ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

Final Report
ARCP2014-10CMY-Shrestha

Runoff Scenario and Water Based Adaptation Strategies in South Asia

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Project Overview

Project Duration	**:**	2 Years
Funding Awarded	**:**	US$ 41,000 for Year 1; US$ 36,000 for Year 2
Key organizations involved	**:**	The Small Earth Nepal, Kathmandu, Nepal Nepal Academy of Science and Technology, Lalitpur, Nepal Center for Environment and Geographical Information Services, Dhaka, Bangladesh Global Change Impact Studies Center, Islamabad, Pakistan Andhra University, India East West Center, Hawaii, USA Department of Environment, Dhaka, Bangladesh

Project Summary

Climate change and climate variability have significant impact on the Himalayas affecting more than 1.4 billion people downstream. The Hindu-Kush Himalaya (HKH) together makes the largest and highest mountain chain over the earth and they are custodian of the third largest ice reserves after the Polar regions. The project aims to understand the climate and changing climate of the region with focus on water resources and its consequences to people and society. We studied the South Asia region in a macro-climatic perspective. For detailed investigation of climate and hydrology, case-study watersheds were selected in each of the partnering countries - Nepal, Pakistan and Bangladesh. We analyzed the archived climate data from the case study watersheds, developed the future climate scenarios with the dynamically downscaled climate model outputs and developed the river runoff for future in the context of climate change. We engaged the policy-making bodies in the project from the very beginning of the project. We organized result sharing workshops in the three levels: 1. Regional level workshop in Dhaka (Bangladesh), 2. National sharing workshop in Kathmandu (Nepal), Islamabad (Pakistan) and Dhaka (Bangladesh), and 3. Basin level sharing workshops in each case study basins in respective countries.

Keywords:

Climate Change, Hydrology, Modelling, South Asia, Adaptation

Project outputs and outcomes

Project outputs:

Publication:

Khatiwada, K., Panthi, J., Shrestha, M., & Nepal, S. (2016). Hydro-Climatic Variability in the Karnali River Basin of Nepal Himalaya. Climate, 4(2), 17. https://doi.org/10.3390/cli4020017

The Small Earth Nepal. (n.d.). Climate and Hydrology of Karnali River Basin. Policy brief, Kathmandu, Nepal. Retrieved from https://smallearthnepal.files.wordpress.com/2017/06/flyre_hig.pdf

The Small Earth Nepal. (2017). Good water based adaptation practices in Karnali River Basin. Retrieved from https://www.youtube.com/playlist?list=PLKA7chBGtbz7WVsmP0HyFPBevBhJEJ6sq

Manuscripts:

- Water Poverty Mapping in the context of Climate Change – A Case Study from Karnali Basin, Nepal *(under review)*
- Community based water adaptation strategies in the Karnali basin of Western Nepal *(in preparation)*
- The projected impact of climate change on water availability in Karnali River Basin, Nepal *(in preparation)*

Capacity Development

- Scientific capacity building of young researchers involved in this project
- Training to the young researchers working in the field of climate and water sectors (two trainings were organized as a part of the project)

Project outcomes:

Project analyzed the archived climate data from the case study watersheds, developed the future climate scenarios with the dynamically downscaled climate model outputs and developed the river runoff for future in the context of climate change. Based on the projected future runoff scenario, project developed the appropriate water adaptation strategies at basin and national levels of all three countries.

Publications

Khatiwada, K., Panthi, J., Shrestha, M., and Nepal, S. (2016). *Hydro-Climatic Variability in the Karnali River Basin of Nepal Himalaya*. Climate, 4(2), 17

Awards and honours

A research student from Nepal (Kabiraj Khatiwada) presented a poster summarizing the results of his projects in an international conference in Kathmandu.

Potential for further work

One of the potential future works is to scale down this project's activities. The runoff scenarios were developed in basin scale, but the scenarios in sub-watershed level would give more and clear information to the policy makers and local communities to develop the adaptation strategies accordingly. This project has created a pool of climatic datasets, which can be used in other modelling activities such as species distribution model, crop model, eco-hydrological model etc.

Pull quote

"This report provides a concise presentation of the APN project, ARCP2014-10CMY-Shrestha: Runoff Scenario and Water Based Adaptation Strategies in South Asia. I congratulate the study team. SEN and APN both are focusing on such projects, which address impacts of global change to human-nature dimensions and viable solutions to such impacts. This project investigated many dimensions of climate change including climate and water sciences, water security and adaptation strategies. Science-Policy-Community parts of this research project will add significant contributions to sustainable management and governance of the water resources as this research presented not only the impacts of climate change on water security but also the adaptation strategies to cope with the challenges. Policy-makers and communities were engaged throughout the project phases. I am highly impressed with the engagement of young scientists in the study. The research outcomes have already been shared with the stakeholders through workshops and policy-briefs. Though the report considered case studies of the three river basins, I strongly believe that the results are relevant to further studies in the other parts of South Asia and beyond. The future water-based development plans should consider the outcomes of this research project."

Dhiraj Pradhananga, President, The Small Earth Nepal

Acknowledgments

Department of Hydrology and Meteorology (DHM) of Nepal, Bangladesh Meteorological Department (BMD) and Pakistan Meteorological Department (PMD) are greatly acknowledged for providing the climate data for the case study sites. We thank Nepal Climate Change Support Programme (NCCSP), a project of government of Nepal implemented by the Ministry of Population and Environment (MoPE) for field coordination during the field assessment. We received valuable feedback and suggestion from various experts from the beginning of this project and project was highly benefited from these feedbacks. Those who provided feedback at different stage of project were much beholden. We are equally thankful to the graduate students and research assistants involved to this project.

1. Introduction

The Asia-Pacific region is a hotspot for climate change and extremes because of its significant regional monsoon climate, interaction with the global climate system and greater economic activity in recent decades (Manton et al., 2011). Among the regions of the world, South Asia includes the most massive geographical features like Himalaya and Tibetan Plateau and is very sensitive to climate variability and its change along with the extreme events. This region depends heavily on precipitation from the regional monsoon system as well as water derived from the snow and glacier melts in the Himalayas; both of these are affected by climate change (Muhammed, 2003). The majority of precipitation studies of southern Asia have excluded the Himalayan belt due to the region's extreme, complex topography and lack of adequate rain-gauge data (Shrestha, 2000). High Himalaya range is literally the 'abode of snow' with glacier ice covering roughly 17% of the area while seasonal snow covers every year an additional area ranging from 30-40%. The melt water from the extensive snow cover and glaciers in the Himalayas drains into the perennial Himalayan river systems; therefore, it is critical for the 1.4 billion of people inhabiting the mountain slopes and plains in south.

The objectives of the project were:

- Develop the future runoff scenarios under the IPCC climate scenarios in medium term (2050) and long term (2080);
- Explore the potential adaptation measures and produce community-based adaptation strategies focusing to water resource management;
- Share the research findings among policy-makers as a decision support system.

2. Methodology

2.1 Selected River Basins

Fig. 1 shows the three river basins in the South Asia over which this study was carried out. The Karnali River Basin (1, Fig. 1) is in western Nepal and is the largest river basin of Nepal in terms of area. It has area of 42,457 km^2. Karnali river is the trans-boundary river and it originates from south of Mansarovar and Rokas lakes located in China (Tibet) and flows through the western part of Nepal and joins the Ghaghara River in India. The second river basin is the Gilgit River Basin (2, Fig. 1) in the high-altitude Karakorum mountain range located in Pakistan and is a major tributary of Upper Indus Basin (UIB). It has a total drainage area of 14,082 km^2. The third river basin is the Ganges Basin within Bangladesh (3, Fig. 1), which covers total watershed area of 46,300 km^2.

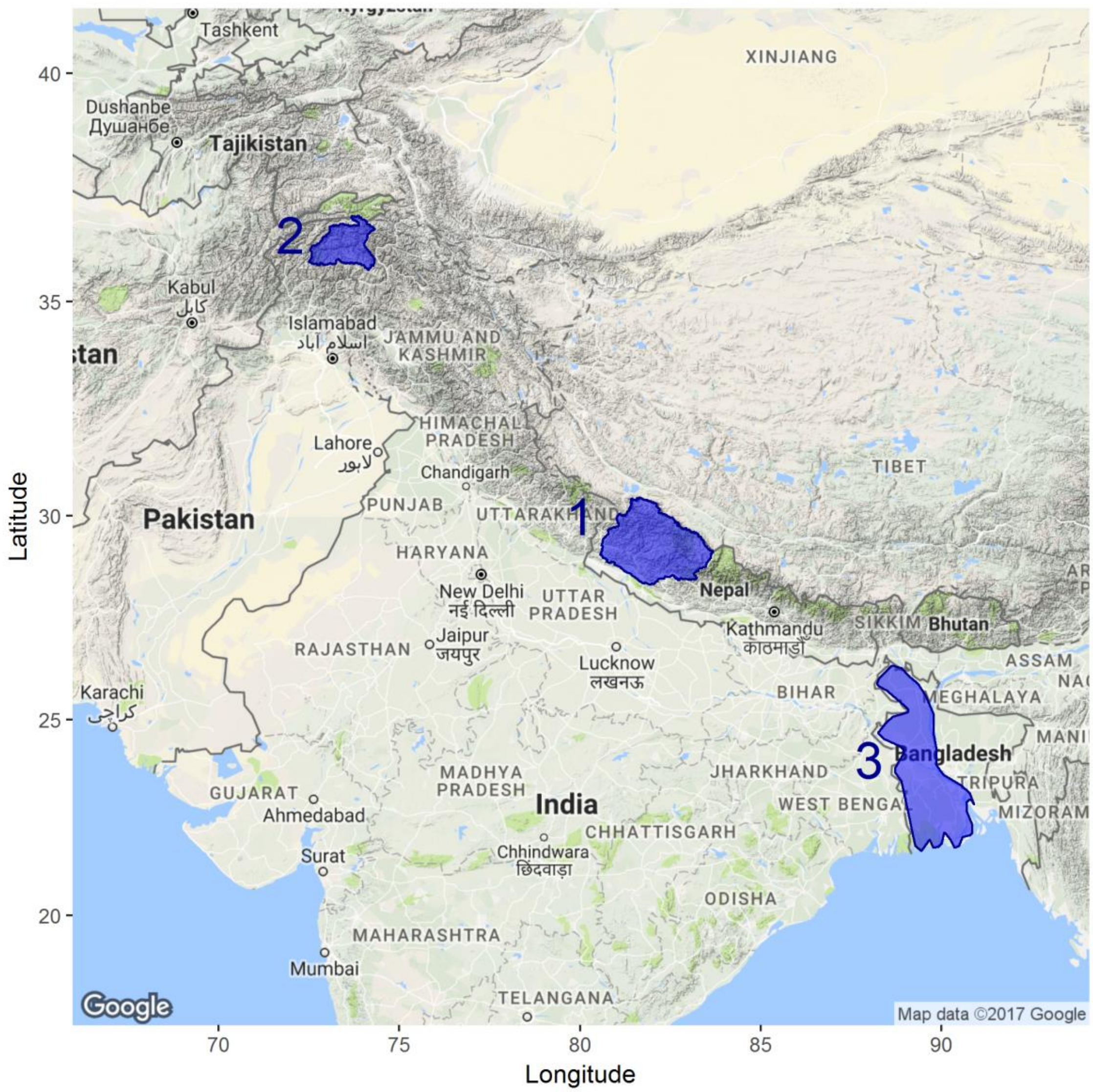


Figure 1 Location of three river basins.

2.2 Study Area Description

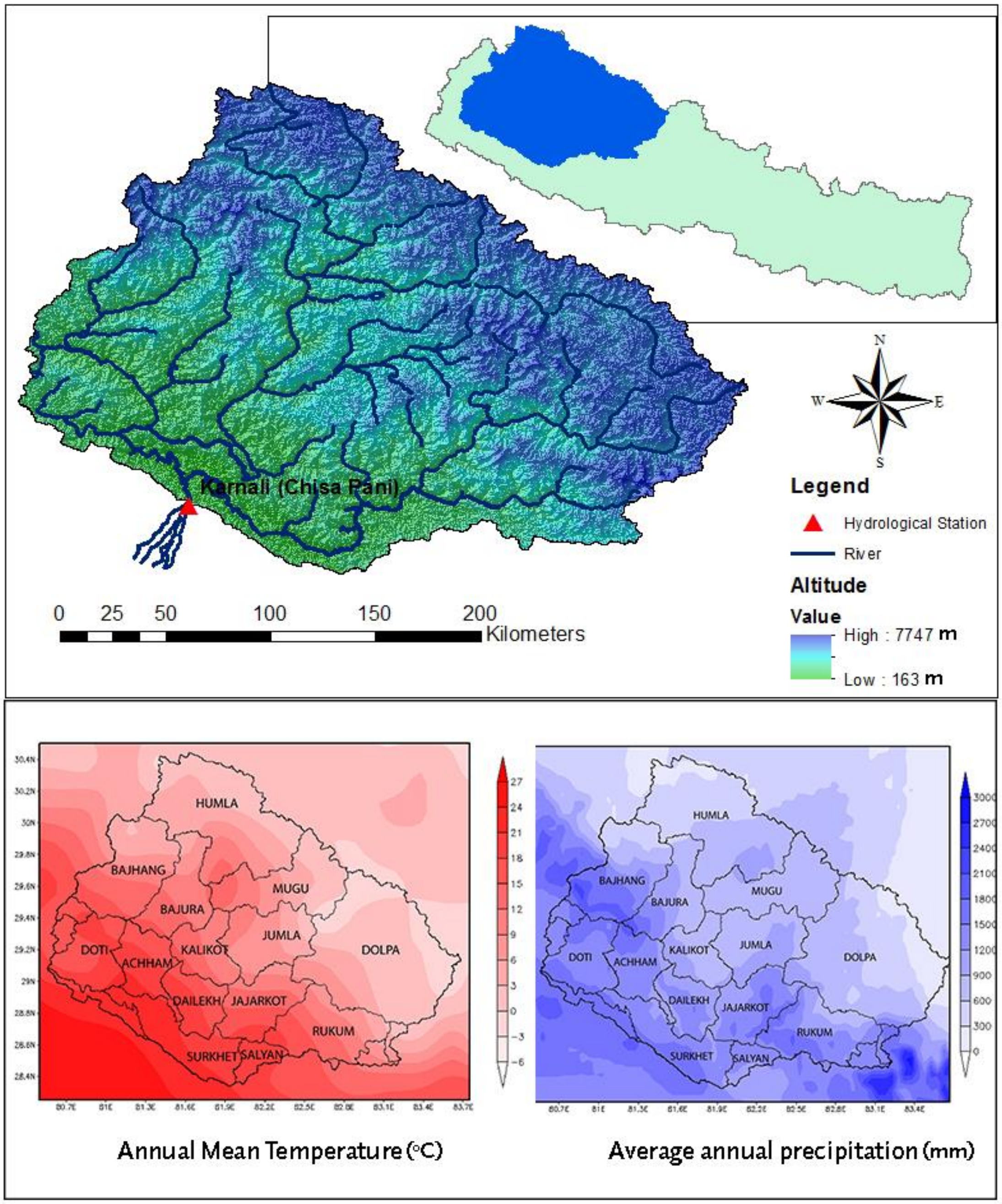


Figure 2 Altitudinal and climatic variability in Karnali river basin

Karnali River Basin: The Karnali River Basin (KRB) is in western Nepal is characterized by high climatic and geographical variability as shown in Figure 2. The average elevation of the basin is 3,180 m but varies from 163 m at southern low land to 7,747 m at higher mountain in the north. Based on variations in elevation and topography, the basin can be broadly divided into four physiographical regions -the Terai region extends up to 200 m in elevation; above this are the hill regions (200–4,000 m) and mountain regions (above 4,000 m); the trans-mountain region lies north of the Himalaya Mountains. It has six major watersheds (West Seti, Humla Karnali, Mugu Karnali, Tila, Thuli Bheri and Sani Bheri).

Highland of the Karnali basin is dominated by snow/glaciers and grassland; and lowland by forest and agriculture lands. In the entire basin, dominated land cover is forest which occupies 33.2 % of basin area and about 16.2% area is covered by agriculture lands. The climate of the Karnali River Basin is mainly influenced by the monsoon system, physiography of the region, and westerlies (Shrestha, 2000). The summer monsoon which originates from the Indian Ocean is the main cause of precipitation in Nepal and as the KRB lies in the western part of Nepal, its influence is weaker than in eastern part (Nayava, 1980). The annual average precipitation in the basin is 1479 mm (Khatiwada, et al., 2016) but have large seasonal, spatial variation as well as inter-annual variation. During the four-month of summer–June to September the area receives about 80% of the annual precipitation. The distribution of the monthly average rainfall in the KRB shows that highest precipitation occurs in July (about 375 mm) and lowest in November (about 10 mm). Northern part of the basin is the driest part, which receives less than 300 mm precipitation in a year, but there are some pockets in the mountainous areas receiving more than 3,000 mm in a year. The hydrology is dominated by the strong precipitation events in summer and snow and glacier melt in winter.

Gilgit River Basin: Gilgit River Basin (GRB), located in the north of Pakistan, is bordered with Afghanistan and China (Figure 3). There are three major tributaries of Gilgit river i.e. Ghizar river, Yasin river and Ishkuman river.

The upper reaches of the basin are mostly glaciated and covered with permanent snow.

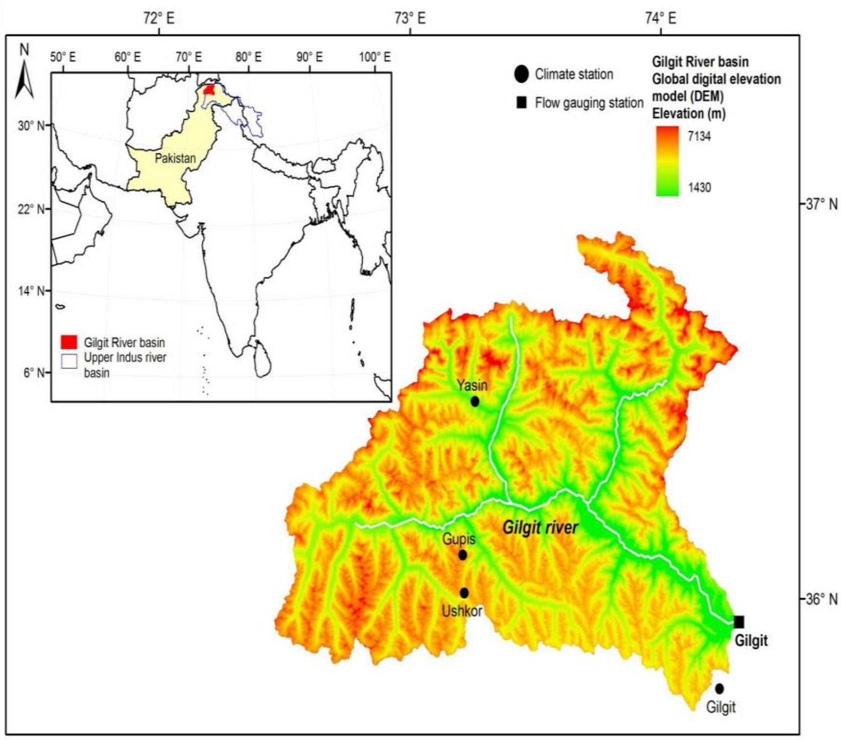


Figure 3 Study area map of Gilgit river basin, Pakistan

Bulk of the runoff occurs during May to September due to snow melt. The elevation of the Gilgit catchment ranges from 1,430 m to 7,134 m with a mean catchment elevation of 3,740 m. Seasonal snow melt and melting of glacial ice both are large contributors in the discharge of this river. In most winters, 80-90 per cent of the area becomes snow covered. Climatic variables are strongly influenced by the altitude of the watershed. Temperatures in Gilgit range from -13.8°C to 19.4°C. Average Rainfall in Gilgit varies from 33 to 180 mm per month. The mean total annual precipitation is 314 mm at Yasin (2,487 m), 311 mm at Ushkor (3,765 m), 186 mm at Gupis (2,156 m) and 132 mm at Gilgit (1,460 m) according to the available data records of the four climate stations in the catchment. The Gilgit river has a mean annual flow of 283 m^3/s gauged at Gilgit hydrological station (1,430 m) according to year 1970–2008 flow record. The Gilgit river flow in summer (June to September) is influenced significantly by the snow and glacier melt.

Ganges Basin (Part within Bangladesh): Third river basin chosen as the study area is part of the Ganges Basin within Bangladesh (Figure 4). The elevation of the area ranges from sea level to 48 m as per the Public Works Department (PWD), datum used in Bangladesh. The upper part of the basin has the highest elevation while the elevation gradually decreases towards the south. The lower part of the study area is almost flat with the range of 0 to 5 m above PWD datum. The major land use of the study area is agricultural land, forest, settlement and water body/river. Aman (monsoon rice) and Boro (winter rice) are the main crop in the study area. Sundarban, the largest mangrove forest in the world is situated at the lower part of the study area.

