ASSESSMENT OF WATER RESOURCES UNDER CHANGING CLIMATE FOR EFFECTIVE HYDROPOWER GENERATIONS AND AGRICULTURE IN PUNA TSANGCHHU BASIN, BHUTAN

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ABSTRACT

The hydropower and agriculture are the backbones of Bhutan's socio-economic development due its abundance water resources in the forms of snow and glacier deposits, which are the most vulnerable to global warming but its impacts are overlooked in Bhutan. To obtain climate change impact on the water resources and to support policy makers in Puna Tsangchhu basin, this study assessed the effect of climate change utilizing past and future meteorological data of General Circulation Models (GCM). The GCMs projected increase of precipitation and temperature, however, the assessment of availability of water resources was very essential. The WEB-DHM-S was employed to simulate and estimate the future hydrological processes and water availability. The simulation indicated the increase of flow and snow cover area despite increase of temperature, which is good for Bhutan's hydropower and agriculture production.

Keywords: hydropower, water resources, climate change, WEB-DHM-S, snow cover area

INTRODUCTION

The snow and glaciers are the essential component of water resources in Bhutan as the largest part of freshwater is preserved in the form snow and glaciers in the mountains. The steep altitudinal variation of landscape with bounteous water in the swiftly flowing rivers is a boom for hydropower development, which is at present is the backbone of Bhutan's economy (~ 45% of the national revenue). Agriculture holds a share of over 15% of the total Gross Domestic Product. However, the both hydropower and agricultural sectors, which are climate sensitive, the most vulnerable to global warming and the changes in hydrological cycle would threaten the countries sustainable development. The effects of climate change on the water resources are increasingly becoming visible in the country (Hoy et al., 2016).

Bhutan's primary focus on economy through hydropower and agricultural developments has apparently overlooked the impact of climate change and only very few investigations have been carried out to assess the impact of climate change on bounteous water resources due to the lack of technical capacity and availability of assessment tools. The hydropower generation can be estimated based on the available river runoff, however, understanding and predicting the hydrological regime of glacial and snowmelt fed rivers for efficient hydropower generation is extremely challenging. The major obstacle faced by the country is to obtain accurate information on snowfall and their deposition amount during winter period and snowmelt runoff and the rainfall amount during summer under changing climate that contribute to the river system for sustainable water resources management. The classification of snowfall and rainfall is very crucial factor and it completely depends on temperature and global warning rate. A few degree changes in the temperature can alter the seasonal water availability, completely. Moreover, due to global warming, the hydrological cycle also gets affected significantly and altering the precipitation amount and intensities. The Intergovernmental Panel for Climate Change is confident about the increasing temperature (Rajendra K. Pachauri, and Leo Meyer, 2014) but there are uncertainties pertaining to precipitation. Furthermore, the future projections of rainfall are associated with the performance of GCMs, which are poor in mountainous region due to coarse resolutions. Therefore, it has become vital to address these challenges with respective to scientific and engineering issues and initiate a study of climate change impact on availability of water resources and consequences on hydropower generation and agricultural sectors.

In this research, Data Integration and Analysis System (DIAS) system developed by the University of Tokyo was utilized to investigate big-data from several GCMs and select GCMs models with better regional performances for bias correction and downscaling. In addition, the selected physically based Water and Energy Budget-based distributed hydrological modeling improved with snow physics (WEB-DHM-S), which is an essential tool to accurately estimate snowfall and rainfall classification based on temperature, snow deposit amount, and snowmelt runoff for simulating of hydrological responses. Moreover, WEB-DHM-S with its capability of long-term simulation can provide reliable results to climate change impact and scientific based decision-making.

Consequently, this study present assessment of the impact of climate change on glacier melt, snowmelt and consequences of it on water availability and the hydropower generation in the Puna Tsangchhu basin. The basin (~9763 km^2) has glacier mass (~3% of basin territory) and two on-going hydropower projects. The basin has yearly flow of more than 9200 MCM observed at Wangdi hydrological station annual average precipitation of more than 1000 mm. and On average, the temperature ranges from –8 to 37^oC. In winter, the precipitation is mainly snowfall, which has seasonal coverage of about ~10% (summer) to ~40% (winter) of the basin area.

THEORY AND METHODOLOGY

Overall methodology includes following four major components as shown in **Figure 1**.

