RCP 8.5 scenarios



Result

Figure 7: Contribution of snow and ice melt and rain and base flow in Upper Chamkhar Catchment (2009– 2100) under RCP 4.5 (a) and RCP 8.5 (b) scenarios

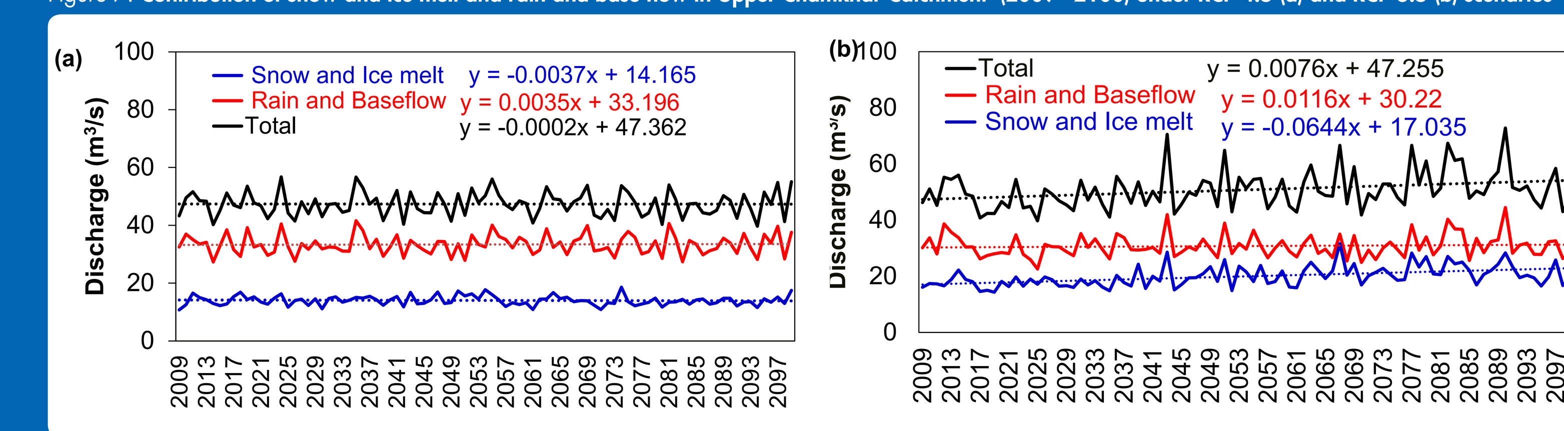
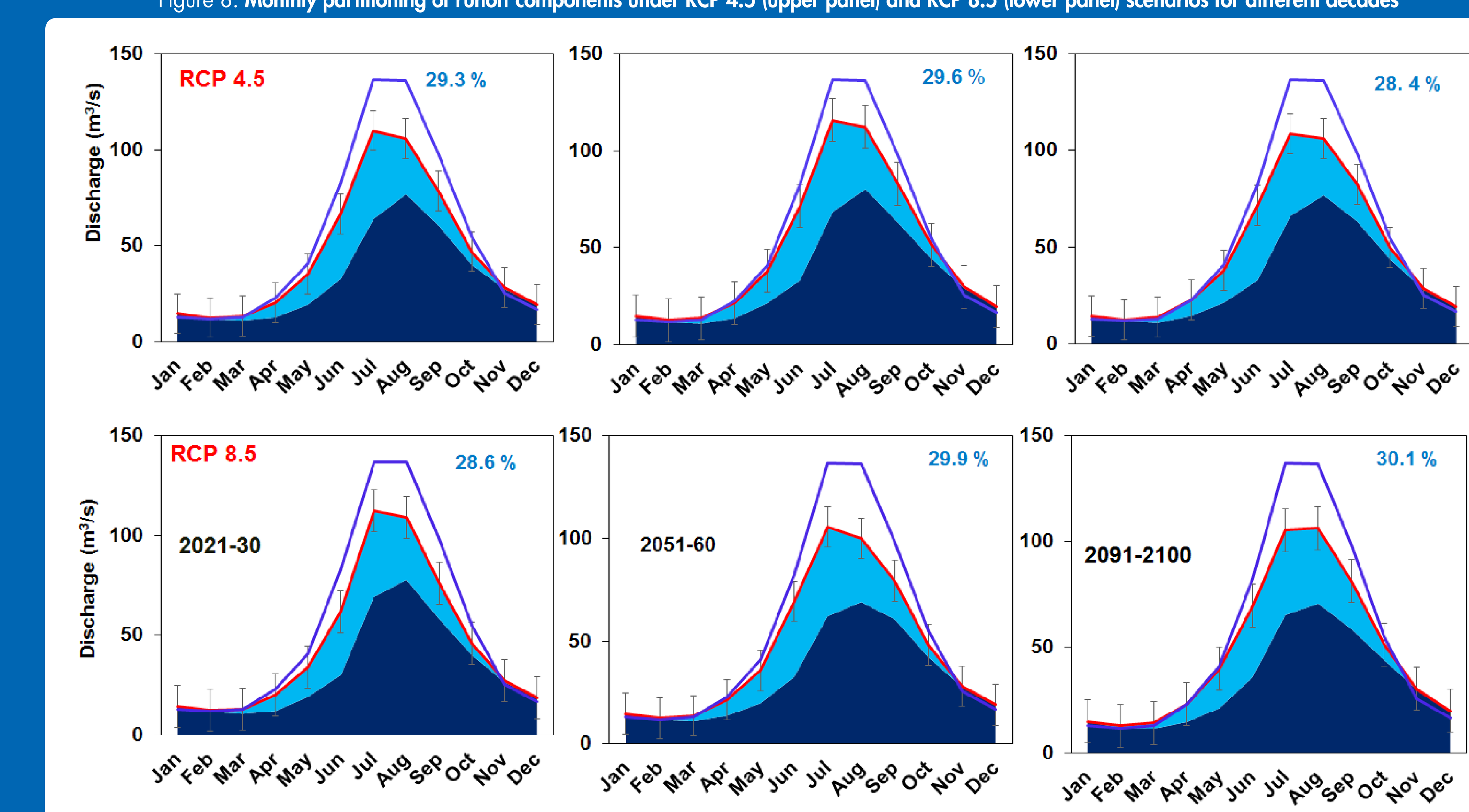


Figure 8: Monthly partitioning of runoff components under RCP 4.5 (upper panel) and RCP 8.5 (lower panel) scenarios for different decades



Conclusions

- The model simulates daily discharge pretty well in both calibration and validation period with NSE 0.81 and 0.76 respectively
- The bias corrected precipitation and temperature data from all six regional climate models along with their ensemble show increasing temperature trends and decreasing precipitation trends in both scenarios.
- Between 2009 and 2099 the average river runoff in the basin is 47.35 m³/s and 46.83 m³/s for RCP 4.5 ad RCP 8.5 scenarios respectively, which is less than the discharge from the reference period (53.39 m³/s).
- Under RCP 4.5 and RCP 8.5 scenarios, snow – ice contribution to river discharge decreases at the rate of 0.037 m³/s and under RCP 8.5, snow and ice contribution increases at the rate of 0.064 m³/s respectively.
- River discharge is highest in the period 2051–60 (48.93 m³/s, ~ 29.6% snow ice melt) for RCP 4.5 and 2091–2100 (47.52 m³/s, ~30.1% snow ice melt) for RCP 8.5

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