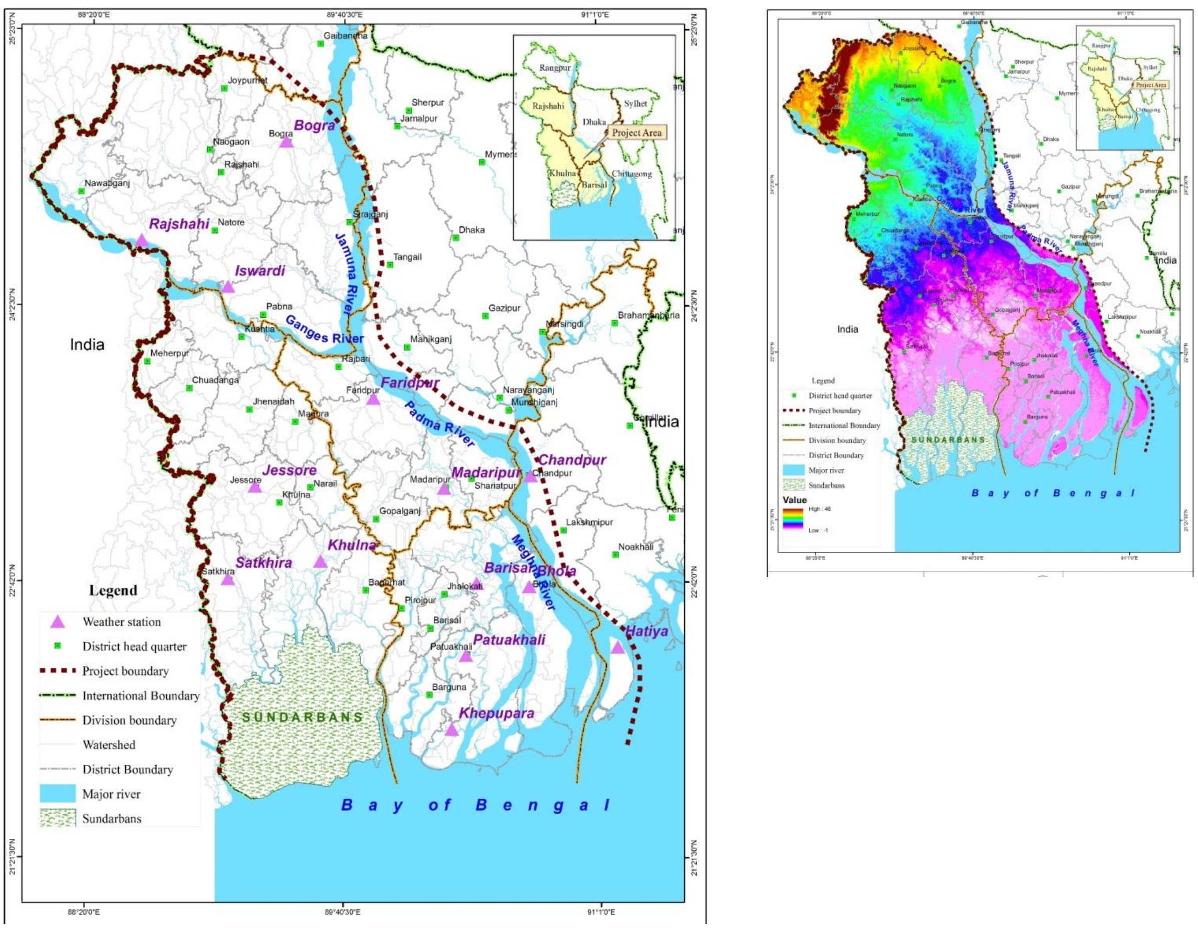


Figure 4 Location map (left) and altitudinal variation of study area in Bangladesh

2.3 Study Approach

There were three major steps to achieving the project objectives: Hydrological model set up with input of climate and hydrological data, water availability assessment based on future climate scenario and generation of future runoff scenario, and exploring the potential adaptation measures produce community based adaptation strategies focusing to water resource management.

2.3.1 Description of the Hydrological Model

Soil and Water Assessment Tool (SWAT) was used as a hydrological model to represent the current hydrological characteristics of the **Karnali River Basin** and **Ganges Basin**; and University of British Columbia Watershed Model (UBC-WM) was used for **Gilgit River Basin** for this study.

The **SWAT** hydrological model is a semi-distributed, continuous-time, processed-based model (Arnold, et al. 1998; Gassman, et al., 2007). It is an open source code with a large and growing number of model applications in various studies ranging from catchment to continental scales (Abbaspour et al. 2015). The model includes climate, hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing as main components.

In SWAT, a watershed is divided into multiple sub-basins, which are then further subdivided into hydrological response units (HRUs) that consist of unique land use, topographical, management and soil characteristics. Simulation of watershed hydrology is done in the land phase, which controls the amount of water, sediment, nutrient etc. to the main channel in each sub-basin, and in the routing phase, which is the movement of water, sediments, etc., through the streams of the sub-basins to the outlets. Hydrologic processes considered by SWAT include canopy storage, surface runoff, and infiltration. In the soil the processes include lateral flow from the soil, return flow from shallow aquifers, and tile drainage, which transfer water to the river; shallow aquifer recharge, and capillary rise from shallow aquifer into the root zone, and finally deep aquifer recharge, which removes water from the system. Other processes include moisture redistribution in the soil profile, and evapotranspiration.

SWAT requires three basic data for delineating the basin into sub-basins and HRUs -Digital Elevation Model (DEM), Soil map and Land Use map. The hydrological cycle is climate driven and required moisture and energy inputs, such as daily precipitation, maximum/minimum air temperature, solar radiation, wind speed, and relative humidity that control the water balance.

The **UBC-WM,** a semi-distributed model, calculates watershed outflow using point measurements of precipitation and temperature data combined with physical watershed characteristics as input. It was designed for the simulation of stream flow from mountainous watersheds, where the runoff from snowmelt and glacier melt may be important, apart from the rainfall runoff. Since the hydrologic behaviour of the mountainous watershed is a function of elevation, the model uses the area-elevation bands concept, which makes it a semi-distributed model. This concept accounts for orographic gradients of precipitation and temperature, which are assumed to behave similarly for each storm event so that, based on temperature, the model estimates whether precipitation falls as rain or snow and estimates snowpack accumulation as a function of elevation. A simplified energy budget approach, based only on data of maximum and minimum temperature is used to estimate snowmelt (Quick, 1995). Furthermore, the geophysical characteristics of each elevation band in a catchment, such as impermeable area, forested areas, vegetation density, open areas, aspect and glaciated areas can be estimated from maps or remotely sensed data, on the assumption of homogeneity of the characteristics within each elevation band.

2.3.2 Model Input Data

The model input data requirement for SWAT includes meteorological data, land use, land cover, soil properties and topography. It also requires the measured stream flow data to calibrate the model parameters and validate the model. The meteorological data required on a daily basis and include rainfall, maximum and minimum temperature, relative humidity (RH), solar radiation and wind speed (Table 1). UBCWM operates using precipitation and temperature as input data.

Summary of data used in this study and its corresponding resolution and sources are presented on table below (Table 1):

Table 1 Summary of data and its corresponding resolution and sources

Basin	Digital Elevation Model		Land Use		Soil Map		Meteorological/ Hydrological data		
	Source	Resolution	Source	Resolution	Source	Resolution (Scale)	No of Stations	Period	Source
Karnali River Basin	ASTER	30 m	ICIMOD	30 m	FAO	(1:1,000,000)	Rainfall-34 Temperature-12 Discharge-1	1981-2005	DHM
Ganges Basin	NWRD, CEGIS		NWRD, CEGIS		SRDI	(1:50,000)	Rainfall-14 Temperature-14 R. Humidity-14 Wind Speed-14 Solar Radiation-14 Discharge-3	1981-2012 1981-2008 (Discharge)	BMD, BWDB
Gilgit River Basin	-	-	-	-	-	-	Rainfall-2 Temperature-2 Discharge-1	1961-2010 1980-2003 (Discharge)	PMD

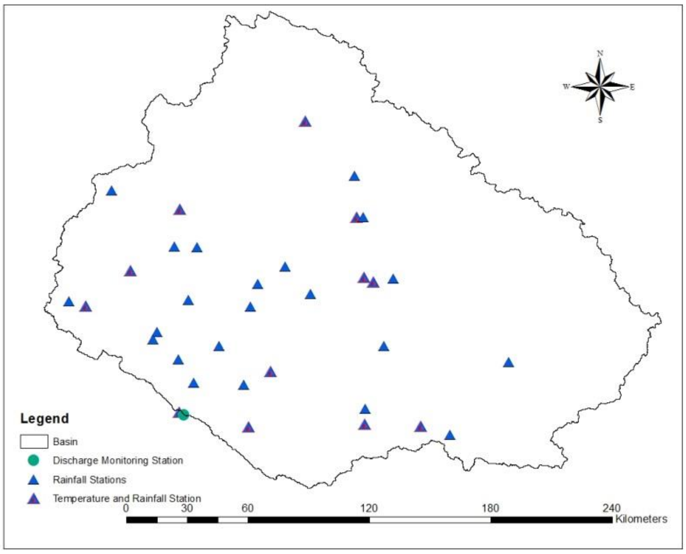


Figure 5 Location of Hydrological and Meteorological monitoring stations in Karnali river basin

For **Karnali River Basin** a 30 m resolution raster Digital Elevation Model (DEM) developed by ASTER, was used to represent the topography of the area. The data was downloaded from http://gdex.cr.usgs.gov/gdex/. Similarly, the Land-use map for the year 2010 was obtained from International Centre for Integrated Mountain Development (ICIMOD). This land use data has been derived from Landsat images using object based image analysis. Similarly, soil map for Karnali River Basin was obtained from global soil database, prepared by Food and Agricultural Organization of the United Nations (FAO). The FAO soil data is available along with a database of soil properties for two layers. Daily observed precipitation and maximum and minimum temperature data for 1981–2005 were obtained from the Department of Hydrology and Meteorology (DHM), Government of Nepal.

Thirty-four precipitation and 12 temperature stations over Karnali River Basin were selected on the basis of long term data availability and on percentage of missing records less than 10%. Similarly, daily average flow discharge values for Chisapani station was also obtained from DHM to use for model evaluation. Locations of the climate and hydrology station in Karnali River Basin are shown on Figure 5.

The digital elevation model and land use data for the **Ganges Basin** were obtained from the CEGIS National Water Resource Database (NWRD) and soil information was obtained from the Soil Research Development Institute (SRDI) of Bangladesh at a scale of 1:50,000. Most of the weather data was collected from the Bangladesh Meteorological Department (BMD). For some locations, precipitation data were taken from the Bangladesh Water Development Board (BWDB). The locations of the weather stations are shown in Figure 4. The daily discharge data at the Baghabari station for the Korotoa River and Chapai-Nawabganj for the Mahananda River was collected from the NWRD. The discharge data were collected for the period of 1981 to 2008.

Weather data from two climate stations i.e. Gupis and Gilgit situated within the study watershed were used for hydrological simulation in **Gilgit River Basin**. These two weather stations are installed and managed by Pakistan Meteorological Department (PMD). These stations have been recording climate data for the last more than 50 years. The river discharge data at Gilgit station was used which is maintained by Water and Power Development Authority (WAPDA). Daily discharge data of this gauge for the period 1980-2003 was used.

2.3.3 Projected Future Climate Data

Downscaled future climate projection data of 50 km resolution were obtained from Coordinated Regional Climate Downscaling Experiment, CORDEX (http://cccr.tropmet.res.in/home/ftp_data.jsp) project. CORDEX is an internationally coordinated framework to generate improved regional climate change projections world-wide for input into impact and adaptation studies, including input to the IPCC's Fifth Assessment Report. CORDEX program was established by the World Climate Research Program (WCRP). In the CORDEX data portal, data for six RCMs at the daily time step for different time scale and in regular grids for south Asia are available. Few researchers have utilized these data in past in order to assess the reliability and uncertainty in the climate projections for the South Asian region. Based on these studies, the dynamically downscaled Regional Climate Model of Swedish Meteorological and Hydrological Institute–Rossby Center Regional Atmospheric Model version 4 (ICHECRCA4) and CSIRO Marine and Atmospheric Research, Melbourne, Australia - Conformal-Cubic Atmospheric Model (CNRMCCAM) were selected and ensemble product of these two models was used to carry out the impact analysis in **Karnali River Basin**. The RCA4 (Rossby Centre's Regional Atmosphere-land Climate Model) developed by Rossby Centre at the Swedish Meteorological and Hydrological Institute (SMHI) is based on -High Resolution Local Area Model (HIRLAM), the numerical weather prediction model. In case of RCA, CMIP5 GCM EC-Earth data set downscaled at a resolution of 0.44° for domain covering south Asia using the latest and fourth version of the model. Two RCP radiative forcing scenarios- 4.5 W/m^{-2} and 8.5 W/m^{-2} were used.

For **Ganges Basin** only regional climate model data of Swedish Meteorological and Hydrological Institute–Rossby Center Regional Atmospheric Model version 4 (ICHECRCA4) data was used for future runoff scenario.

For **Gilgit River Basin**, two RCMs namely REMO and RCA4 from CORDEX simulations over South Asia were selected based on ease of the data availability and their better performance for Pakistan as compared to other CORDEX-SA RCMs. The data has been post processed and analyzed over two project climate data sites i.e. Gupis and Gilgit. The REMO is a limited-area three-dimensional hydrostatic model of Max Planck Institute (MPI) Germany. The first realization of the MPI-ESM GCM experiments downscaled with REMO to the CORDEX domain covering south Asia at a resolution of 0.44° has been post processed and analyzed for the two said sites.

Before using them for generating future climate data, the performance of all selected CORDEX-SA RCMs was evaluated in terms of spatial and temporal (annual cycle) representation of the climate for south Asia domain (presented in the Results section). Upon satisfactory outcome of this evaluation process, for both the RCMs, the data sets of historical periods (1971–2000) and two RCP scenarios i.e. RCP4.5 & RCP8.5 for the time periods comprising near future and far future have been analyzed.

2.3.4 Model Setup

ArcMap integrated **SWAT** version, the ArcSWAT 2010 interface is used to setup and parameterize the model. The ArcMap environment provides this tool for delineating of watershed, defining HRU, data base editing, weather stations defining, inputs parameterization and editing and simulation.

On the basis of DEM, the entire **Karnali River Basin** was discretized into 25 sub-basins, which were further subdivided into 379 HRUs based on soil, land use, and slope. Each HRU is thought to be a uniform unit where water balance calculations are made. The entire simulation period was from 1990 to 2005 with warm up period 1981-1989. These years are used as equilibration period to mitigate the initial conditions and were excluded from the analysis.

The **Ganges Basin** has been divided into 328 sub-basins on North-West region and 296 sub-basins on South-Central region. The total numbers of HRUs for the two modelling regions are 3416 and 3674 respectively. The simulation period was 1981 to 2012.

For the simulation in both basin (Karnali River Basin and Ganges Basin) the skewed normal probability distribution function was used to describe the distribution of rainfall amounts. Water is routed through the channel network using the Muskingum method. For estimating runoff, the SCS Curve Number (CN) method was used. For calculating Potential Evapotranspiration (PET) for the study area, the Hargreaves method was used, since it requires less data (air temperature only).

Since **UBCWM** model divides watersheds into elevation bands (up to eight), and model parameters can be set within each band, **Gilgit River Basin** was distributed into 8 elevation bands. Table 2 presents elevation bans-wise hydrological model parameter values related to land cover, topography (obtained through a detailed RS/GIS analysis of the spatial land cover information the study watershed) and climate information.

Table 2 Elevation band-wise hydrological characteristics of the study watershed

PARAMETER	**Band1**	**Band2**	**Band3**	**Band4**	**Band5**	**Band6**	**Band7**	**Band8**
Band mid-elevation (m)	1800	2500	3200	3900	4600	5300	6000	6700
Mean band area (Km^2)	290	850	745	3703	5015	1008	70	2
Forested fraction	0.30	0.30	0.20	0.15	0.00	0.00	0.00	0.00
Density of the forest canopy	0.3	0.30	0.30	0.30	0.00	0.00	0.00	0.00
Orientation index (0=North & 1=South)	0.82	0.85	0.86	0.88	0.88	0.88	0.89	0.93
Glaciated area (km^2)	0	0	16	80	490	270	21	0
Fraction of glaciated area with south-orientation	0	0.24	0.41	0.34	0.35	0.46	0.61	0.73
Fraction of impermeable area	0.30	0.35	0.40	0.55	0.60	0.70	0.75	0.80
Climate station selection index for temperature	1	1	1	1	2	2	2	2
Climate station selection index for precipitation	1	1	1	1	2	2	2	2
Precipitation adjustment factor (as a decimal fraction) default=0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Climate station selection index for evapotranspiration	1	1	1	1	2	2	2	2

2.3.5 Calibration, parameterization, and sensitivity analysis

The SUFI-2 algorithm (Abbaspour, et al. 2004) in the SWAT-CUP software package was used for model (SWAT) calibration, validation, and sensitivity analysis for the **SWAT** simulation output. The best parameter estimates based on the available data, literature, and analyst's expertise. Based on the performance of the model at outlet station, relevant parameters in the upstream sub-basins are parameterized as suggested by Abbaspour, et al. (2015). Based on parameters identified and one-at-a-time sensitivity analysis, initial ranges are assigned to parameters of significance. In addition to the initial ranges, user-defined absolute parameter ranges are also defined for every SWAT parameter in SWAT-CUP where parameters are not allowed to be outside of this range. Once the model is parameterized and the ranges are assigned, the model is run 500 times. Manual calibration method was used to calibrate for the **UBCWM** model output.

2.3.6 Model performance analysis

In calibration and validation, model evaluation was done statistically and graphically. The graphical model evaluation technique was used to make a visual comparison of simulated and measured constituent data and a first overview of model performance (ASCE, 1993). The graphical evaluation is essential for determining appropriate model evaluation (Legates and McCabe, 1999). In this report both graphical techniques and quantitative statistics were used to evaluate the model. Four objective functions were assessed in model simulations:

- Nash–Sutcliffe efficiency (NSE)
- Coefficient of determination (R^2)
- Mean relative bias (PBIAS)
- Ratio of the root mean square error to the standard deviation of measured data (RSR)

NSE is normalized statistics. The comparison of the relative magnitude of the residual variance (noise) and the measured data variance (information) is determined by NSE (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line (Moriasi, 2007). The NSE value of 1 indicates a perfect fit (Table 3).

The co-efficient of determination (R^2) describes the proportion of the variance in the observations explained by the model. The range of R^2 is from 0 to 1 where higher value (1) gives less error variance and values greater than 0.5 are considered as acceptable range (Santhi et al., 2001, Van Liew, et al., 2003). It only measures the deviation from the best fit line.

PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. Positive values of PBIAS indicate model underestimation bias, and negative values indicate model overestimation bias of total volume (Gupta, et al., 1999).

RSR was calculated applying the ratio of the root mean square error (RMSE) between simulated and observed values to the standard deviation of the observations (STDEVobs) (Moriasi, et al., 2007). RSR should be less than 0.7 for the acceptance of model performance. The lower the RSR, the better the model simulation performance is. The equations and the interpretation of the values of the statistical functions are given in Table 3. After automatic calibration, the monthly stream flow was compared against the observed data.

Table 3 General performance ratings for NSE, PBIAS, RSR and R^2 for calibration and validation process (adopted from Rossi et al., 2008)

Formulae	Value	Performance Rating
$NSE = 1 - [\frac{\sum_{i=1}^{n}(Xobs(i) - Ymodel(i))^2}{\sum_{i=1}^{n}(Xobs(i) - \overline{Xobs})^2}]$	> 0.65 0.54 to 0.65 > 0.50	Very good Adequate Satisfactory
$PBIAS = \left[\frac{\sum_{i=1}^{n}(Xobs(i) - Ymodel(i))}{\sum_{i=1}^{n}(Xobs(i))}.100\right]$	< ±20% ±20% to ±40% >± 40%	Good Satisfactory Unsatisfactory
$RSR = \frac{[\sqrt{\sum_{i=1}^{n}(Xobs(i) - Ymodel(i))^2}}{\sqrt{\sum_{i=1}^{n}(Xobs(i) - \overline{Xobs})^2}}$	0.00 < RSR < 0.50 0.50 < RSR < 0.60 0.60 < RSR < 0.70 RSR > 0.70	Very good Good Satisfactory Unsatisfactory
$R^2 \frac{[\sum_{i}^{n}(Xobs(i) - \overline{Xobs})(Ymodel(i) - \overline{Ymodel})^2}{\sum_{i}^{n}(Xobs(i) - \overline{Xobs})^2 \sum_{i}^{n}(Ymodel(i) - \overline{Ymodel})^2}$	R^2> 0.5	Satisfactory

Where: Xobs = Observed data, $\overline{Xobs}$= Mean of Observed data, Ymodel = Output data of model simulation, Yobs= Mean of Output data of model simulation

3. Results & Discussion

3.1 Past climate trends

A strong warming in **Karnali River Basin** over the past five decades is firmly supported by continuous measurements from 7 meteorological stations. The annual maximum, minimum, and average temperature anomaly of the basin is shown in Figure 3, which shows that the trends are positive, and more inter-annual variation has been seen in the minimum temperature.