1. Assessment of existing in-situ hydro-meteorological data
2. Climate Model
3. Hydrological Model
4. Impact Assessment and Evidence based Information

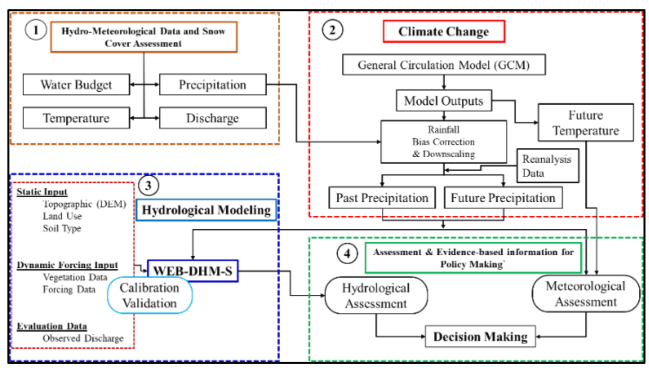

Figure 1. Methodology

The analysis of past observed hydro-meteorological data provided important inforamtion about the hydro-meteorologic conditions in the near past. Four GCMs were selected using DIAS platform, to assess the impact of climate change in the future. The GCM outputs from CMIP5 under RCP8.5 climate scenario underwent bias correction in the DIAS using in-situ meteorological data. Since the hydrological processes in the basin is governed by the interplay of precipitation and temperature, the correction and resampling of available data were necessary for meaningful results. Moreover, the spatial distribution of precipitation and temperature was relatively challenging for the mountainous basin in which the streamflow comprised of runoffs from glacier, snowmelt and rainfall. The glacier of the basin was distributed to each model grid based on its elevation and location as precipitation using equation (1). The glacier coverage was considered statistically constant across glaciated area of the basin.

$$M(x,t) = \begin{cases} DDF \times T(x,t) & if\ T > 0 \\ 0, & if\ T \leq 0 \end{cases} \quad (1)$$

Where *M(x,t)* is melt water from glacier, *DDF* is the positive degree day factor and *T* is the temperature. The ground elevations of the basin change abruptly with minimum of 107 m to more than 7000 m above mean sea level (Fig. 2).

$$T_{corr} = T_{obs} - \left(\frac{0.5}{100}\right) \times (Z_i - 3000) \qquad (2)$$

Where T_{corr} is corrected temperature, T_{obs} is observed temperature, Z_i is the elevation. Using temperature lapse rate of 0.5 ^{O}C/100m, vertical profile of temperature (VPT) was developed and the 3-Dimensional spatial distribution of temperature in each model was provided in order to classify the precipitation (snow/rain). The use of equation (2) corrected the temperature and spatially distributed to each model grid based on elevation. The temperature and precipitation for the future were adjusted in line with the GCM projections. The difference of the future and the past monthly averaged precipitation and temperature were multiplied or added respectively to the observed data. The adjusted data were finally used for simulating the future streamflow and snow cover area. WEB-DHM-S coupled with three layer snow physics was used for simulation and estimation of past and future streamflow. The result and GCM outputs were utilized to project the future climate and hydrology and then assessed the impacts on hydropower and agriculture.

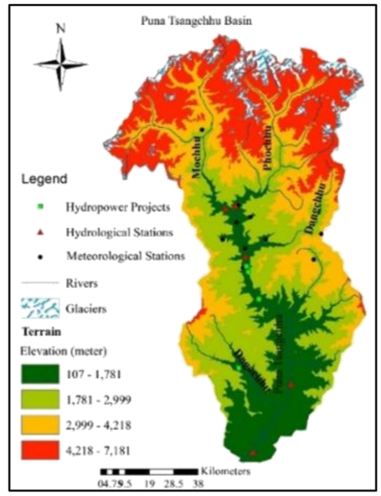

Figure 2. Study Area and hydro-meteorological stations

DATA

The hydrological, meteorological and topographical data, which were used in this study, given in **Table 1**