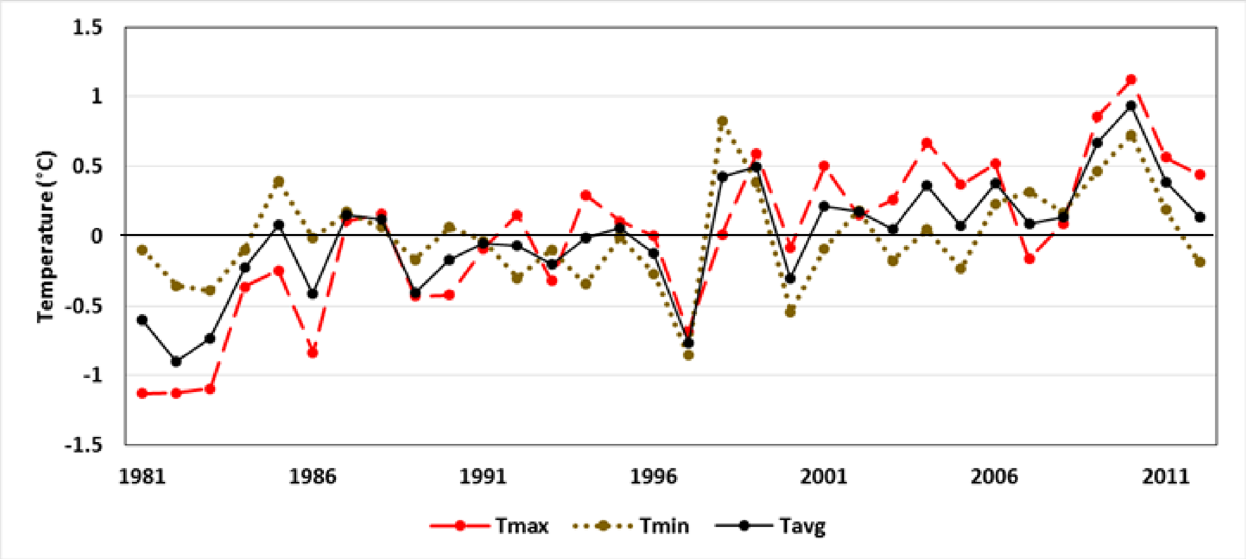


Figure 6 Average annual maximum, minimum, and mean temperature anomaly of the KRB

Mean temperature are increasing in most of the stations with statistical significant rate in mid- to high-altitude regions. The maximum and average temperature increase rate is higher in higher altitudes, whereas, the minimum temperature trend decreases with increasing altitude. Table 4 shows the maximum, minimum, and the average temperatures trend in different monitoring station in Karnali River Basin. Based on available data, the temperature variation in the KRB depicts that the maximum temperature is increasing at a faster rate (0.05^0 C per year) than the minimum temperature (0.01^0C per year) and most of the stations show high altitude mountains regions have the higher positive maximum temperature trends.

Table: 4 The maximum, minimum, and the average temperatures trend in different monitoring station in Karnali River Basin

S.N	Station Name (Index, Altitude in Meter)	Pre-Monsoon			Monsoon Winter			Post-Monsoon			Winter		
		Tmax	Tmin	Tavg	Tmax	Tmin	Tavg	Tmax	Tmin	Tavg	Tmax	Tmin	Tavg
1	Chisapani (405, 225)	0.05*	0.04*	0.058*	0.02	0.01*	0.02+	0.02	0.02	0.02+	-0.01	0.01	0
2	Dipayal (218, 652)	0.06*	0.08***	0.07**	-0.01	0.02*	0.011	0.01	0.04*	0.02	0.04	0.05**	0.04*
3	Surkhet (406, 720)	0.09***	0.03	0.06**	0.05**	0.01	0.03**	0.07***	0.03*	0.05**	0.08***	-0.01	0.03**
4	Chaut Jhari (513, 910)	0.04	0.02	0.03+	0.01	0.04***	0.02	-0.12***	0.05**	-0.03+	-0.04*	0.02	-0.01
5	Dailekh (402, 1402)	0.22***	0.0013	0.11***	0.14***	-0.10*	0.02	0.17***	-0.04	0.06*	0.11***	-0.01	0.04+
6	Musikot (514, 2100)	0.05	0.00018	0.02	0.002	-0.04**	-0.02	0.07***	0.003	0.04*	0.08**	0.02	0.04*
7	Jumla (303, 2300)	0.06**	0.02*	0.05**	0.03**	0.03***	0.03***	0.07***	0.02	0.05**	0.05*	0.01	0.03
	Average basin	0.08**	0.03*	0.05***	0.04***	-0.01	0.02*	0.03*	0.02	0.02*	0.05**	0.01	0.03*

p<0.001(***), p<0.01(**), p<.05(*), p<0.1(+)

In **Ganges basin**, we analyze data from two stations, one station from each region, and it has been found that the maximum temperature for the Khepupara station increase while no trend was found for the Rajshahi station (Figure 7) during the period of 1970 to 2010. Besides, for the minimum temperature, there exists a decreasing trend for the above two station.

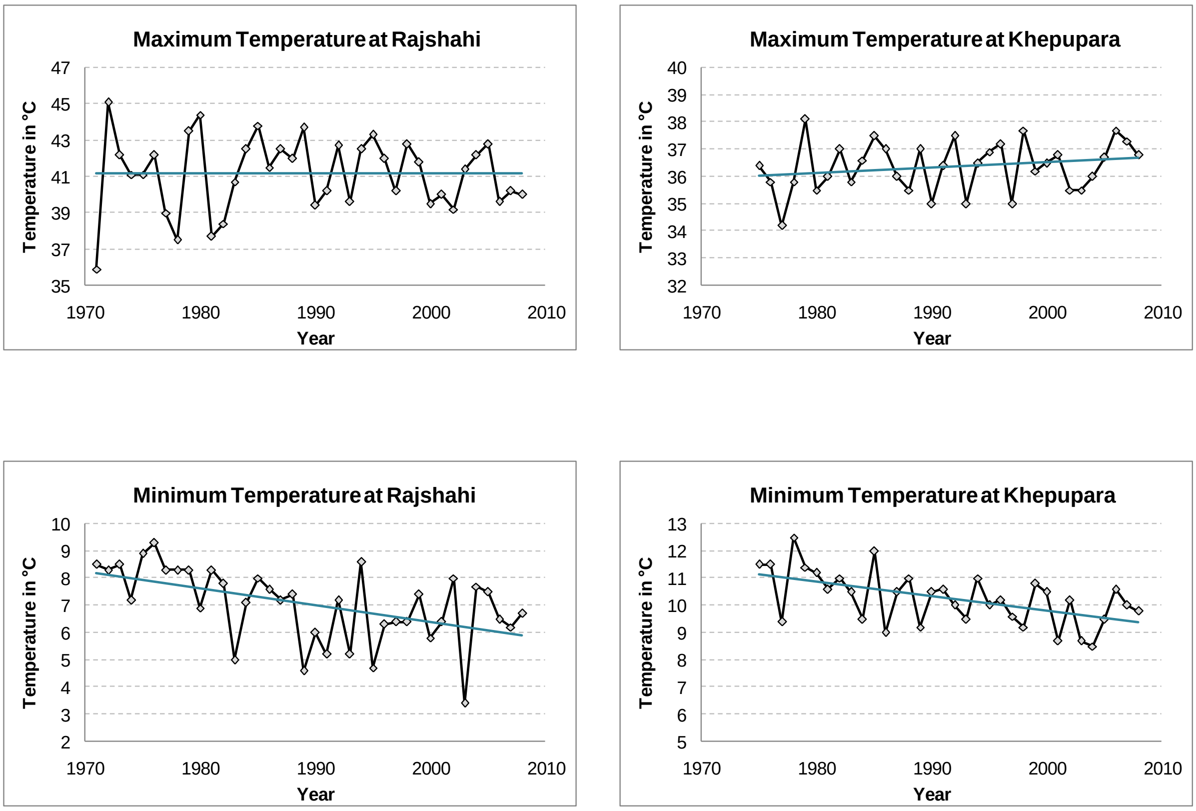


Figure 7 Temperature trend in Ganges basin

Analysis of Gilgit and Gupis meteorological station data in **Gilgit River Basin** is presented in Figure 8. This analysis shows that the overall maximum temperatures are increasing for the whole observed period while minimum temperatures are decreasing. While there is a decreasing trend of the summer (AMJJAS) average temperatures and increasing trend of the winter (ONDJFM) average temperatures in Gilgit station and almost no trend in the Gupis station.

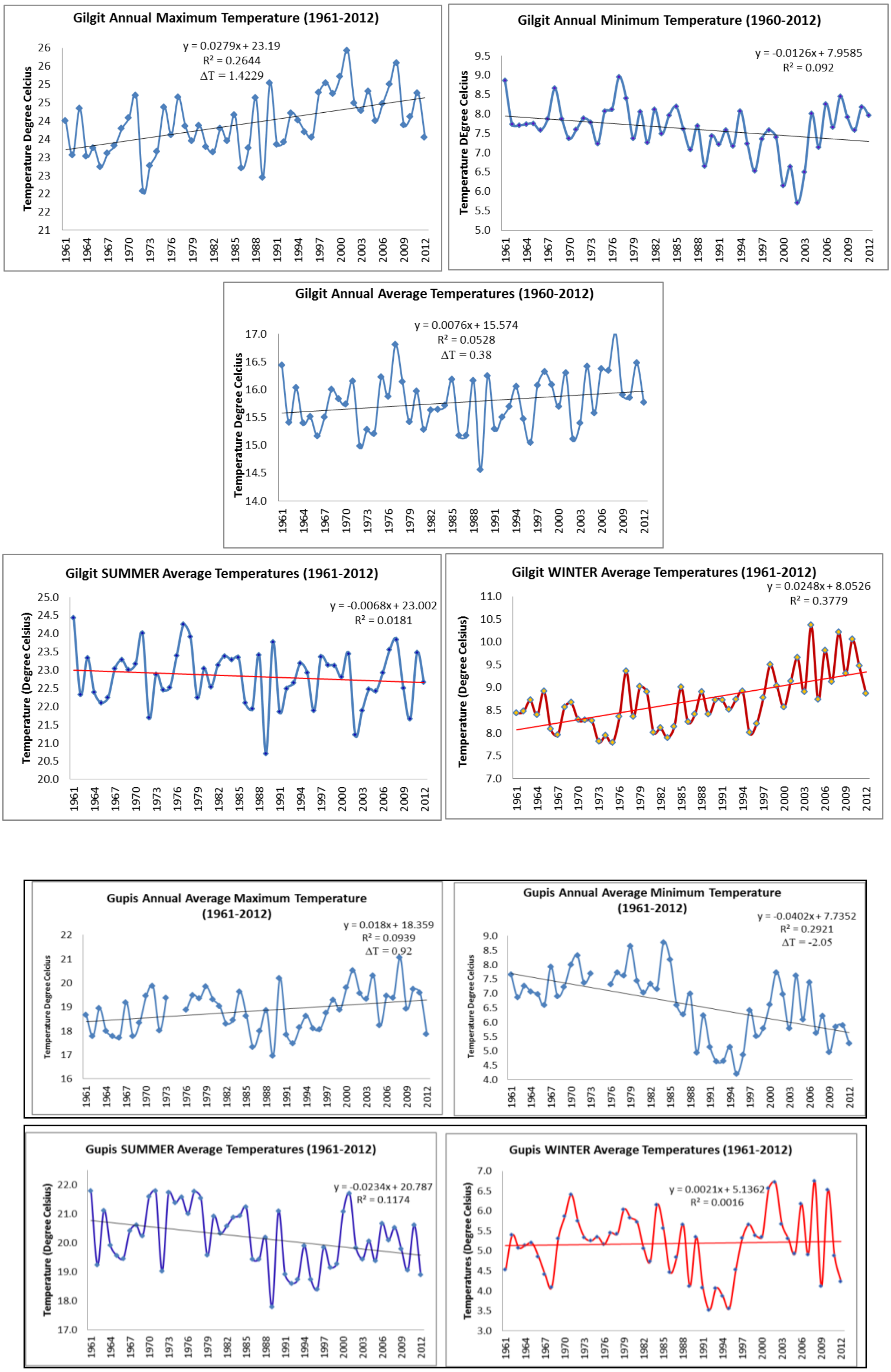


Figure 8 Temperature trend in monitoring stations in Gilgit basin

From the meteorological data analysis presented above, it is revealed that the maximum temperatures for both Gilgit and Gupis stations are increasing with a significant decrease in minimum temperatures, thereby indicating an increasing trend in the diurnal temperature range in the watershed. Similarly, analysis for average temperatures of both stations reveals that these are decreasing in summer while increasing in winter providing more energy for melting of snow and ice.

The trend of annual average precipitation of the **Karnali Basin** is heterogeneous and many of the stations show decreasing trend while stations at the mountains of the KRB is showing increasing trend. Decreasing trend is higher in Hills and Trans-Himalayan regions. The results of the single-site trend analysis for precipitation are shown in Figure 9. Red triangles facing downward and blue triangles facing upward represent decreasing and increasing trends of precipitation, respectively.

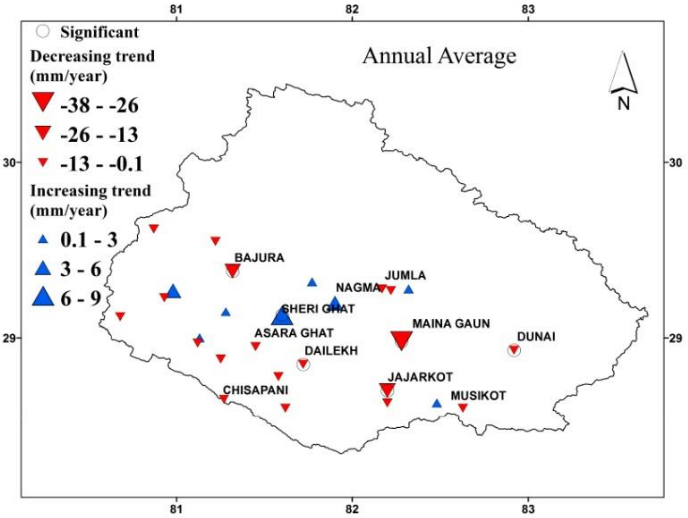


Figure 9 Single-site precipitation trend in Karnali river basin

The precipitation recorded in Gilgit meteorological station in **Gilgit Basin** is also increasing in the annual and summer season and significantly decreasing trends of precipitation are observed in winter (Figure 10). On the other hand, the trend of the precipitation data recorded at the Gupis meteorological station is increasing in both the summer and winter seasons.

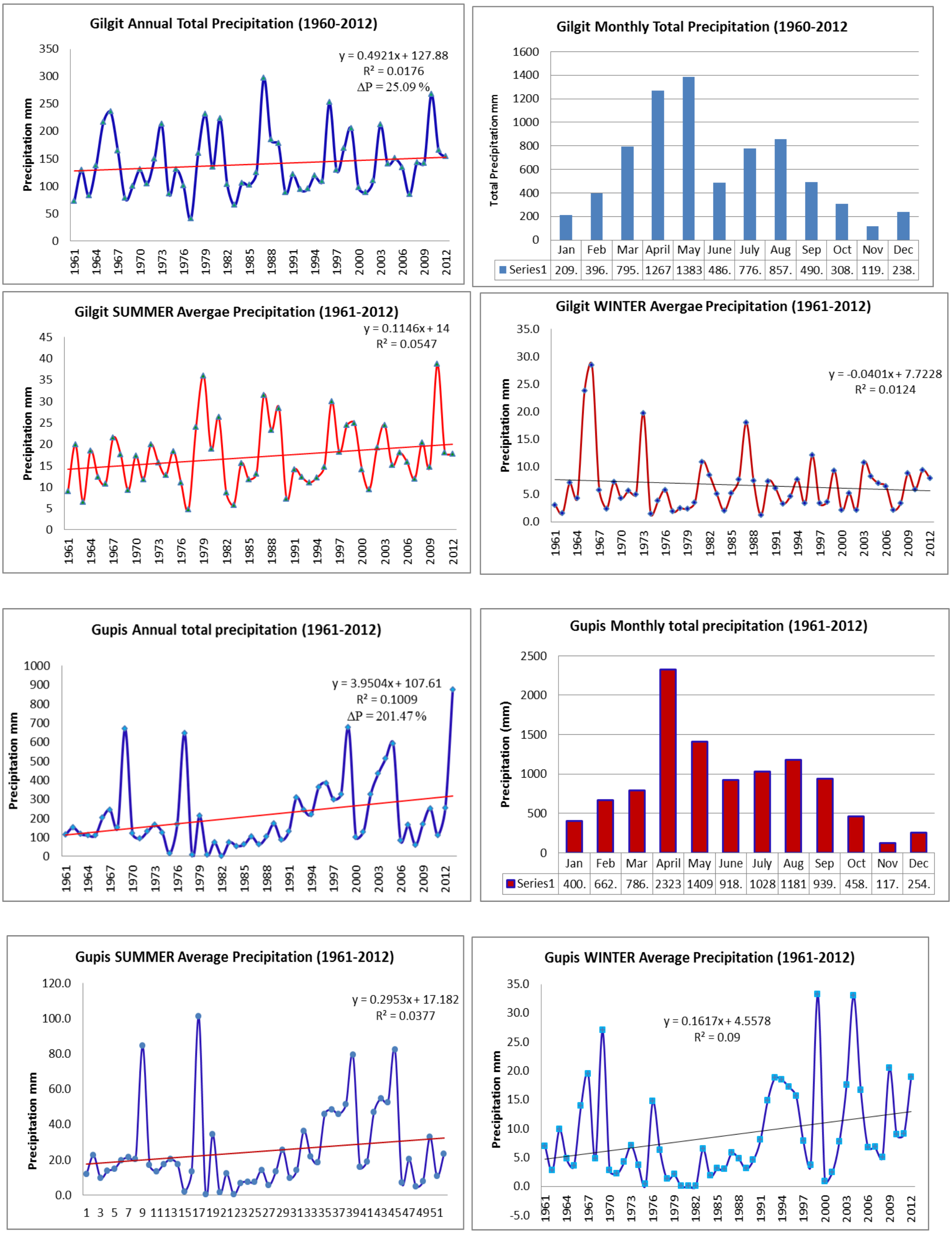


Figure 10 Average monthly precipitation and trend analysis of rainfall records in different station in Gilgit Basin

Four stations have been studied the variability of rainfall in **Ganges Basin**. The selected meteorological stations are Rajshahi, Faridpur, Khulna and Khepupara (Figure 11). From the temporal analysis it has been found that there is an increasing trend of rainfall pattern for the lower part of the study area (Khulna and Khepupara) while for the Faridpur station, it has the decreasing trend during the period of 1970 to 2008. There is no temporal variation of rainfall in the Rajshahi station.

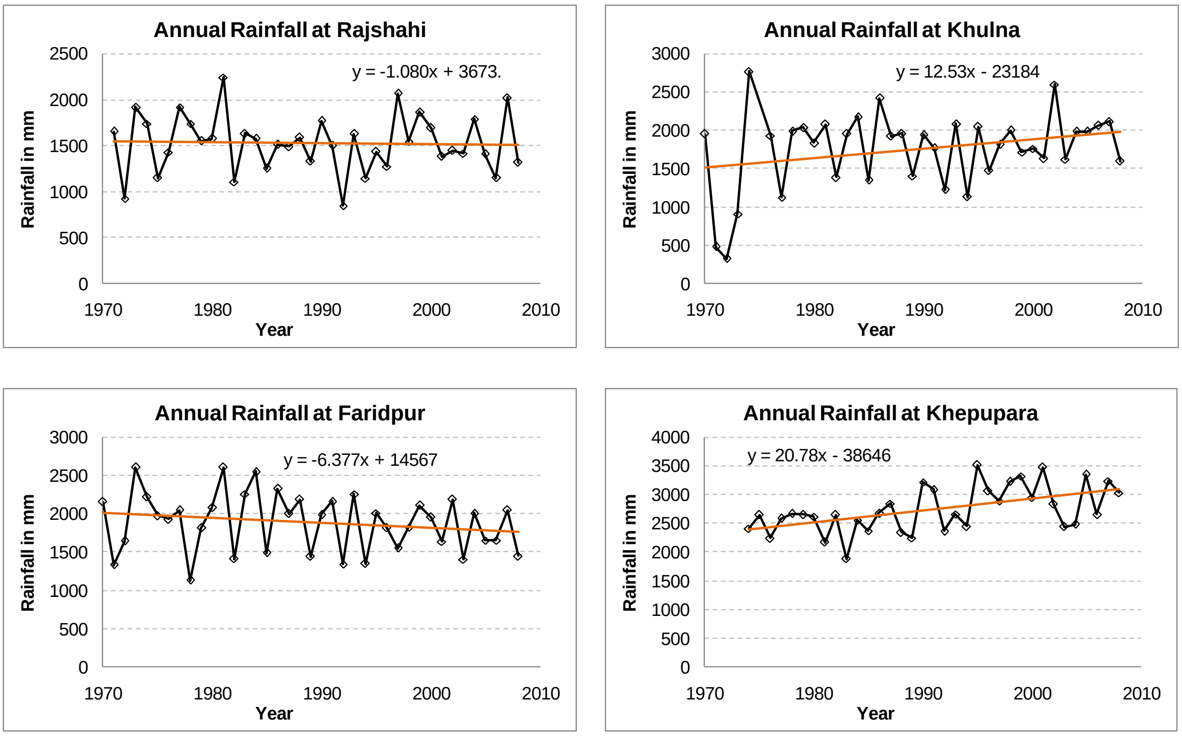


Figure 11 Trend analysis of precipitation in Ganges basin

3.2 River Runoff and Water Resources

The mean annual discharge at the outlet of the **Karnali River Basin** at Chisapani is 1,369 m^3/s with the highest runoff during the month of August (4278 m^3/s) and lowest during February (302 m^3/s). Likewise, during 1981–2010, the annual discharge ranged from 1,013 m^3/s (lowest) in 1987 to 1,790 m^3/s (highest) in 2000. While studying the mean annual and seasonal discharge (Figure 12), it is nearly constant with large inter-annual variability.

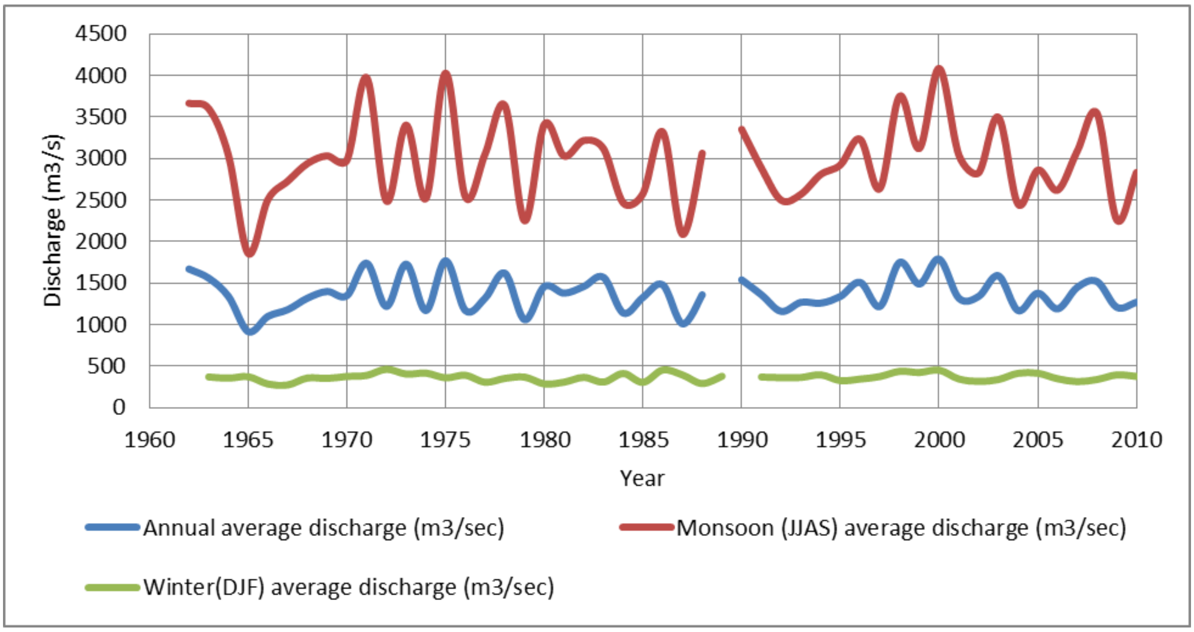


Figure 12 Annual, Monsoon and Winter average river discharge at Chisapani.

The monthly precipitation of KRB and discharge at its outlet Chisapani is shown in Figure 13. The discharge in KRB begins to increase in May and peaks in August. During the pre-monsoon season when the temperatures starts rising, the snow and glacier melt contribute to the stream flow. The higher runoff time coincides with the monsoon season and continues until the post-monsoon period when temperatures are relatively high. Likewise, after August there is more discharge at its outlet Chisapani than the precipitation in the KRB where probably the groundwater contribution and glacial discharge may be playing a major role.

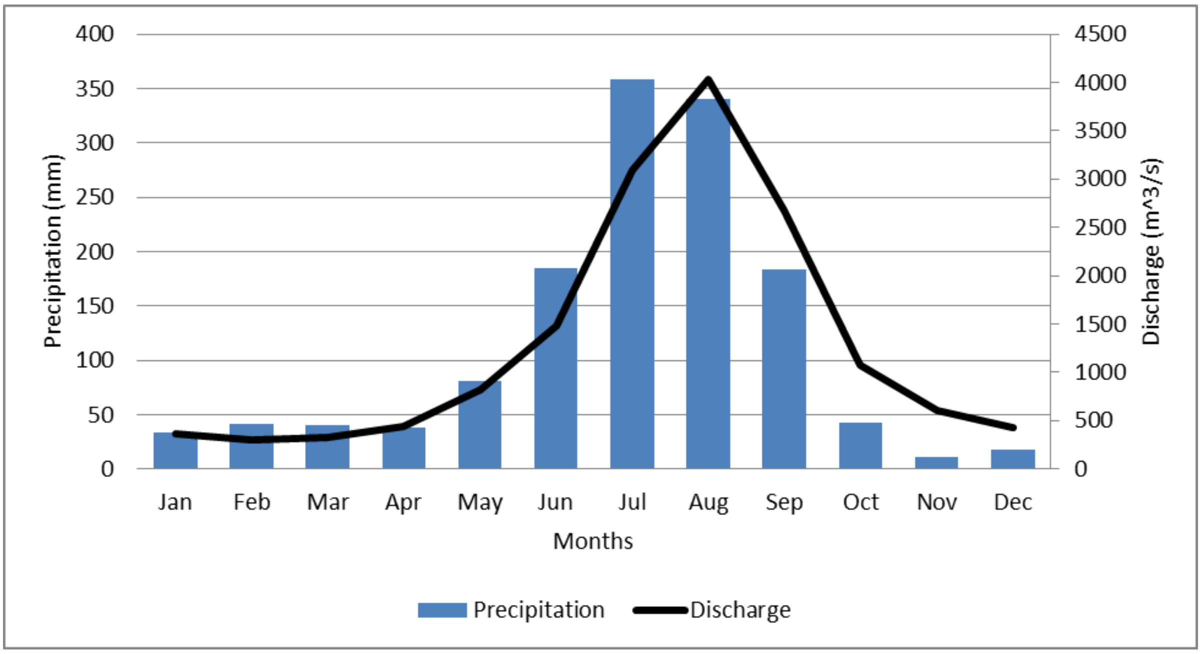


Figure 13 Monthly average precipitation and discharge relation in KRB

The inflow of the Ganges- river at Hardinge Bridge in Bangladesh is shown in Figure 14. It is observed from the analysis of data that the annually 343,000 Mm^3 of water enters to the GP basin and the flow is mainly concentrated in the wet season (Jul-Oct). Maximum monthly flow is observed during August (97,000 Mm^3).

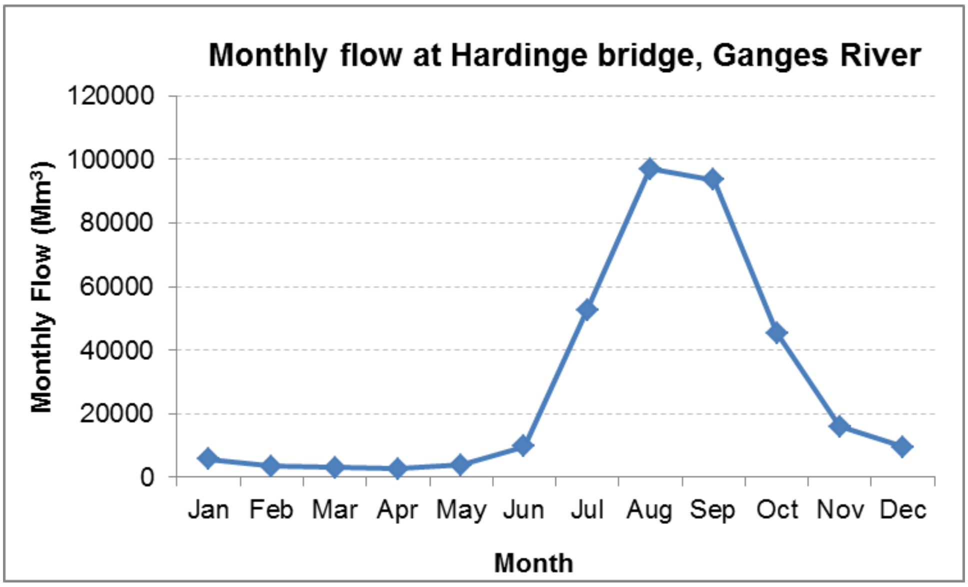


Figure 14 Monthly flow at Hardinge bridge on Ganges river (1970-2006)

Analysis of the Gilgit River annual average discharge at Gilgit station shows an increasing trend during the last few decades (Figure 15). Seasonal analysis of the discharge data shows a significant increase in summer flows and a slight increase in winter flows (Figure 16). Considering the increasing trend of temperature and precipitation in summer (shown earlier), this increase in flows is justified.

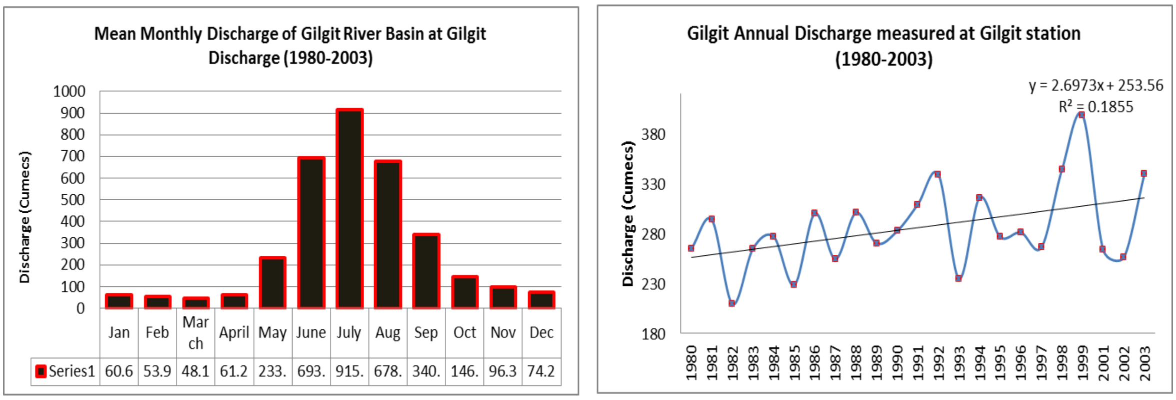


Figure 15 Mean monthly and average annual flows of Gilgit watershed at Gilgit for the period 1980-2003

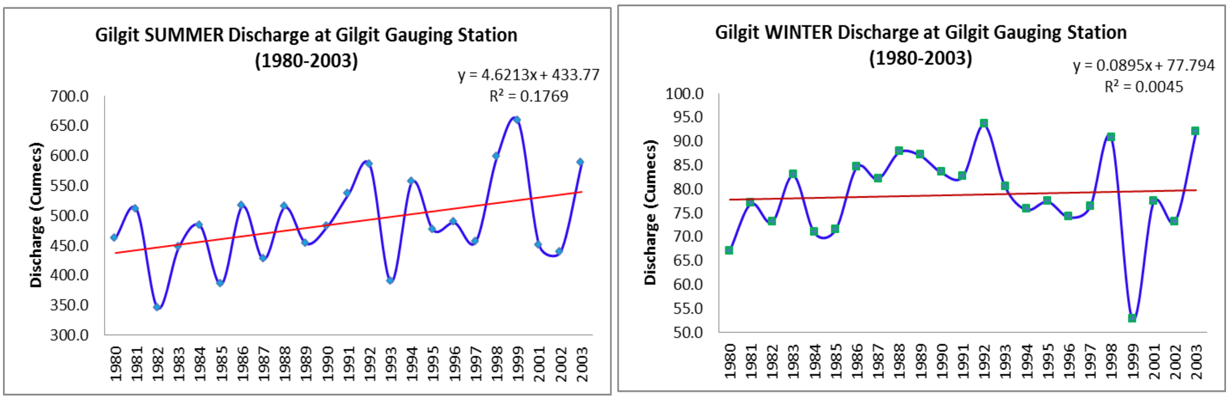


Figure 16 Seasonal mean flows of Gilgit watershed at Gilgit for the period 1980-2003

More summer precipitation is observed in last few decades in the study catchment with slightly decrease of winter precipitation. Increase in maximum temperatures with more precipitation in summer can be attributed as the reason of increased flows in the Gilgit River.

3.2 Future Climate Projection

Temperature and precipitation data of the Regional Climate Models used from CORDEX simulations over South Asia were first evaluated by comparing them with these variables from Climate Research Unit (CRU) dataset. This comparison is presented in Figure 17 and 18. It reveals that these RCMs reproduce the spatial patterns of average climate over south Asia with a reasonable agreement with the CRU dataset. Hence, the climate data from these two RCMs can be used with confidence for further climate change analysis.

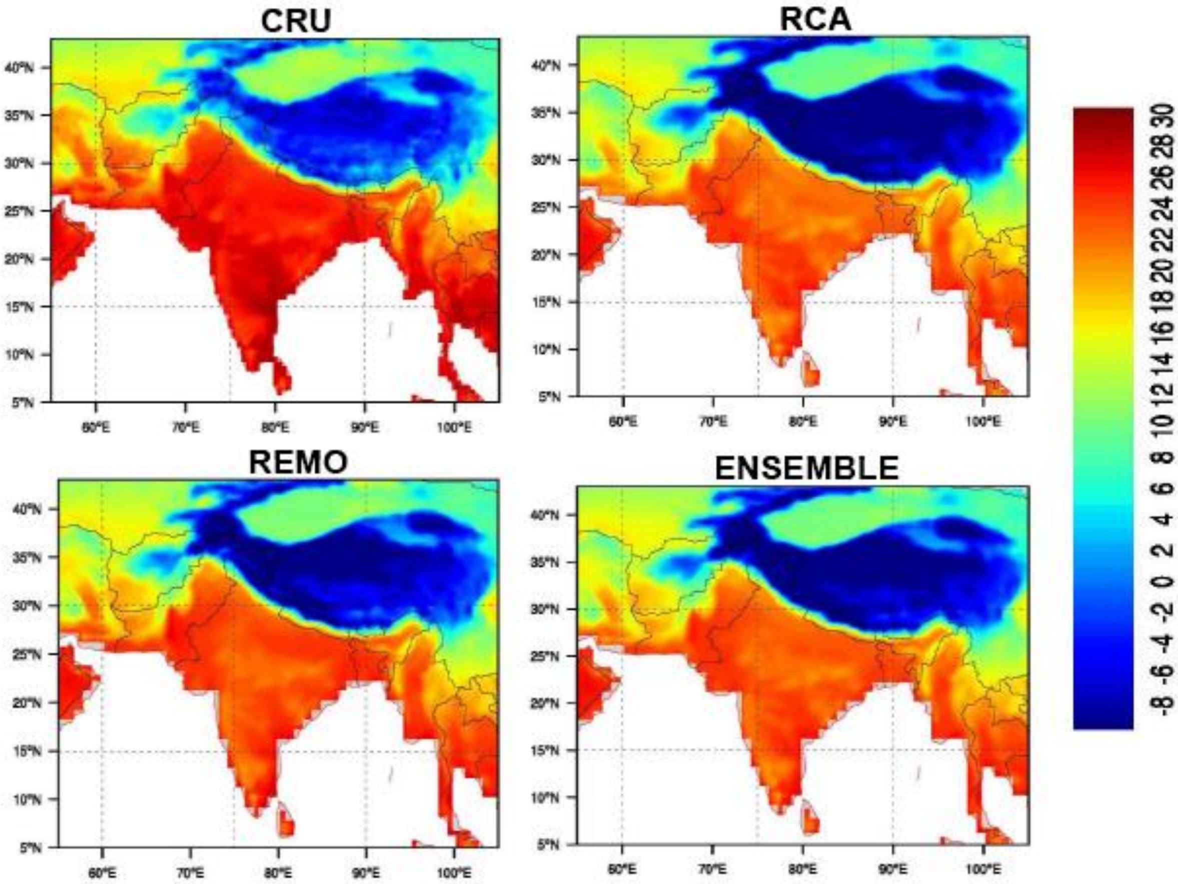


Figure 17 Comparison of RCMs and CRU Mean baseline (1971-2000) temperature (°C) over whole of South Asia

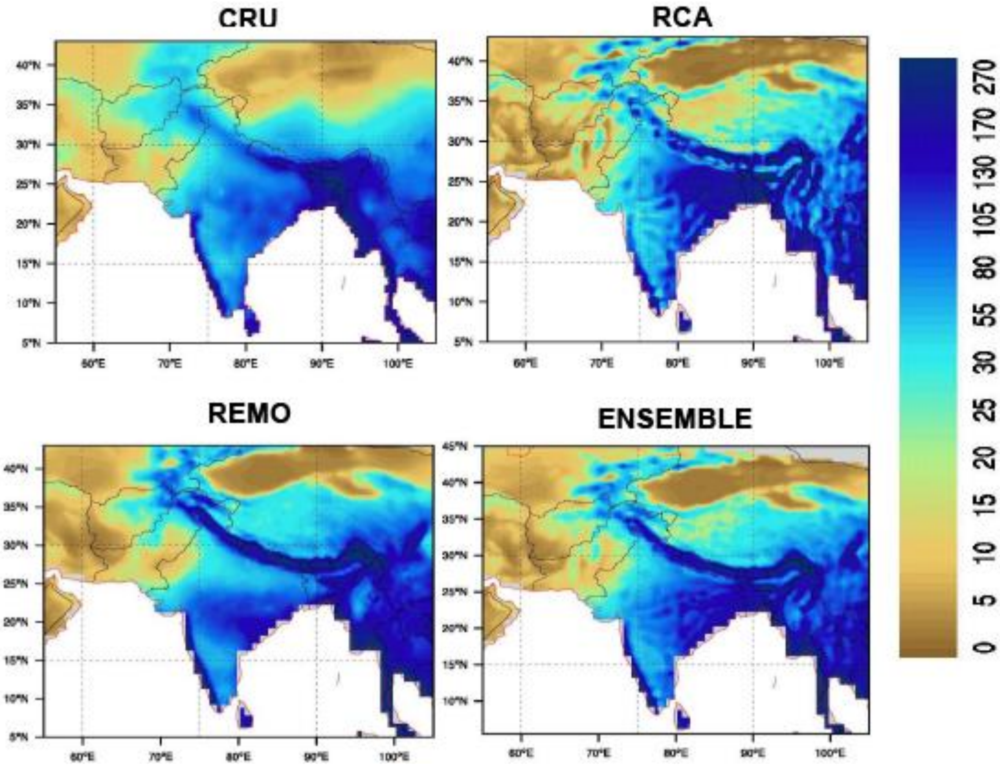


Figure 18 Comparison of RCMs and CRU in terms of monthly mean baseline (1971-2000) precipitation (mm/day) over whole of South Asia

Projections (ensemble) indicate that, compared to the average in the baseline period, average annual temperatures could rise by more than 2°C over land in most of South Asia by the mid-21st century and exceed 3°C, up to more than 6°C over high latitudes, by the late 21st century under a high-emissions scenario (Fig. 19).