Table 1. Input Data for WEB-DHM-S

Data Type	Spatial Resolution	Temporal Resolution	Source
DEM (Resampled)	Grid 500 m	Static	www.hydroshed.org
Land use	500 m	Static	FAO
Soil Type	500 m	Static	FAO
Discharge	Gauge Data	Daily (1992-2019)	NCHM, Bhutan
Precipitation	Gauge Data	Daily (1996-2019)	NCHM, Bhutan
Meteorological data (SWR, LWR, wind speed, humidity, air pressure, air temperature)	Gridded Data	Dynamic: 3 Hourly	JMA (JRA-55)
Vegetation indices (LAI/FPAR)	Grid 500 m	Dynamic: 8-day average	MODIS Terra (MOD15A2)-MRT@500m
Snow Cover	Grid 500 m	8-day (max. snow extent)	MODIS Terra (MOD10A2)-MRT@500m
Glacier Cover (resampled)	Gridded 10 m	-	NLCS, Bhutan

RESULTS AND DISCUSSION

The results are discussed in the following four representative components based on the methodology given in **Figure 1**.

1. Hydro-meteorological Assessment: The trend analysis was performed for the precipitation and temperature data. The trend line in the **Figure 3** showed a gradual increase of annual average precipitation during the period of 1996-2019. Moreover, there were huge inter annual variabilities in precipitation

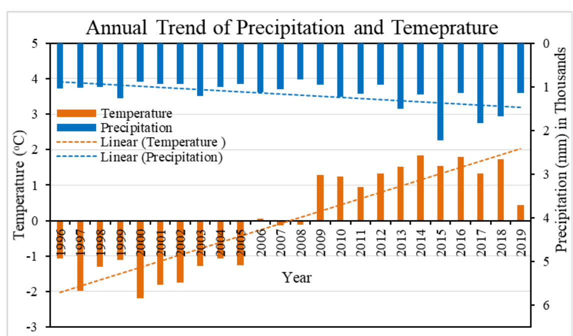

Figure 3. Annual trend of temperature (Observed)

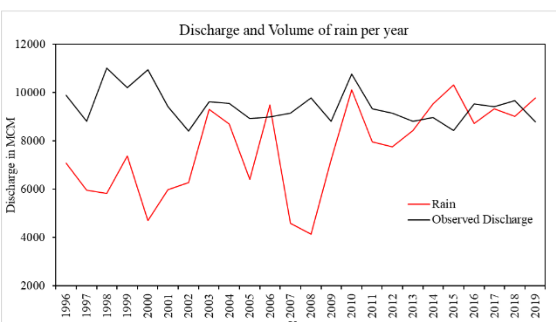

Figure 4. Trend of annual discharge and water budget estimation

during the recent decade. Similarly, the temperature trend in the **Figure 3** indicated the increase of it by 0.43 ^{O}C – 1.12 ^{O}C during the period of 24 years. The hydrological station at Wangdi was chosen for analysis, simulation and compare the future hydrological regime. According to the **Figure 4**, the trend of discharge indicated that discharge has not been increasing despite increase of precipitation; though with high inter annual variations. The water budget analysis indicated that the annual volume of precipitation in the basin was less than the measured flow. The huge gap between the volume of precipitation and observed discharge was due to the poor network of rain gauges, heavy local rainfall, and under-catch precipitation, non-consideration of snowmelt and glacier melt runoff contributions in the precipitation volume estimation.

2. Future Climate Assessment: 1981-2000 was considered as the past baseline period and 2026-2045 as the near term future period. The comparison of four GCMs and their outputs indicated that the precipitation and temperature will increase in the future. The **Figure 5** represents the inter-model comparison among the GCMs using the outputs obtained from DIAS, the platform. All the GCMs agreed that the precipitation and temperature will increase in future. The increase of precipitation ranges from ~6% (projected by ACCESS1.0) to ~35% (projected by CNRM-CM5). Increased number of extremes will accompany the increased precipitation with higher intensity of rainfall. The basin will also experience the rise in temperature by 1.11 ^{O}C to 1.82 ^{O}C during the period of 2026-2045. The analysis of temperature showed that the increment is higher during winter compared to the rise of temperature during summer..