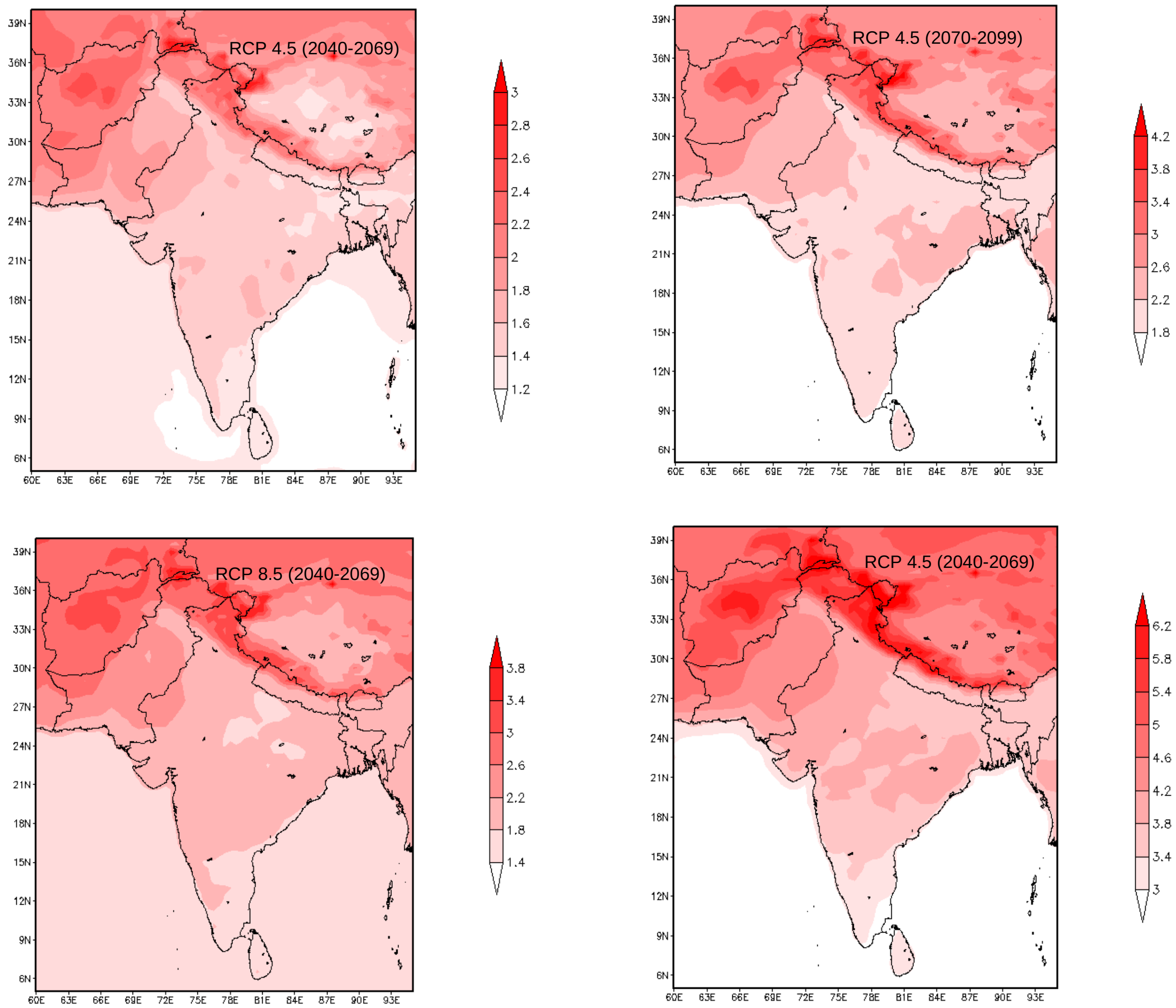


Figure 19 Projected global annual average temperature(°C) for South Asia

Projections indicate that more rainfall will be very likely at South Asia by the mid-21st century under a both emissions scenarios (Fig. 20).

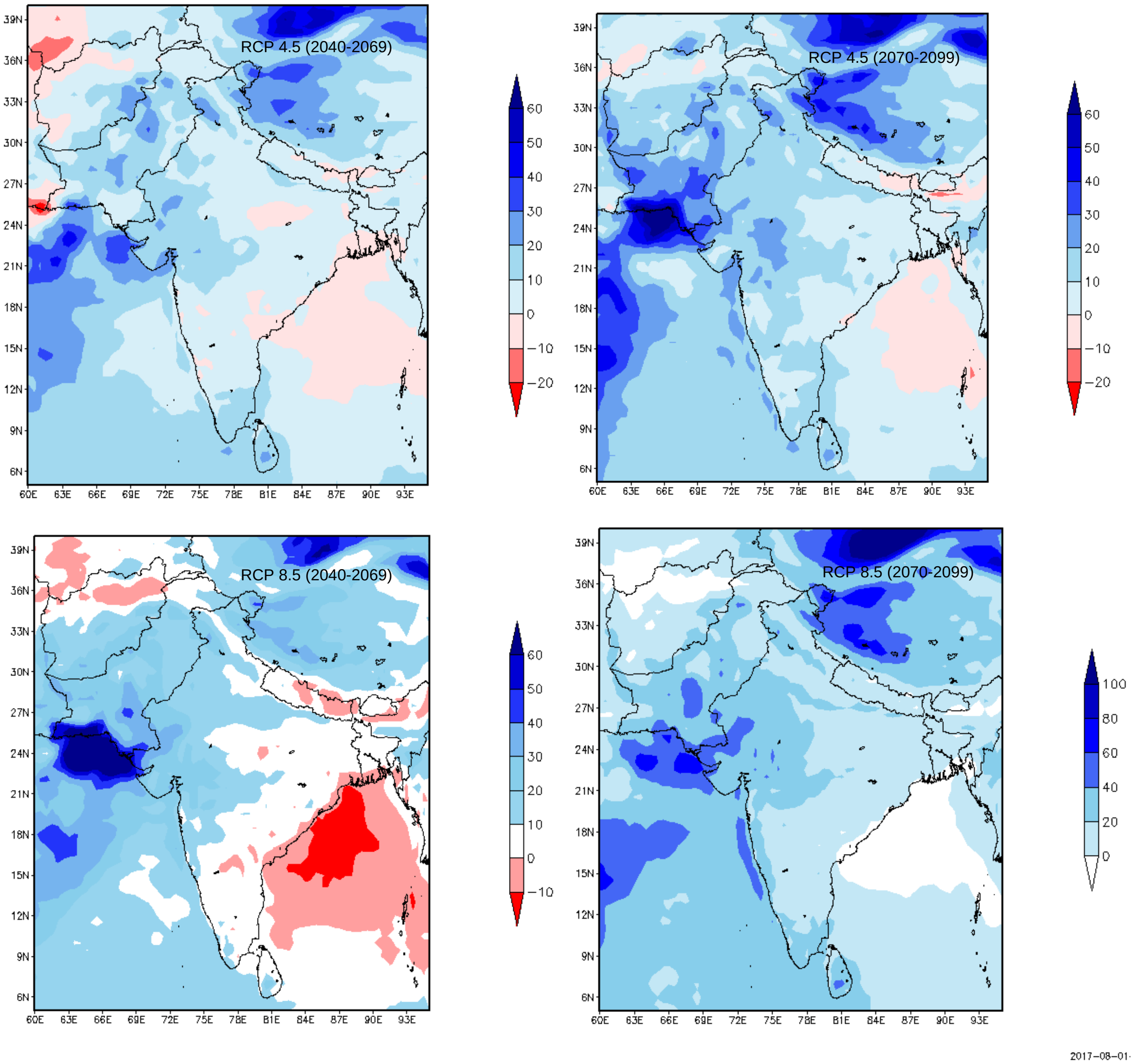


Figure 20 Projected global annual average precipitation (%) for South Asia.

Analysis of future projection of temperature show increase in **Karnali Basin** for both time scales 2040-2069 and 2070-2099 for the both RCP4.5 and RCP8.5 scenarios. RCP 4.5 scenario shows that the changes in mean temperature between baseline and projected period will be between 1.4°C to 2.6°C for 2040-2069 and 1.6°C to 3.4°C for 2070-2099. Similarly, RCP 8.5 scenario shows that the changes in mean temperature will be between 1.8°C to 3.8°C for 2040-2069 and 3.0°C to 6.2°C for 2070-2099. Figure 21 present the spatial map of projected changes in the future temperature at basin level for different scenario and time scale relative to the baseline period of 1971-2000. The Figure show that temperature is expected to be increase more in higher altitude than low land for both time scale and the higher radiative forcing in RCP 8.5 results in generally higher temperature increase for all area of the basin.

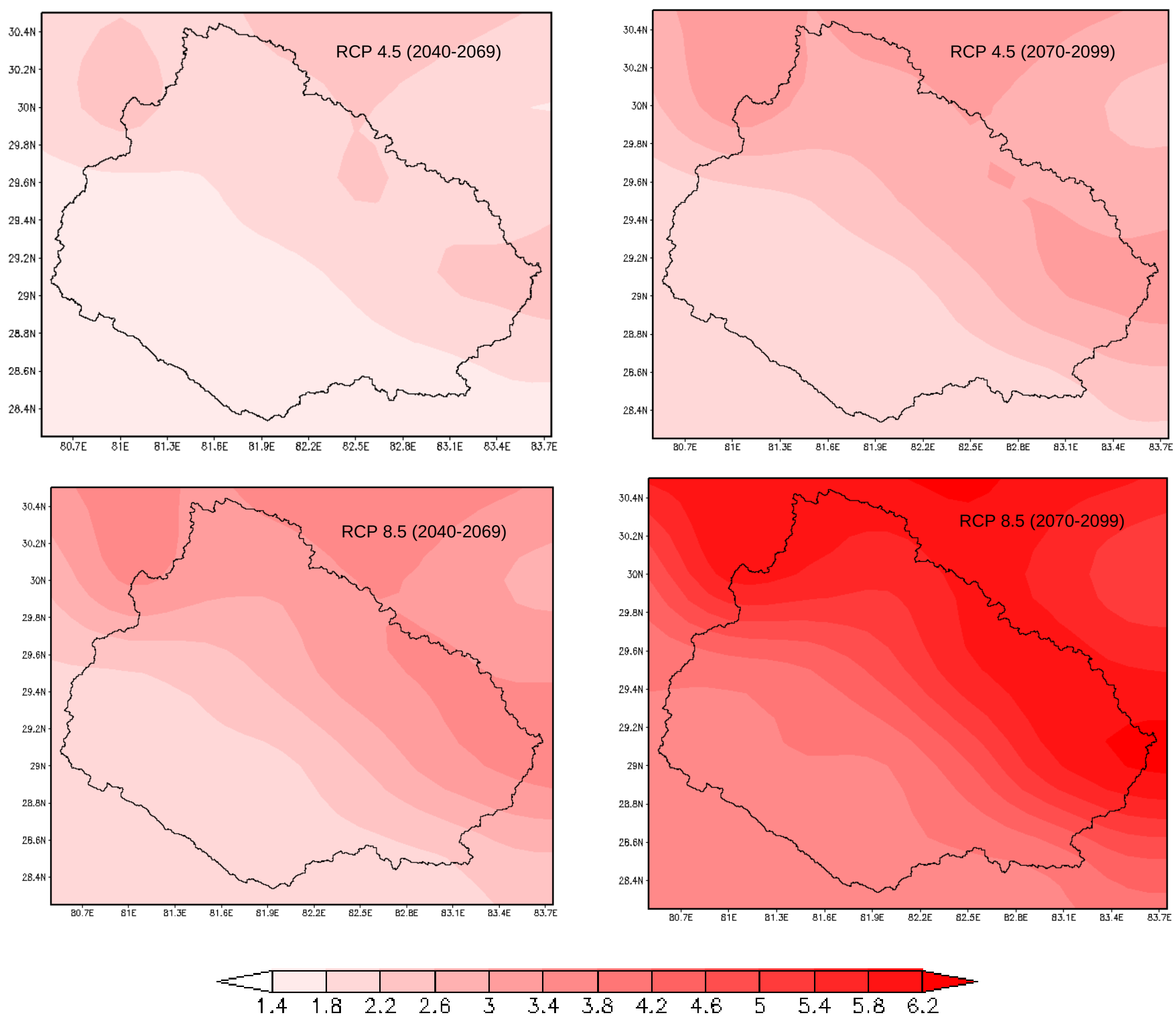


Figure 21: Projected Changes in the future temperature (^oC) at basin level for different scenario and time scale relative to the baseline period of 1971-2000

Figure 22 present the spatial map of projected changes in the future precipitation at **Karnali Basin** level for different scenario and time scale relative to the baseline period of 1971-2000. The Figure shows that precipitation is expected to be increase in most of the area for both time scale and scenarios. Graph show that for RCP 4.5 scenario, the changes in annual total precipitation, may increase up to by 12%. Similarly, RCP 8.5 scenario shows that the changes in annual precipitation will be up to 30%. Very few areas show the decreasing in precipitation for both scenarios and time scales.

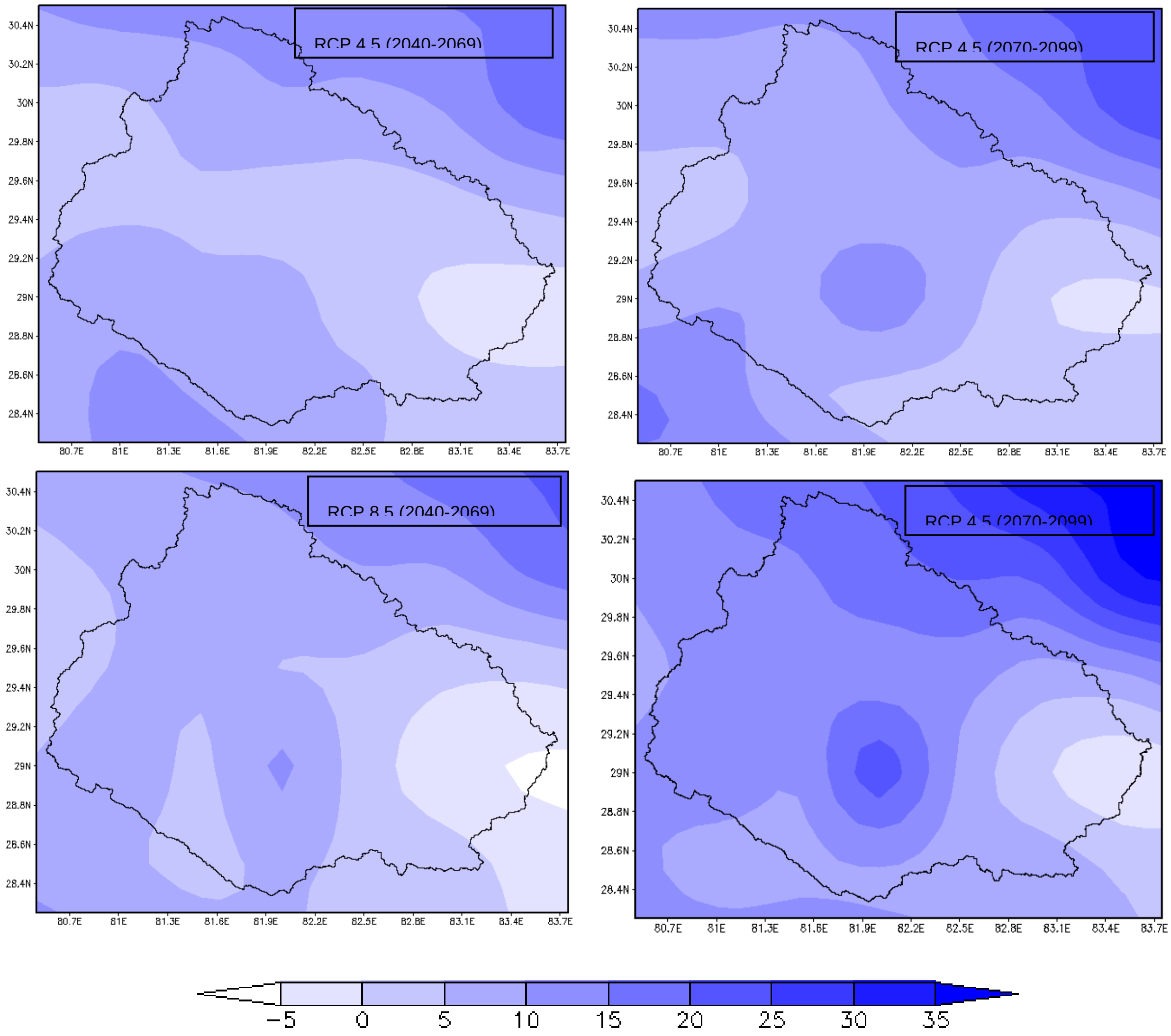


Figure 22 Projected Changes in the future precipitation (%) at basin level for different scenario and time scale relative to the baseline period of 1971-2000

Figure 23 demonstrate the monthly variability in the future rainfall in comparison to the baseline period for both time scale and climate scenarios. For RCP 4.5 and RCP 8.5 scenario, comparatively pre-monsoon and monsoon precipitation is expected to increase both during the early (2040-2069) and the later part (2070-2099s) of the century compared to the baseline period. Contrast to this, both RCP 4.5 and RCP 8.5 scenarios show the decreasing rainfall in month of

November for both time scales which is the driest month of the basin which could lead to increase in winter droughts in the future.

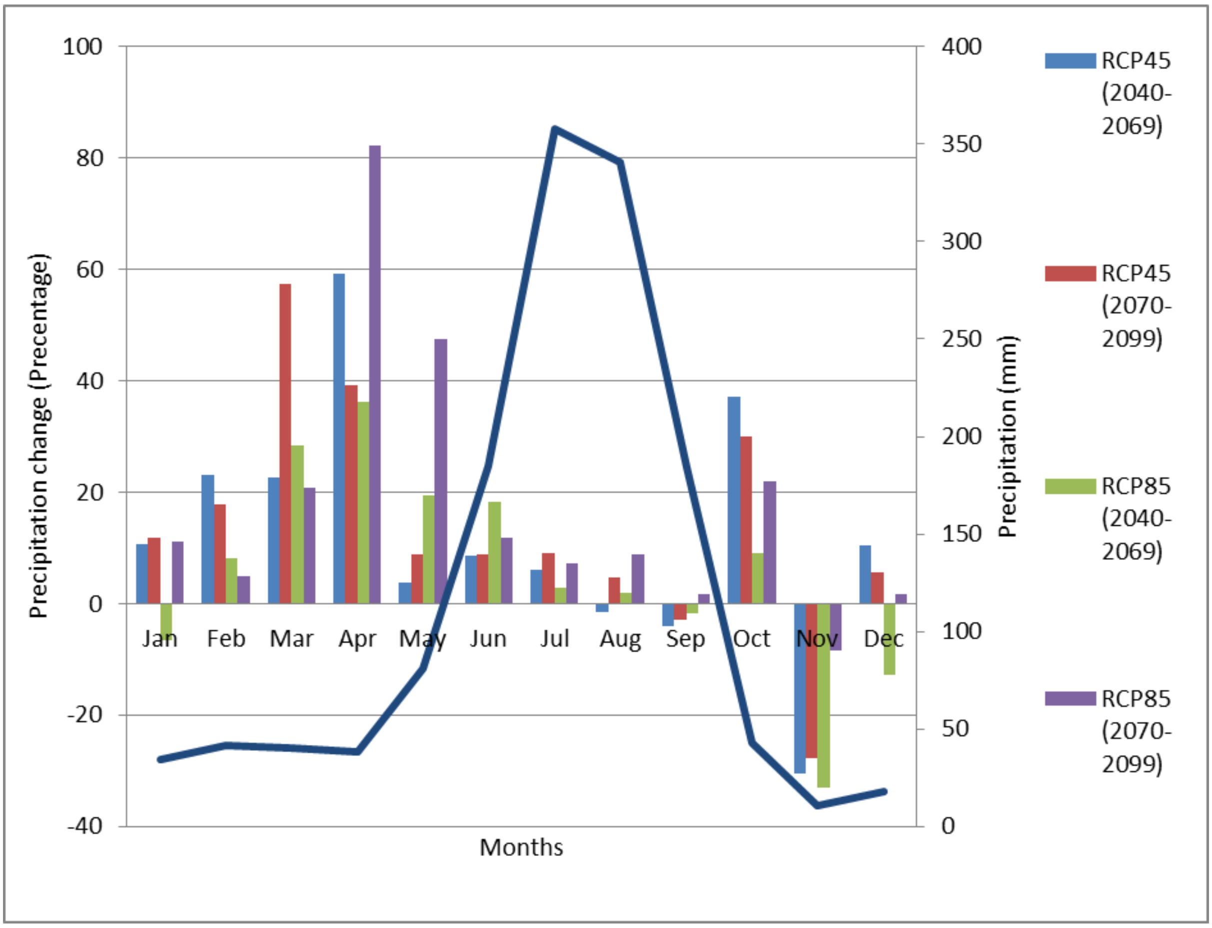


Figure 23 Projected changes in the average monthly precipitation at basin level for different scenario and time scale relative to the baseline period of 1971-2000. Dark blue line indicates the observed rainfall in KRB (secondary y axis)

Similar trend can be observed for both RCP 4.5 and RCP 8.5 but for most of the case RCP 4.5 expects with a larger increase in the predicted rainfall compared RCP 8.5 scenario and expects more increase for the period 2040-2069 than 2070-2099.

From the climate trend analysis in Ganges basin it was found that in 2030s and 2050s precipitation would be less than base period (1981-2010). But in 2080s it would be little higher. Figure 24 shows the future climate trend in Ganges basin.

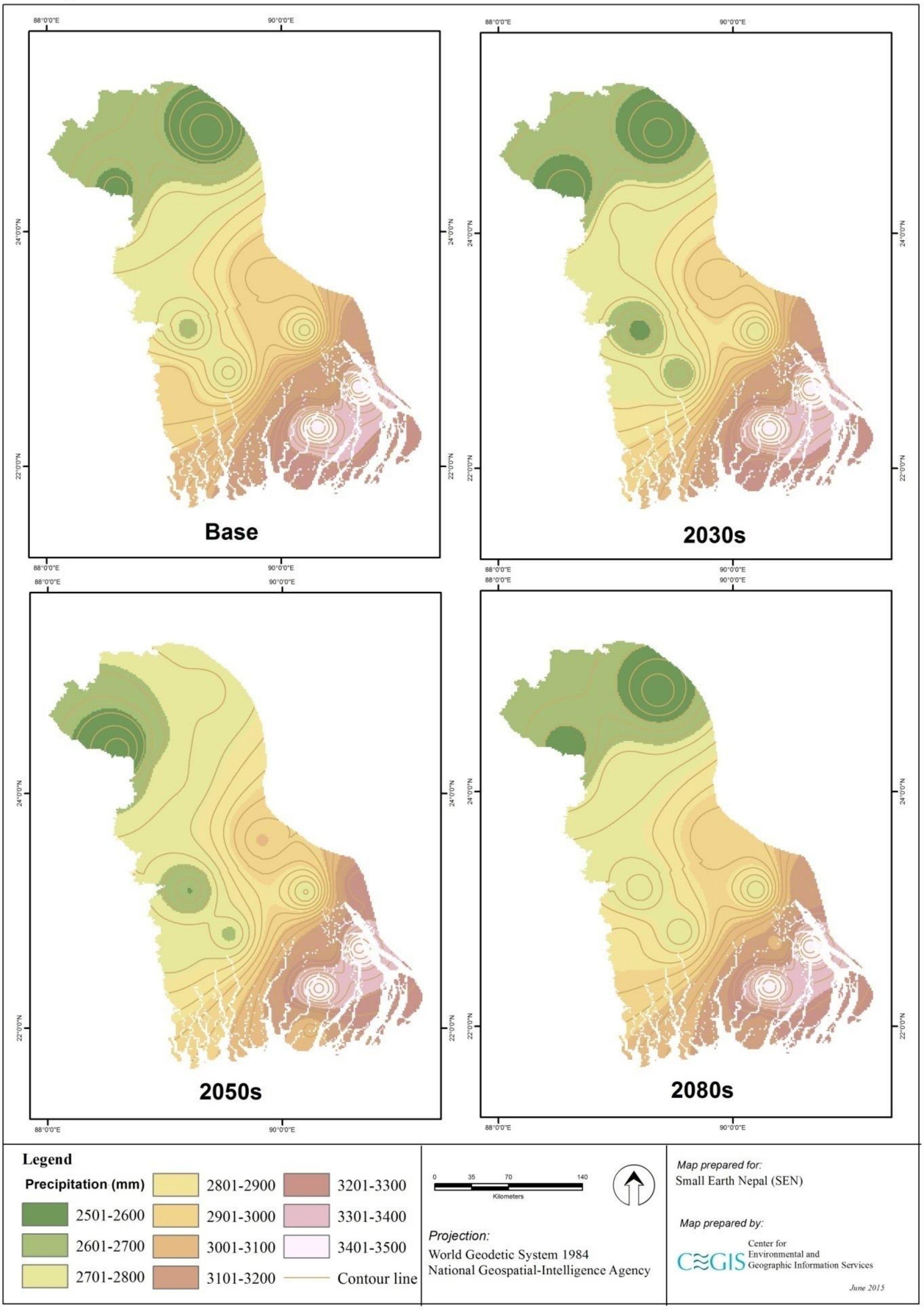


Figure 24 Baseline and projected future precipitation in Ganges basin

In 2030s, maximum temperature will be slightly less compared to base. On the other hand, 2050s and 2080s are showing similar trend like base in **Ganges basin** (Figure 25).

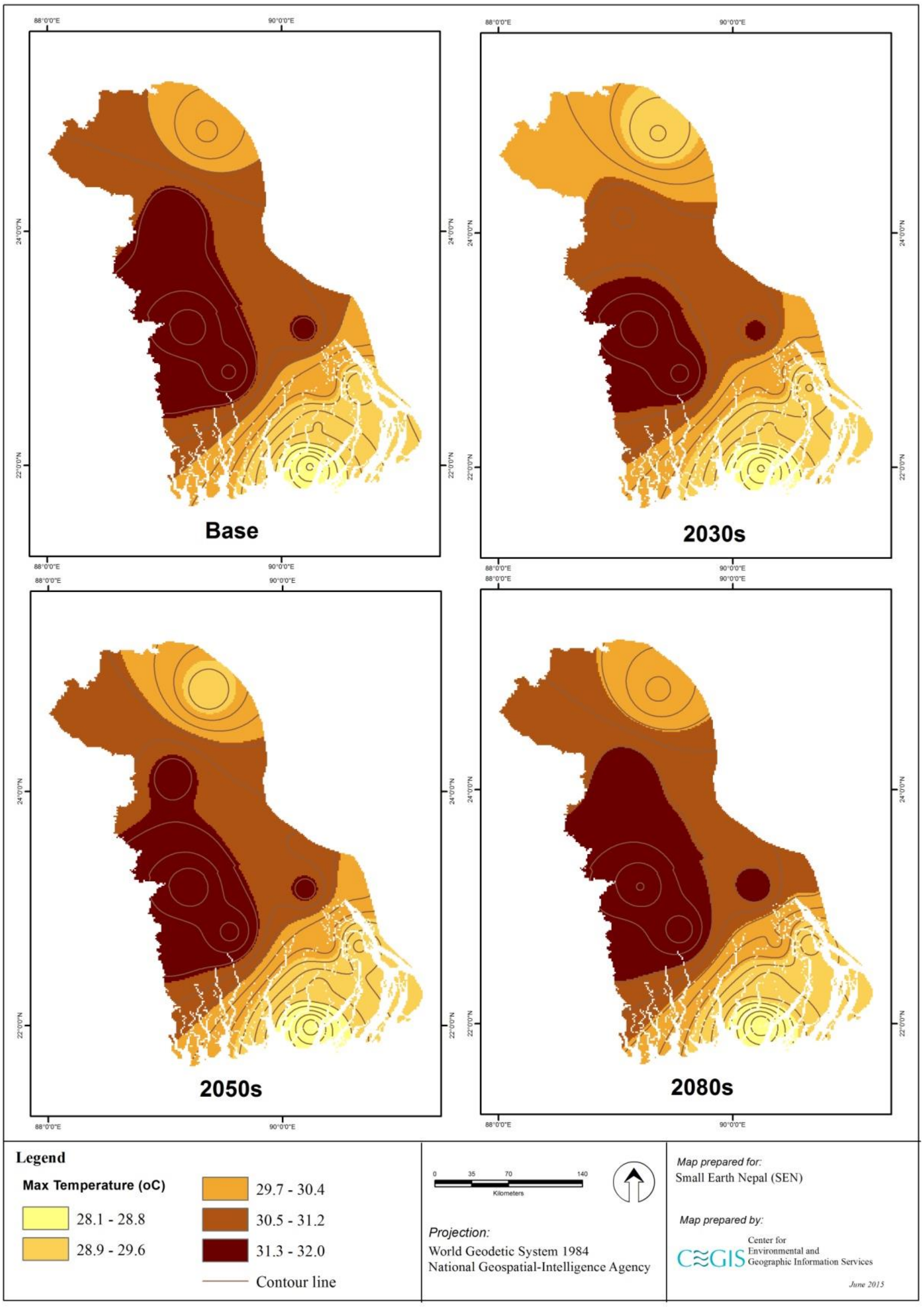


Figure 25 Baseline and projected future maximum temperature in Ganges basin

In case of minimum temperature 2030s, 2050s and 2080s are showing more or less same trend like baseline period (Figure 26).

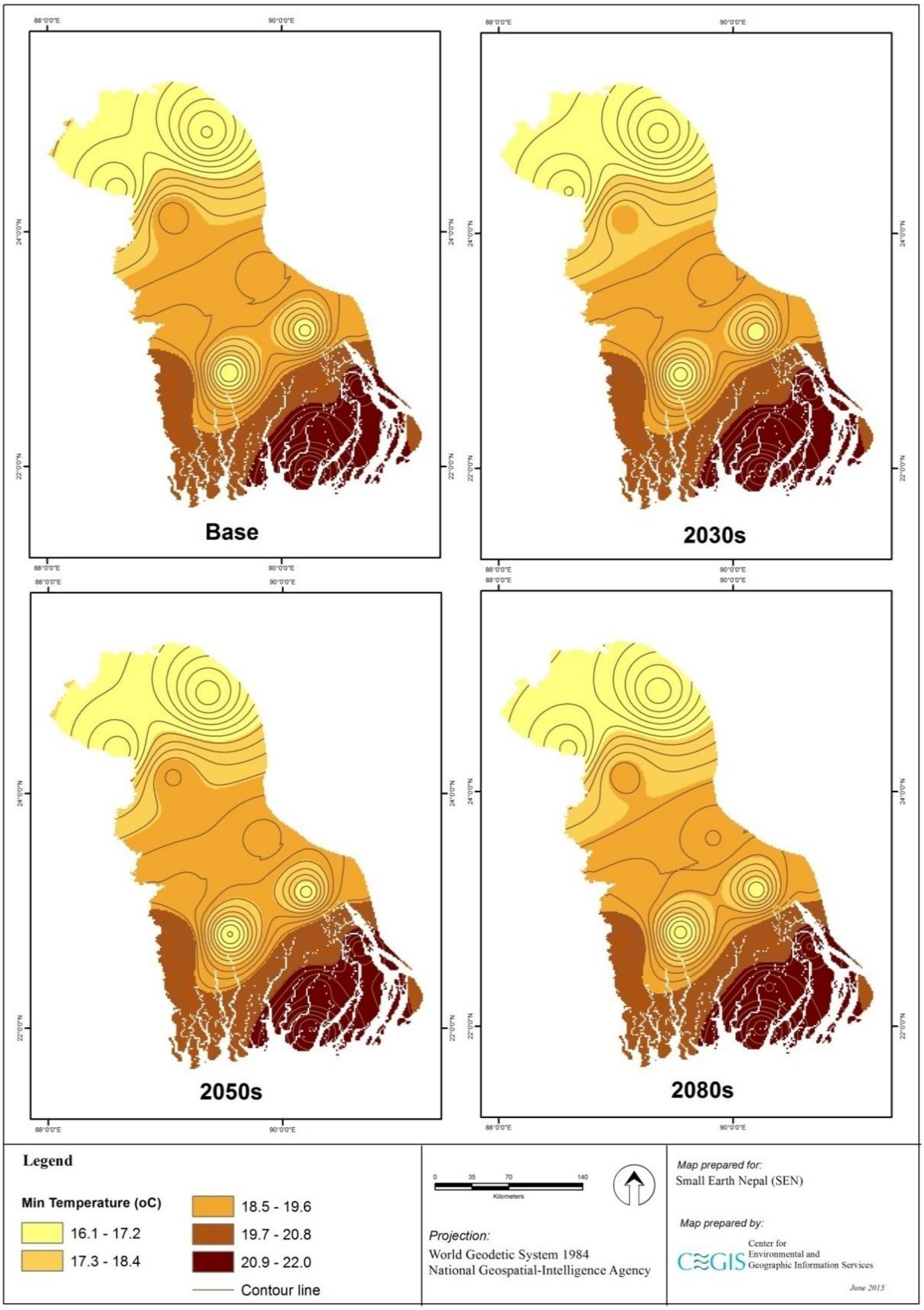


Figure 26 Baseline and projected future maximum temperature in Ganges basin

3.3 Calibration and Validation Results of hydrological Model

Figure 27 represents the graphical comparison between the observed and simulated monthly discharge for Chisapani station in **Karnali River Basin**. The NSE for this station during the calibration and validation periods were 0.85 and 0.83, respectively. Similarly, the cumulative volume of the simulations exceeded that of the observations by 1.9% during the calibration period and by 3.9% during the validation period. The summary statistics of model performance is summarized in Table 5.

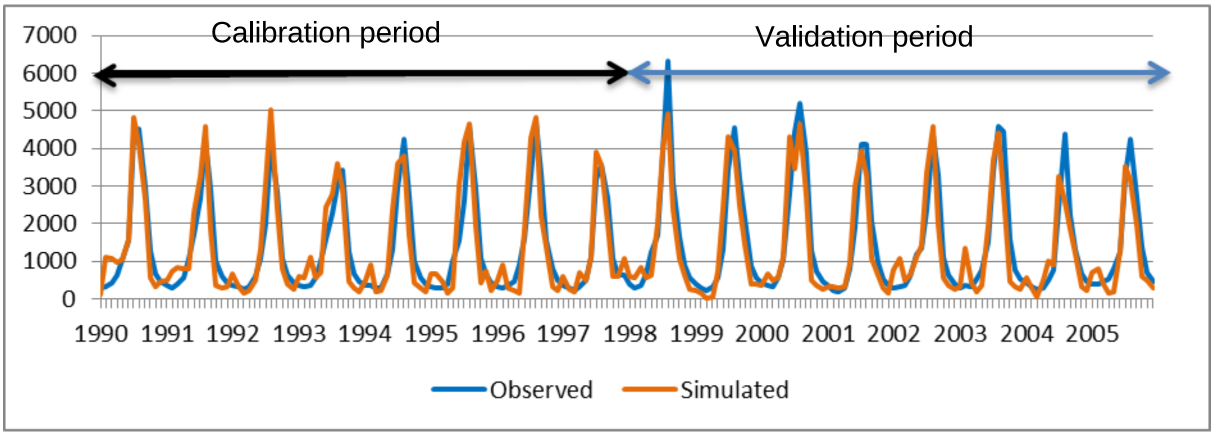


Figure 27 Observed and simulated discharge at Chisapani for both calibration and validation period.

Table 5 Summary statistics of model performance

Criteria for Model Skill Evaluation	Calibration	Validation
Nash-Sutcliffe Efficiency (NSE)	0.85	0.83
Percent Bias in Volume (PBIAS)	1.9	3.9
Coefficient of Determination (R^2)	0.86	0.84
RMSE-observations standard deviation ratio (RSR)	0.39	0.41

The model for the **Ganges Basin** (North-West region) was calibrated against observed daily stream flow data of Chapai-Nawabganj station on the Mahananda River and at Rohanpur station on the Punarvaba River. The model was calibrated for the years 1981 to 1988 and validated for the years 1989 to 1994. The calibration and validation periods vary for different model based on availability of observed data. The visual comparison of observed and simulated stream flow at Chapai Nawabganj station for the calibration period is shown in Figure 28 and for the validation period in Figure 29. For both the periods, the model could capture the dry season flow, rising limb and recession limb with good accuracy; but the model could not capture the peak flow for some years. In conclusion, the model could simulate the behavior of observed flow reasonably well.

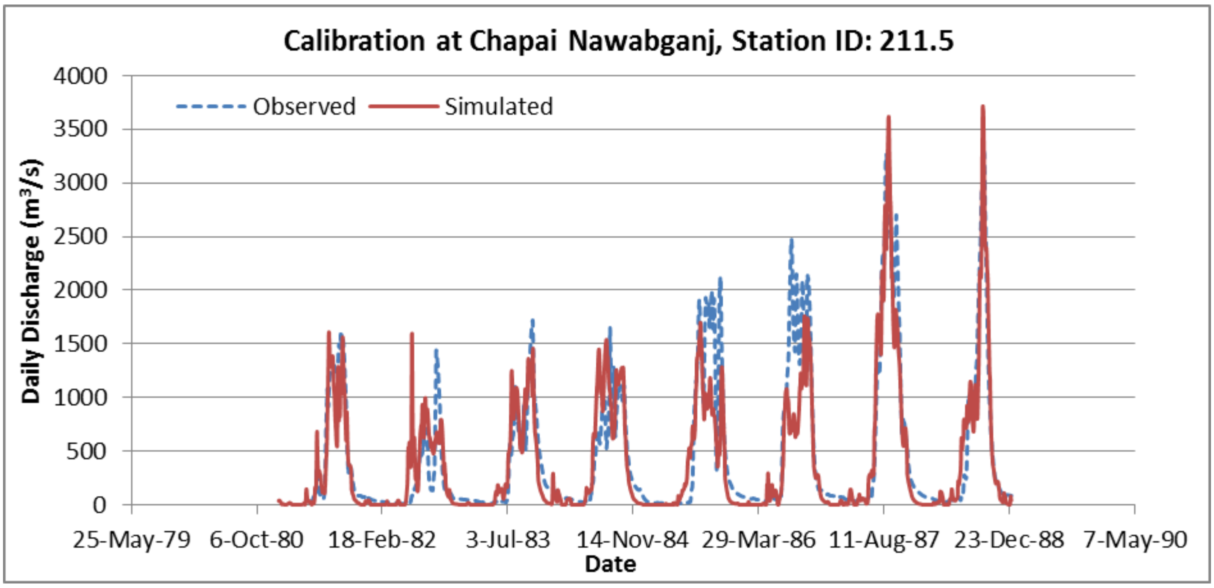


Figure 28: Daily observed and simulated stream flow during calibration period (1981 – 1988)

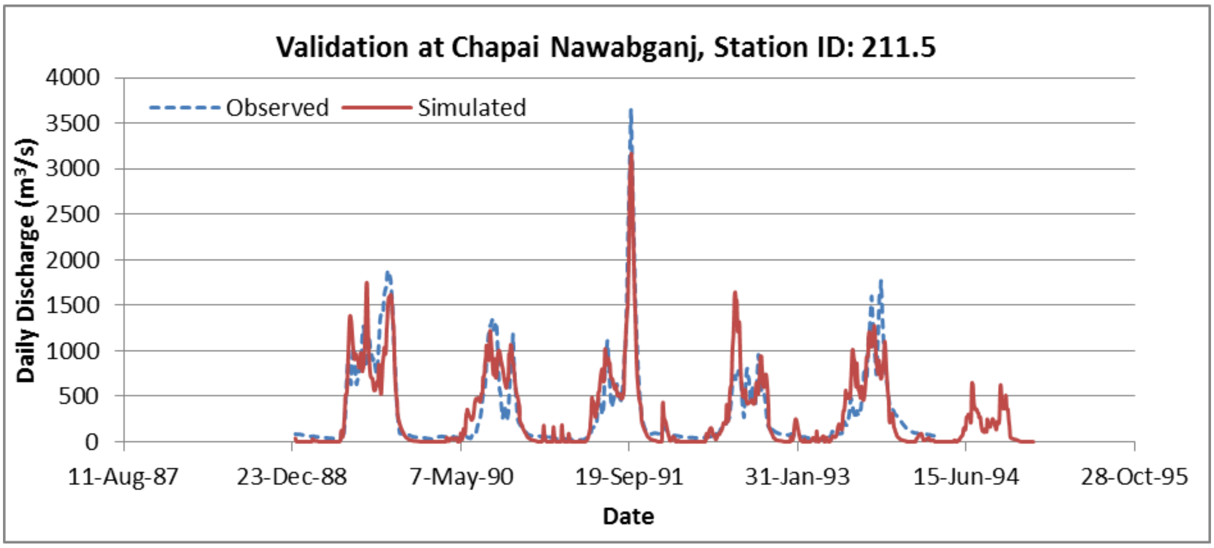


Figure 29: Daily observed and simulated stream flow during validation period (1989 – 1994)

The statistical comparisons of observed and simulated values are shown in Table 6. The simulated mean is slightly underestimated compared to observed mean for the calibration period and the validation period.

Table 6 Model performance statistics for calibration and validation period for the North-West region under the Study area at Chapai Nawabganj

Modeling Phase	Observed Mean (m^3/s)	Simulated Mean (m^3/s)	Model Performance			
			NSE	PBIAS	RSR	R2
Calibration	485.75	436.00	0.70	-2.27	0.55	0.73
Validation	342.49	333.81	0.81	2.53	0.44	0.81

The visual comparison of observed and simulated stream flow at Rohanpur station for the calibration period is shown in Figure 30 and for the validation period in Figure 31. For both of the periods, the model could capture the dry season flow, rising limb and recession limb with good accuracy; but the model could not capture the peak flow for some years. In brief, the model could simulate the behavior of observed flow reasonably well.