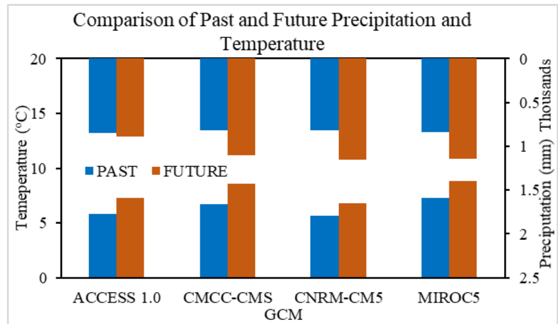

Figure *5*. Variation of future temperature and precipitation (projected)

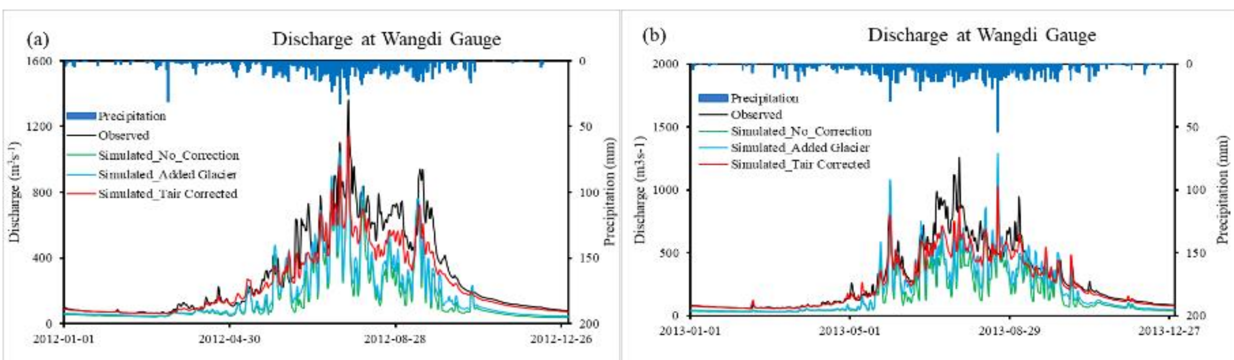

Figure 6. Simulation of discharge (a) calibration (b) validation

3. Hydrological Modeling: The model was corrected for errors and the initial conditions were obtained by running the model several times with the forcing data until near to hydrological equilibrium was achieved. The model calibration was performed by comparing simulated discharge with the daily streamflow observed at Wangdi hydrological station for the year 2012. The model was simulated in three-model setup, a) with default parameters, b) with glacier input and c) with the corrected temperature and precipitation. As shown in **Figure 6**(a), the simulation with default parameters was not able to reproduce the discharge as the precipitation input was taken as rainfall only and could not induce the snow. There was improvement in the hydrograph with inclusion of glacier, and further successfully simulated when introducing the corrected temperature and precipitation. In the model simulation, precipitation below the threshold

Table 2. Evaluation results of model performance

Model Simulation	Calibration		Validation	
	NSE	RE	NSE	RE
Default Simulation	0.36	-0.47	0.43	-0.42
Simulation with Glacier	0.52	-0.39	0.62	-0.28
With Corrected air temperature	0.86	-0.17	0.87	-0.12

temperature (0 ^{O}C) falls as snow, rather than rain. The threshold temperature is a constant value and a tuning parameter in the model.The parameters were calibrated to the discharge of the year 2012. The models simulated under three setups were evaluated using Nash Schutliff Efficieny (NSE) Coefficient method and Relative Error method given in **Table 1**. The parameters calibrated to 2012 was then utilized, simulated and compared with the discharge of 2013 for validation as shown in **Figure 6**(b) and the performace evaluation of the validated models are also given in **Table 1.**

4. Snow Cover Modeling: The snow cover area (SCA) of September 2012 – August 2013 obtianed from MODIS/Terra Snow Cover 8-day global data was prescribed as initial conditions for the simulation. The simulated snow coverage was evaluated by comparing with MODIS 8-day observed snow cover data, as shown in **Figure 7**. The simulation of model with default parameters and addition of glaciers was not able to simulate the snow cover since the default temperature input was high and could not induce snow. The use of VPT was able to correct the temperature and precipitation based on the elevation. The model was capable to simulate the snow process when the corrected temperature and precipitation was introduced.