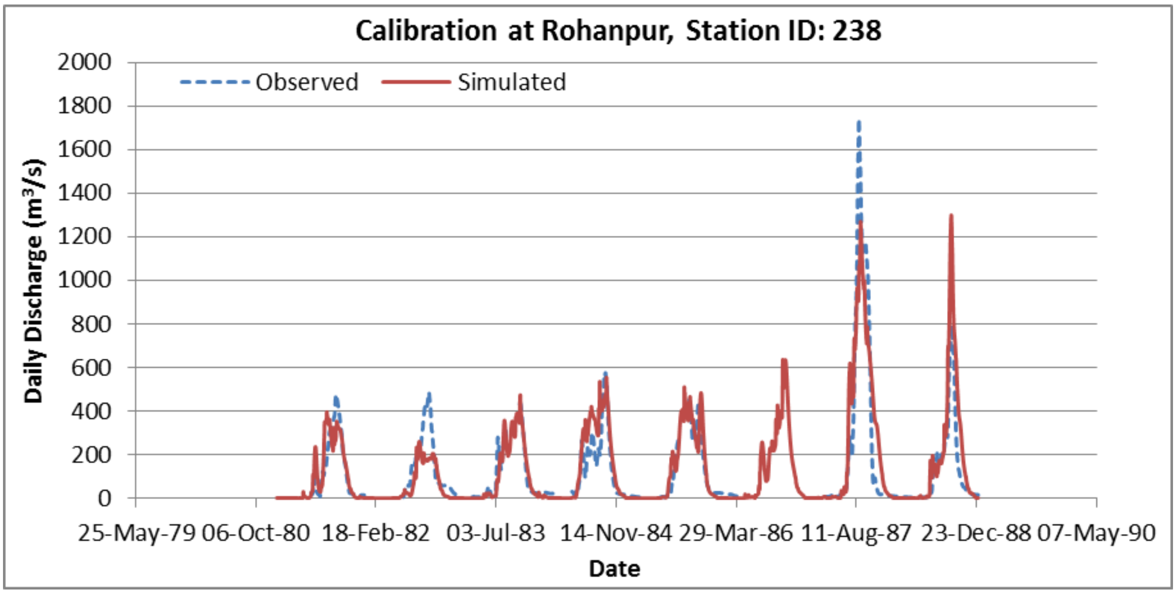


Figure 30 Daily observed and simulated stream flow during calibration period (1981 – 1988)

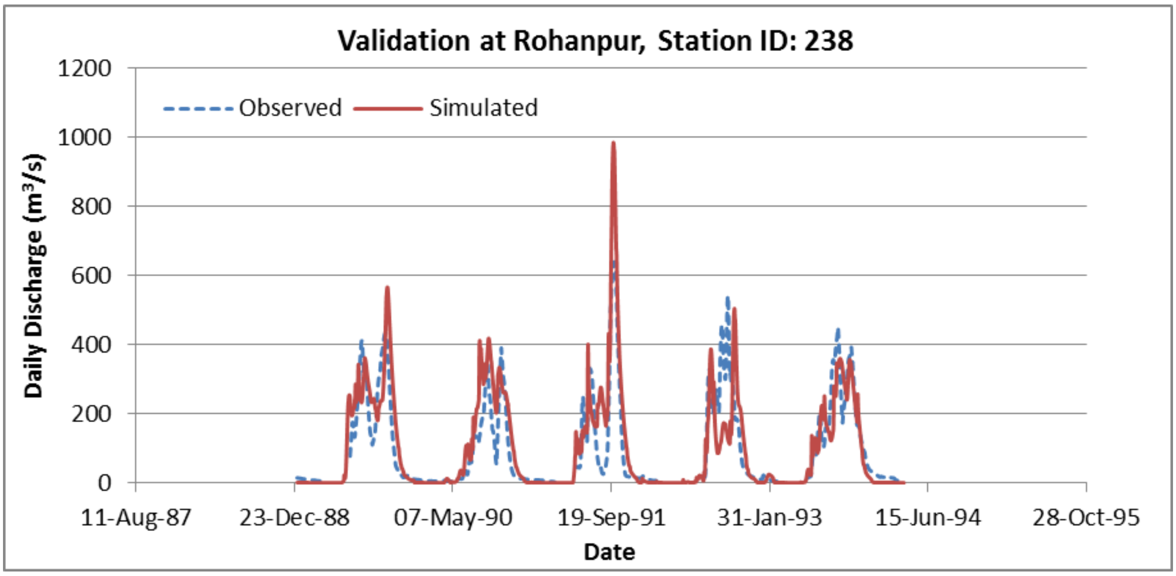


Figure 31 Daily observed and simulated stream flow during validation period (1989 – 1994)

The statistical comparisons of observed and simulated values are shown in Table 7. The simulated mean is overestimated compared to observed mean for the calibration period and the validation period.

Table 7 Model performance statistics for calibration and validation period for the North-West region under the Study area at Rohanpur

Modeling Phase	Observed Mean (m^3/s)	Simulated Mean (m^3/s)	Model Performance			
			NSE	PBIAS	RSR	R2
Calibration	147.15	158.31	0.77	-7.58	0.48	0.77
Validation	116.41	130.93	0.59	-12.47	0.64	0.69

Table 8 and Figures 32 and 33 shows that **UBC hydrological model's** performance in **Gilgit River Basin** in both calibration and validation phases is good as the values of the evaluation parameters i.e. R^2 and NSE are well within the range termed as 'good'. Thus, it provides with enough confidence to use this validated hydrological model for generation of future scenarios of Gilgit River at Gilgit discharge for analysis of likely changes in future hydrology of the watershed. After analysing the type and extent of hydrological changes in the study watershed, we would be able to recommend suitable adaptation strategies.

Table 8 Performance evaluation of the hydrological model in calibration and validation phases

Simulation period	**NSE**	**R^2**
Model Calibration (1995-1999)	0.85	0.75
Model Validation (2000-2003)	0.87	0.81

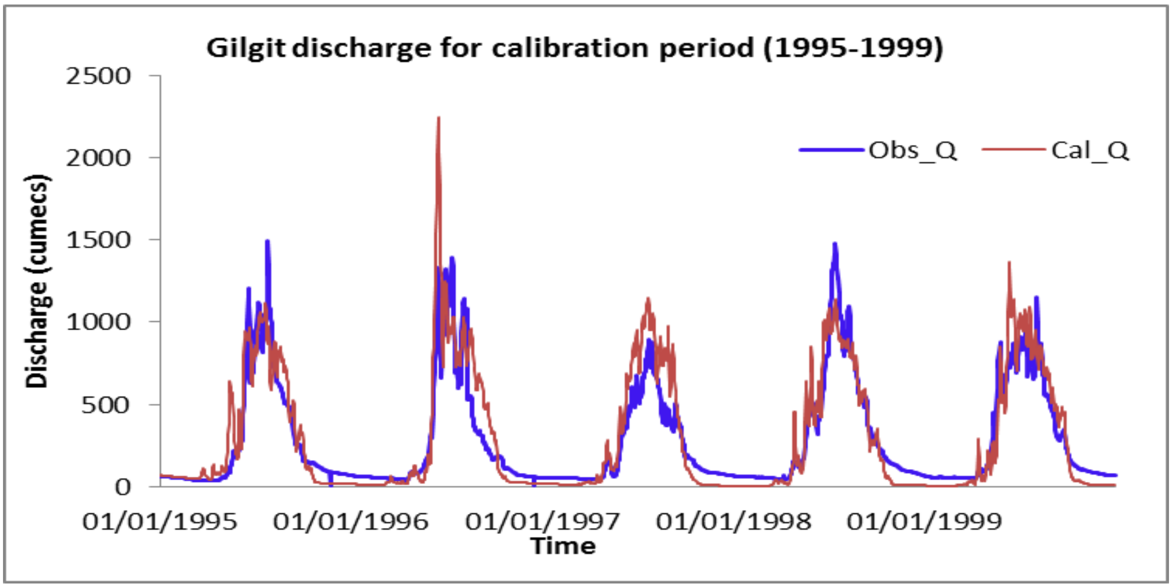


Figure 32 Comparison of Observed and Simulated daily hydrographs during the calibration phase

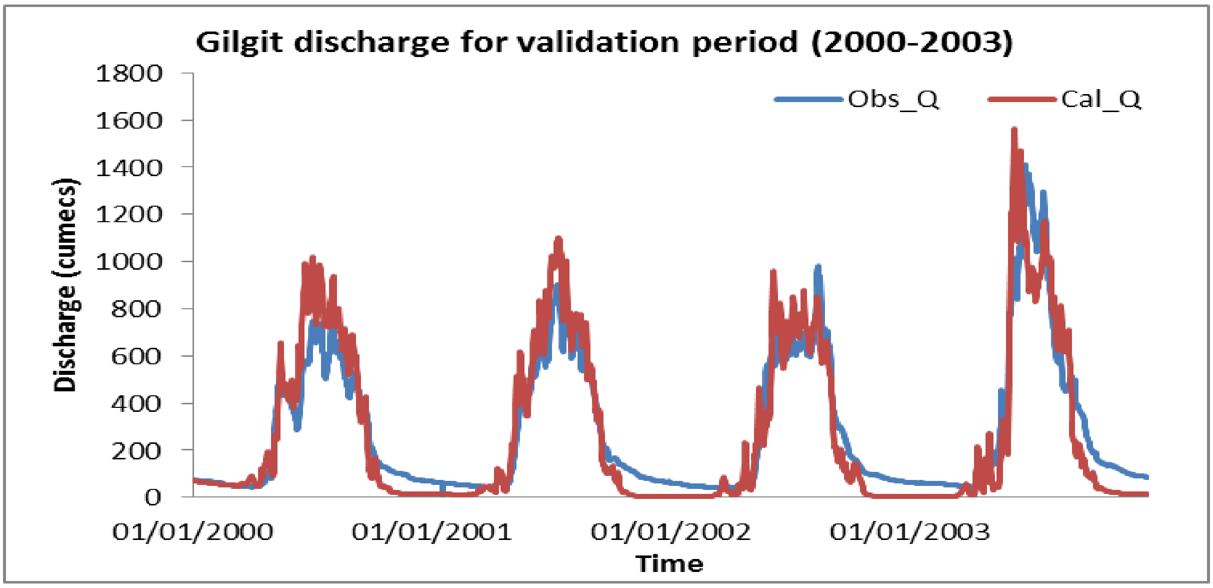


Figure 33 Comparison of Observed and Simulated daily hydrographs during the validation phase

3.4 Hydrological Response to Climate Change

An analysis of the monthly characteristics of streamflow in future at Chisapani station in **Karnali River Basin** is presented in Figure 34. The increase in precipitation has been reflected in terms of the streamflow. The Figure shows that striking increases in stream flow from March to July in future but water yield is likely to decrease during the early winter causing dry winter.

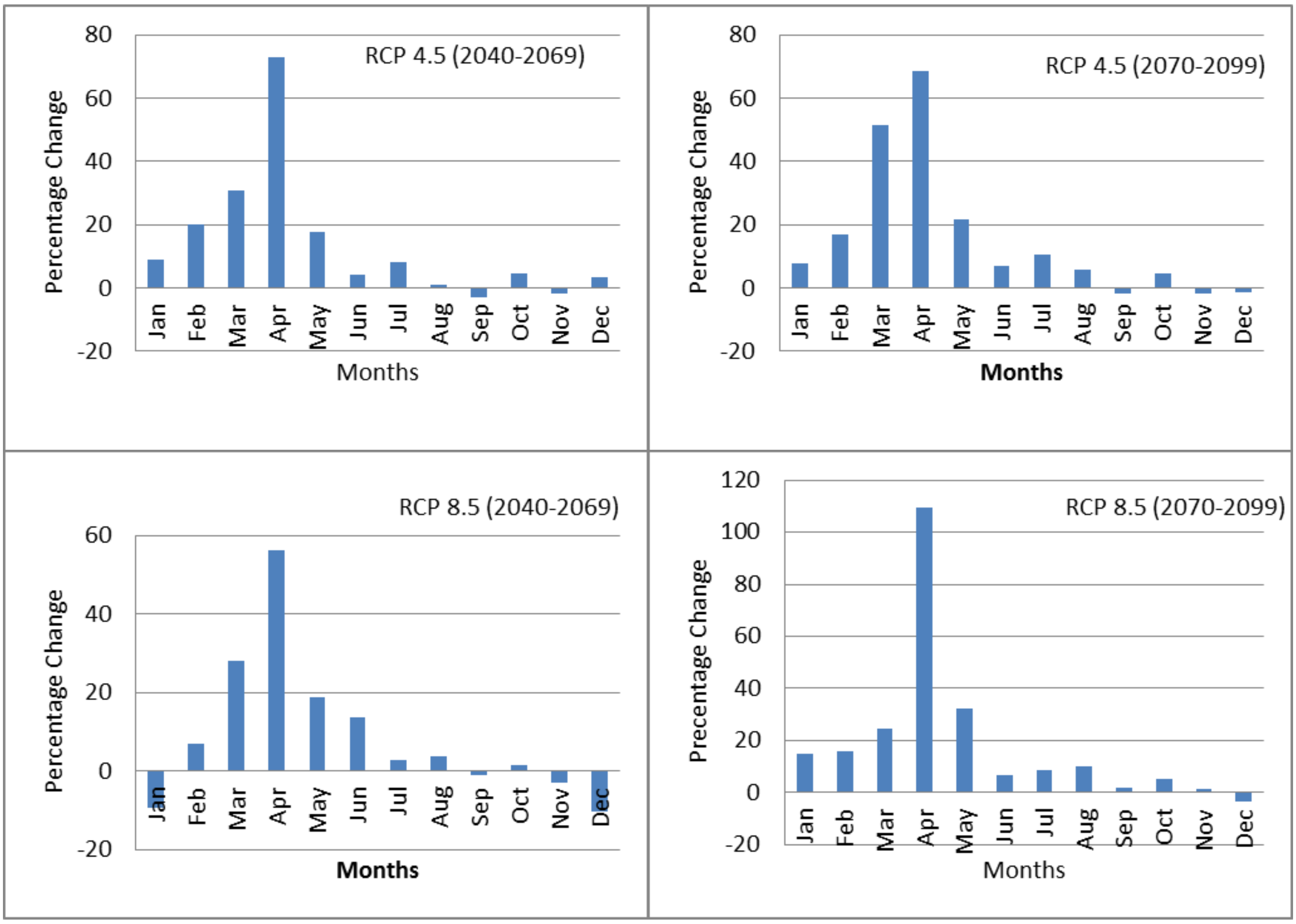
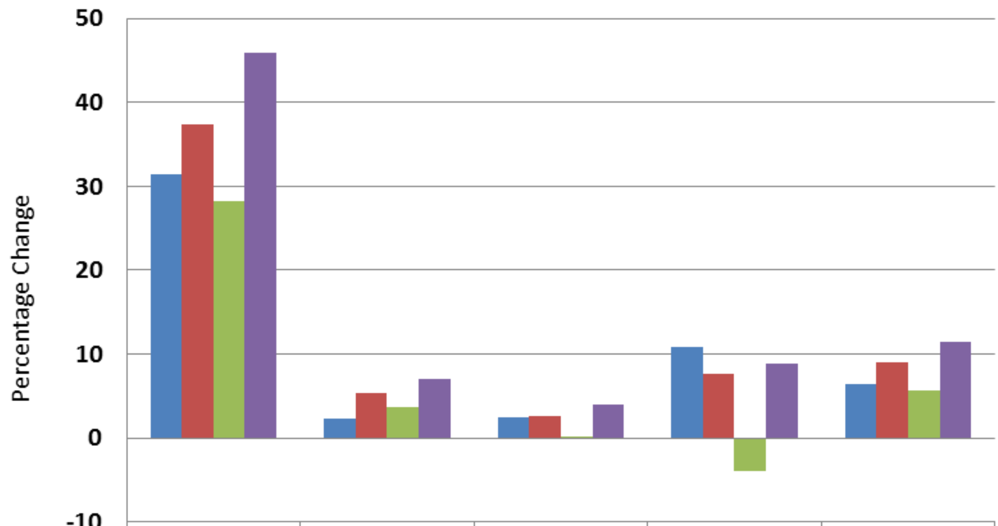


Figure 34 Monthly variations in water availability at Chisapani station for both scenarios and time scale.

Figure 35 shows the variations of stream flow in each season in future compare to the baseline period. The graph shows that the annual water availability is likely to increase in the future under all the scenarios considered. Both scenarios expect increase in stream flow more in later time scale (2069-2099) and it will be increase by at least 9% compare to baseline period. Annual water availability is likely to increase more for later time scale (2070-2099) under both scenarios.



	Pre monsoon	Monsoon	Post Monsoon	Winter	Annual
RCP 4.5 (2040-2069)	31.42	2.31	2.49	10.84	6.44
RCP 4.5 (2070-2099)	37.31	5.31	2.57	7.70	9.00
RCP 8.5 (2040-2069)	28.25	3.62	0.04	-3.99	5.60
RCP 8.5 (2070-2099)	45.87	7.12	4.02	8.86	11.53

Figure 35 Seasonal variation in water availability at Chisapani station for both scenarios and time scale.

Examination of future runoff scenario of **Gilgit Basin** reveals that projected rise in temperatures under both scenarios (i.e. RCP 4.5 and RCP 8.5) results in a considerable increase in peak flows (~30-40% in the case of RCP 4.5 and ~30-60% in the case of RCP 8.5) with early rise in river flows (Figure 36). Only, the future runoff hydrographs under Remo's RCP 4.5 and RCP 8.5 simulations for near future (yellow line) are showing a shift in peak flow towards an earlier month (i.e. June), otherwise, for all other scenarios, the peak flow stays in the month of July with a flattening of the peak.

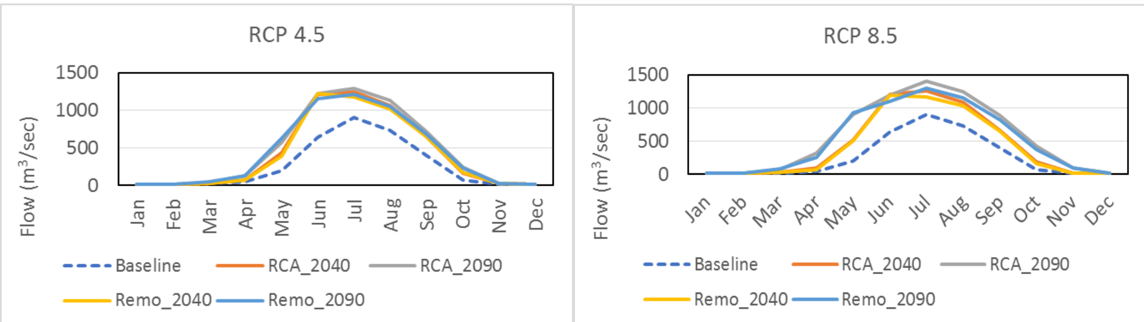


Figure 36 Comparison of baseline (1999-2003) and near and far future hydrographs under RCP 4.5 and 8.5 simulations of RCA4 and Remo RCMs

Future runoff hydrographs for RCP 8.5 are showing a significant rise in river flows in the months of Mar-May, especially in the far future scenario. This is mainly due to early start of snow and ice melt under higher temperatures. Such a change in the river regime may have serious implications for agricultural activities in the watershed as it may lead to change in cropping patterns and sowing windows.

Figure 37 presents an overall summary of future runoff scenarios' results under both climate change scenarios and based on simulations of both the RCMs for near and far future in terms of percentage change in river runoff in Gilgit Basin.