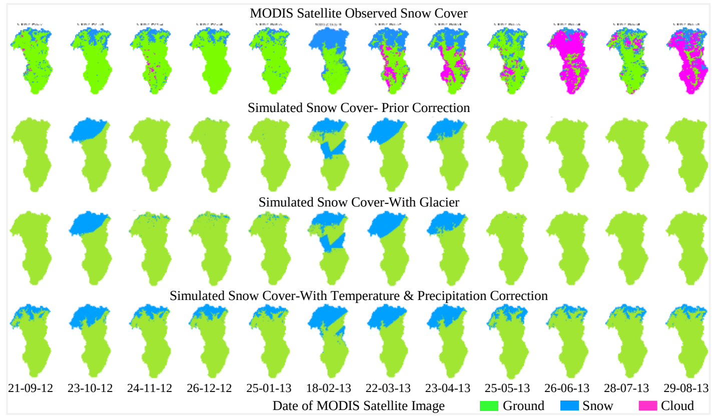

Figure 7. Simulated snow cover area

5. Climate Change Impact Assessment

5.1 Snow Cover Area: The increase in future precipitation will be accompanied by increased solid precipitation which is why the model simulation indicated that the overall future snow cover area will be increased by 5% to 9%. This has been agreed by all the GCMs. **Figure 8** shows that the snow cover area during autumn and summer will be increased compared to the past snow cover area.

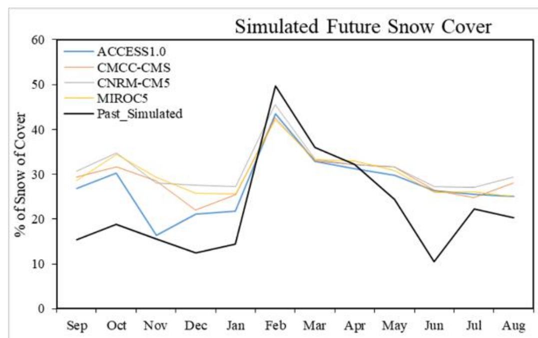

Figure 8. Projected snow cover

5.2 Discharge: Figure 9 compares the simulated discharge using GCM outputs and the past observed discharge at Wangdi hydrological station. All the GCMs agreed that the discharge in the future will be increase by 17% to 47% corresponding to increase in precipitation in the near future. According to **Figure 9**, the projected hydrographs of all models diverted from the observed one which indicates that the snowmelt has been enhanced due to increased temperature and the melt begins from March. The hydrograph also indicates that autumnal snowmelt will also be increased.

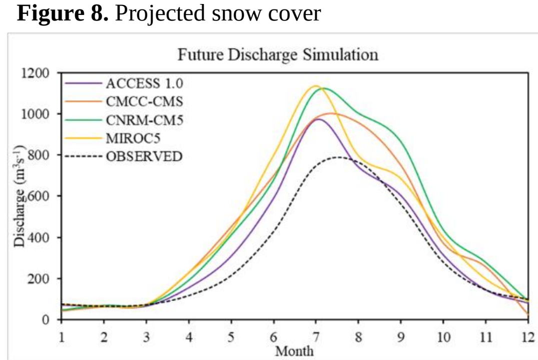

Figure 9. Model-wise projected streamflow

6. Policy Implications: The findings of this research have a number of policy level implications for the government, non-governmental organizations and other donor agencies, which can also be utilized in policy making for preparedness, prevention, mitigation of disaster risk. The anticipated future shifting of the seasonal flow will be significant for flood disaster managers, hydropower and farmers. The flood disaster managers are concerned about the timing of the peak and maximum probable flow, which need to be considered during the planning and designing of flood control structures. Besides planning the structures, the intensity of future extremes and seasonal variations of flow can be used for improving early warning systems from conventional to automated warning system. Moreover, the indication of increased water resources could be used in planning more hydropower plants in the basin.

CONCLUSION & RECOMMENTATIONS

In this study, most contemporary advance technology has been successfully applied and climate change implications to water resources in Puna Tsangchhu basin, Bhutan are demonstrated. For detail hydro-meteorological analysis, including climate change impact assessment, the use of meteorological forcing data and well-calibrated distributed hydrological models are indispensable, which are successfully achieved. The impacts of climate change on hydrology of Puna Tsangchhu basin have been assessed using four CMIP5 GCMs under RCP8.5 scenario. WEB-DHM-S simulated both the past and future hydrological processes in the basin which indicated the increase in water resources in the near future. Though the GCMs indicated the rise in temperature by 1.12^{O}C to 1.82^{O}C, the rate of increase of temperature will not exceed the threshold where the basin is experiencing about -8^{O}C on average during snow season. That is why, there is no negative impact on snow cover area rather it increases by 5% to 9%. These signified that the water resource in the basin improved with increased snow cover and precipitation, however with more number of extremes with high intensity of precipitation. With the improved water resources in the basin, Bhutan could further planned additional hydropower plant with capacity of more than 2GW at current design standards.

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