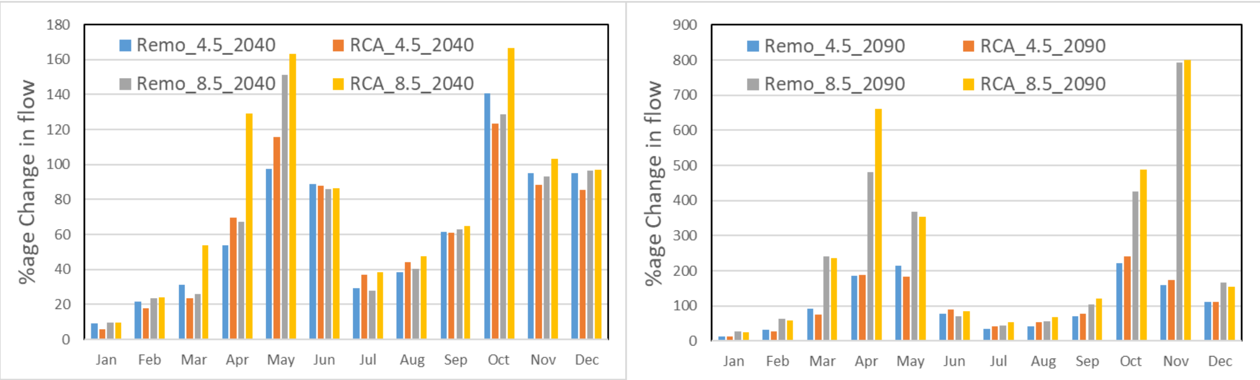


Figure 37: Summary of 2040s and 2090 results in terms of percentage change in river flow

Table 9 shows the change in runoff during the 2030s timeframe for South central region of **Ganges Basin**. Chuadanga would have highest change in runoff -7.02%. Bagerhat would have the lowest decrease in runoff with an increase of 0.34% compared to other Districts in the **Ganges Basin**. In the 2050s timeframe, Jessore would have a decrease in runoff by 1.70%, which is the highest decrease in runoff in this timeframe. In the 2080s timeframe, Jessore, Jhenaidah and Bagerhat would have the highest decrease in runoff by 7.84%, 7.70% and 7.40% respectively. Among all the Districts in the study area, Rajbari would have the lowest decrease in runoff in this timeframe (-2.68%).

Table 9 Percentage change of runoff scenario for the South-Central region

District	2030s	2050s	2080s
	Change (%)	Change (%)	Change (%)
Barguna	4.66	3.59	-5.82
Barisal	0.02	3.40	-3.36
Bhola	4.69	4.65	-4.57
Jhalokati	2.89	4.23	-2.90
Patuakhali	4.73	3.92	-5.21
Pirojpur	1.88	3.42	-3.62
Chandpur	-2.55	1.86	-4.99
Lakshmipur	4.47	5.23	-3.55
Noakhali	4.26	4.93	-3.50
Faridpur	-3.84	2.81	-2.56

District	2030s	2050s	2080s
	Change (%)	Change (%)	Change (%)
Gopalganj	-2.76	1.67	-4.69
Madaripur	-2.85	1.88	-4.67
Rajbari	-4.25	2.96	-2.68
Shariatpur	-2.89	1.80	-4.87
Bagerhat	-0.34	0.73	-7.40
Chuadanga	-7.02	0.77	-6.91
Jessore	-5.52	-1.70	-7.84
Jhenaidah	-5.83	-1.08	-7.70
Khulna	-3.36	-0.70	-7.49
Kushtia	-8.65	3.04	-5.73
Magura	-5.29	-0.12	-6.38
Meherpur	-8.29	3.03	-5.99
Narail	-5.28	-1.16	-6.51
Satkhira	-5.24	-0.97	-7.72
Natore	-9.47	3.02	-5.88
Pabna	-9.12	3.00	-5.92
Rajshahi	-10.22	3.09	-5.75

According to Table 10, the runoff during the timeframe 2030s would be reduced by 12.16% in Rajshahi and 12.02% in Tangail, which would be the highest changes in this timeframe. Naogaon would have the lowest change in runoff (-1.96%) in north west region of **Ganges Basin**.

The runoff of Rajbari would increase to 3.19% which is the highest in the 2050s timeframe. In the 2080s timeframe, Rajshahi and Nawabganj would be reduced by 10.17% and 9.34 in runoff respectively which is the highest in this time frame.

Table 10 Percentage change of runoff scenario for the North-West region

District	2030s	2050s	2080s
	Change (%)	Change (%)	Change (%)
Manikganj	-7.40	2.85	-3.65
Rajbari	-8.91	3.19	-5.88
Tangail	-12.02	2.62	-6.36
Kushtia	-9.83	2.16	-6.90
Bogra	-9.49	2.46	6.76

District	2030s	2050s	2080s
	Change (%)	Change (%)	Change (%)
Joypurhat	-8.09	0.26	0.70
Naogaon	-1.96	0.89	-3.29
Natore	-9.39	2.17	-3.02
Nawabganj	-10.55	-1.43	-9.34
Pabna	-9.24	2.82	-6.09
Rajshahi	-12.16	-1.67	-10.17
Sirajganj	-10.33	2.96	-2.62
Dinajpur	-7.25	-1.31	-4.22
Gaibandha	-9.29	1.73	5.37

3.5 Water Based Adaptation Strategies

Nepal (Karnali River Basin)

Existing good practices

Many conventional and some new innovative water based adaptation practices were observed in community level across the Karnali basin. One of the interesting practices is multiple and multipurpose use of water in different sectors in a harmonious way.

The equity in water distribution is another success story. People are using the available water wisely and fairly among different user groups and people. People are collecting the small quantity of spring water in a reservoir and they irrigate vegetable and paddy fields with the water. They distribute the water in a rotational basis so that the small quantity of water is fairly distributed and human resource is efficiently managed in heavy workload periods such as paddy plantation and harvesting time. The water is efficiently distributed to different sectors. The water mills are running in day time, micro-hydro plant in morning and evening time - the time with maximum power demand - and for irrigating field in night time.

In some cases, the resource conservation and benefit sharing between the upstream and downstream communities have been organized in a manageable way. At different locations of the Karnali basin, there are many water mills, which are in cascading pattern: the outflow water from the upper mills is used by another mill in downstream section, and the ultimate water is channelized to hydropower. Also, there are plans to install pico-hydropower plant in existing water mill to produce electricity.

Potential water adaptation measures

It is essential to estimate the total water availability from different sources in a sustainable way and the total requirement of the water for anthropogenic use and ecosystem sustainability. An inventory of the water sources with their existing conditions and quantifying the water availability and the water user sector and their water demand provides an outlook of water balance situation within the watershed. According to the water availability situation, different water efficient practices can be proposed to optimize the available water. This also gives an idea of inter-watershed water diversion.

Management of water resources consists of efficient distribution as well as conservation for sustainable supply in future too. In many places, we found that there are an irrigation canals but the trees around the source of water have been cut massively. Therefore, the water resource management projects have to be aligned with the holistic approach including source conservation.

Due to availability of water and hydraulic heads, there is high number of water mills. Therefore, there is high potential of producing electricity installing a small set of generators, and the electricity can be used for a household. Though the basin is an important area for small-scale hydropower production, the region has to be connected to the national transmission line too.

The springs are the major sources of drinking water in mountain regions of Nepal, however many people including from Karnali have reported that the springs are drying up in recent years. There needs to be an inventory of such springs to identify the actual number of springs and their current conditions. One of the reasons for drying up of the springs could be less recharge due to deforestation. One potential solution could be to construct recharge ponds upstream of the springs. The ponds collect the rainwater and recharge the groundwater. Another potential option to harvest the rainwater is to construct multipurpose community ponds. The water can be used for livestock feeding and irrigation, and at the same time the groundwater is recharged and the downstream peak flood risk is reduced. Afforestation around the water sources is obviously a good practice for spring restoration.

There are several agencies within the government system to manage the water and its related issues; therefore, there are many duplicity of works in central and district levels. For example: division irrigation office under the Ministry of Irrigation exists each of the district, and at the same time NCCSP, an adaptation project by the Ministry of Population and Environment is also working in construction and maintenance of irrigation canals which are very orthodox system of irrigation. However, the project implements the most urgent needs prioritized by community to mitigate the climate impacts (GoN/UNDP, 2012), but can experiment the proven technologies and innovative models for few years, and handover, if succeeds, to the mandated agencies. Also, it is essential, at first, to estimate the water budget for future and the management plan in sub-watershed level.

Pakistan (Gilgit River Basin)

Consequent upon the findings of the modelling based study of future flow regime (presented in the previous section) and two field assessments in the watershed conducted for retrieving the community perception about climate change and their adaptation needs, the following potential water based adaptation measures/strategies are recommended here:

- Water storage ponds (with low cost lining) close to source (stream)
- Use of drip irrigation for ever increasing fruit orchards
- Sprinkler irrigation for crop fields
- Early warning systems to minimize damage from more frequent extreme events

Bangladesh (Ganges River Basin)

Many adaption options have been practiced from the local to national levels across Bangladesh. Previous researchers talked about a few adaptation practices such as flood shelters, cyclone shelters and school/college/madrasa building, and coastal and flood embankments in the flood and coastal areas, plinth raising of houses to protect houses and homesteads from the risks of climatic disasters in the coastal and floodplain areas, and tree plantations in the floodplains and drought prone areas around homesteads are the major effective structural adaptation measures of Bangladesh. Bangladesh is a flood prone country; due to being situated on the Ganges Delta and the many distributaries flowing into the Bay of Bengal. Coastal flooding, commonly combined with the bursting of the river banks, which affects the landscape and society of Bangladesh. The floodplain area of Bangladesh is about 80% and it has an extensive sea coastline, rendering the nation very much at risk of periodic widespread damage. Whilst more permanent defences, strengthened with reinforced concrete are being built, many embankments are composed purely of soil and turf and made by local farmers. Some of the major adaptation measures potential to the site are:

- Improve the quantity of water availability through rehabilitation of different water storage sites (e.g. existing dams, boreholes, reservoirs, water diversions, water bodies and irrigation infrastructure).
- Improve the capture and natural storage of water through improved land management process.
- Establish a regulatory framework for water management along with the local level management and capacities for water resource management system.
- Improve the quality of water through water treatment plants that should be constructed at the community level treatment of water low-cost and legislation for water pollution control.
- Construction of river embankments, check dams and retaining walls to protect flood-prone areas and also to control the intrusion of saline water.
- Improve access to water supply through provision of piped water supply.

4. Conclusions

Based on the results presented in this study, a clear climate change signal can be identified for both temperature and precipitation in the past in study area. Warming has occurred, at a basin scale as well as country scale, across most of the area over the 20th century. Rainfall trends are characterized by high variability with both increasing and decreasing trends observed in different parts.

Temperature and precipitation are expected to increase in the entire South Asia region in the future. Projections (ensemble) indicate that, compared to the average in the baseline period, average annual temperatures could rise by more than 2°C over land in most of South Asia by the mid-21st century and exceed 3°C, up to more than 6°C over high latitudes, by the late 21st century under a high-emissions scenario. More rainfall will be very likely in South Asia by the mid-21st century under both emissions scenarios.

Result shows that more water will be available in the future in streams especially during the pre-monsoon and monsoon, and this scenario is likely to increase in the late century. It may come with a caveat of increased potential of floods and extreme events, which would be more harmful than useful in the low-lands, especially during the rainy season. Riverine and urban floods linked to extreme rainfall events could cause widespread damage to infrastructure, livelihoods and settlements in the future in South Asian region. The risks of water-induced disaster and loss of life and property associated with it, is high in all Nepal, Bangladesh and Pakistan.

Adaptation is found to be an effective option to manage the negative impacts of climate change in this region for both short term and long term period. Establishment of monitoring and early warning systems; scientific system to identify exposed areas and good mechanism to assist vulnerable areas and households during disaster will be common adaptation priorities in all three countries. Integrated water resource management, water infrastructure and reservoir development, diversification of water sources including water re-use, more efficient use of water (e.g multiple use of water) could be the best adaptation practices for drying region.

In this region, people and local communities are already adopting some practice to climate change adaptation at the regional, national and local levels. Best practices from this region show the potential for effective climate adaptation approaches that can be enhanced and scaled up in the future. This information at the local communities helps to integrate disaster risk reduction and development and climate change adaptation in location-specific solutions and outsiders.

Strengthening the links between science and policy could help to improve the level of adaptation and reduce the risk of climate change. Mainstreaming national and regional adaptation action in government plans policies will be the key step to institutionalize and strengthen the local adaptation action in widespread community.

5. Future Directions

5.1 Development of coupled Human-Nature model: The nature and the society both are dynamic, therefore to address the water and climate related issues the world is facing we need to develop an integrated process based model encompassing the various dimensions of climate, hydrology and society. The new concept 'socio-eco-hydrology' should be advanced taking few case study sites.

5.2 Working in finer resolution: We developed the river runoff scenario in different RCPs in different time period but the information is for the entire basin's flow at the outlet. However, to make the information more useable and convince the policy makers to make concrete decision, we need to develop the scenarios in finer resolutions.

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7. Appendix

Agenda of Inception Workshop

Runoff Scenario and Water Based Adaptation Strategy in South Asia
23-24 November, 2013
Kiran Hall, Hotel Summit, Kathmandu, Nepal

Day I: 23 November, 2013
Session I: Opening Ceremony

0900-0930	Participants and guests' registration,
09:30-09:35	Dignitaries on Dias Chairperson: Prof. Dr. Kedar L. Shrestha-Former VC-NAST and President, IDI-Nepal Guest: Mr. Gautam Rajkarnikar, DDG-Dept. of Hydrology and Meteorology Guest: Prof. Dr. Narendra Man Shakya, IOE, TU Host: Dr. Madan Lall Shrestha, Project PI-The Small Earth Nepal Host: Md. Waji Ullah, Executive Director, CEGIS, Bangladesh Host: Mr. Sudarshan Rajbhandari, Vice President, SEN
0935-0940	Welcome address, Mr. Sudarshan Rajbhandari
0940-0945	Project overview, Dr. Madan Lall Shrestha
0945-0955	Key Speech by Prof. Dr. Narendra M. Shakya
0955-1000	Key speech by Mr. Gautam Rajkarnikar
1000-1005	Key speech by Md. Waji Ullah
1005-1010	Key remarks by Dr. Yubak Dhwoj GC
1010-1020	Closing remarks by the chairperson
1020-1025	Vote of thanks, Jeeban Panthi, Research Coordinator, SEN
1025-1035	Group Photo
1035-1105	Tea/Coffee Break
1105-1120	Inception report presentation by Mr. Jeeban Panthi
1120-1200	Feedback and discussion on the report ***Moderator: Dr. Madan Lall Shrestha***
1210-1230	Discussion summarization and session wrap up by the moderator
1230-1330	Lunch Break

Session II: Hands on Training

1330-1700: Hands on Training-Gridded data analysis with GraDS by Dr. P Sunitha, Andhra University, INDIA
1530-1600: Tea Break

Day II: 24 November 2013

0900-0945: Key Speech - preview on the Availability of the climate model data and relevant issues for South Asia, Ailikun, MAIRS, China
0945-1100: Hands on Training, MODIS-MRT tool by Ms. Qurat-ul-Ain Ahmad, GCISC, Pakistan

1100-1130: Tea Break
1130-1230: Remote Sensing Application in Hydrological Monitoring and Modelling, by Dr. Tarendra Lakhankar, City University of New York, USA
1230-1330: Lunch Break
1330-1400: Hydrological Modelling-Few Experiences by Prof. Dr. Narendra Man Shakya
1400-1500: Data requirement and pre-processing for Hydrological modeling, Motaleb H. Sarker, CEGIS, Bangladesh
1500-1530: Tea Break
1530-1630: Team meeting and way forward (Meeting host: Dr. Madan Lall Shrestha)
1630-1700: Wrap up of the inception workshop

<u>**Agenda of Regional Level Training Workshop**</u>

Application of University of British Columbia (UBC) Watershed Model for Hydrological Studies
Hotel Crown Plaza, Jinnah Avenue
ISLAMABAD, PAKISTAN
27- 30 APRIL 2015

Day I

09:00 - 09:30	Registration
09:30 – 11:30	Inaugural Session
09:30 – 09:35	Recitation from Holy Quran
09:35 – 09:50	Opening and Welcome Remarks (Dr. Mohsin Iqbal, Head Coordination, GCISC)
10:05 – 10:20	Chief Guest Remarks
10:20 – 10:35	Remarks by The Guest of Honor, Dr. Ameer Muhammad (APN SPG Member & Rector FAST University, Islamabad)
10:35 – 10:50	Group Photo
10:50 – 11:30	Tea Break
11:30 – 13:00	TECHNICAL SESSION - I
11:30 – 11:45.	Mr. Ghazanfar Ali (GCISC), Overview to Pakistan Water Resources
11:45 – 12:00	Dr. Ghulam Rasool (PMD), Impact of Climate Change on UIB Water Resources
12:15 – 12:30	Dr. Umar Khan Khattak (NUST), The Role of GIS and RS in Distributed Hydrological Models
12:30 – 12:45	Dr. Bashir Ahmad (NARC), modelling to evaluate the impact of climate change on watershed yield
12:45 – 13:00	Dr. Zia ur Rehman Hashmi, Preparation of Climate Scenarios to Study Future Hydrology in Upper Indus Domain

13:00 – 14:00 Lunch & Prayer Break

14:00 – 17:00	TECHNICAL SESSION - II
14:00 – 15:00	Introductions to UBC Watershed Model by Mr. Daniyal Hashmi, WAPDA
15:00 – 15:20	Installation of UBC in DOS Version by Dr. Rehan Anees, GCISC
15:20 – 16:00	Preparation for Input Data
16:00 – 16:15	Tea Break
16:15 – 17:00	Hands on practice on UBC Watershed Model (Mr. Daniyal Hashmi, WAPDA, Lahore)

Day II

09:00 – 11:00	TECHNICAL SESSION - III
09:00 – 10:00	Input Data Requirements, Data Preparation to Simulate UBC Model
10:00 – 11:00	UBC Model Calibration
11:00 – 11:20	Tea Break

11:20 – 13:00	Hands on Exercise on UBC Model
13:00 – 14:00	Lunch & Prayer Break
14:00 – 15:00	UBC Model Calibration (Contd…)
15:00 – 16:15	UBC Model Validation
16:15 – 16:30	Tea Break
16:30 – 17:00	General Discussion on Model queries by Participants

Day III

09:00 - 11:15	TECHNICAL SESSION - IV
09:00 – 09:15	Application of UBC on UIB by Dr. Shaukat Ali- Twenty first century hydrological changes using UBC models over Upper Indus Basin of Himalayan region of Pakistan
09:15 – 11:15	Hands on Exercises on UBC Model Calibration/ Validation on Selected Study Areas by each Participant
11:15 – 11:30	Tea Break
11:30 – 13:00	Hands on Exercises on UBC Model Calibration
13:00 – 14:00	Lunch & Prayer Break
14:00 – 16:30	Hands on Exercises on UBC Model Validation
16:15 – 16:30	Working Tea
16:30 – 17:00	Group Formation & Assignments

Day IV

09:00 – 11:00	Group Exercises on UBC Calibration & Validation
11:00 – 11:30	Tea Break
11:30 – 13:00	Modelling Results Analysis & Development of Presentation
13:00 – 14:00	Lunch & Prayer Break
14:00 – 15:30	Short Presentation by Each Groups
15:30 – 16:00	Closing Remarks & Certificate Distribution (Dr. Arshad M Khan, Executive Director, GCISC)

Agenda of River Basin Research Sharing Colloquium

21 March 2017
Hotel Himalaya, Kupodole, Lalitpur

Technical Session I: Water Resources Management Approaches
Session Chair: Mr. Keshab Dhoj Adhikari, Joint Secretary, Water and Energy Commission Secretariat (WECS), Government of Nepal
Note keeper: Jeeban Panthi, SEN

0830-0900	Guests and participants arrival and registration	Tea/Coffee upon arrival
0900-0905	Session chair and presenters on Dias	
0905-0910	Welcome and highlights of the program	Session chair
0910-0925	Keynote speech: Integrated water resource management in the context of Nepal	Prof. Narendra Man Shakya, IOE/TU
0925-0940	Nepal's water risk scenarios and opportunities for resilient development	Mr. Rajesh Sada, WWF Nepal
0940-0955	Upstream-downstream linkages for catchment level Water Use Master Plans (WUMP)	Dr. Santosh Nepal, ICIMOD
0955-1025	Multi-perspective analysis of river basins in Western Nepal: An attempt of DJB-project	Dr. Vishnu Prasad Pandey et. al, IWMI
1025-1040	Q/A and discussion	
1040-1045	Concluding remarks	Session Chair

Tea/Coffee break and a group photograph: 1045-1100

Technical Session II: Focus of Recent Research in Water Sector
Session Chair: Dr. Madan Lall Shrestha, Academician, Nepal Academy of Science and Technology (NAST)
Note keeper: Dilli Bhattarai, SEN

1100-1115	Climate and hydrological assessment in Karnali Basin, Nepal	Mr. Jeeban Panthi, SEN
1115-1130	Livelihood vulnerability assessment due to climate change in Gandaki Basin, Nepal	Mr. Piyush Dahal, SEN
1130-1145	WWF's experiences on implementing river basin management approach in ground	Dr. Shalu Adhikari/ Dr. Jagannath Joshi, Hariyo Ban/WWF Nepal
1145-1200	UBC modeling in Gilgit basin, Pakistan: Potentially replicable to Nepal	Dr. Muhammad Zia Hashmi, GCISC, Pakistan
1200-1215	Water security in rapidly urbanizing mid hill towns in Koshi and Gandaki Basins: Cases from Dhulikhel and Bidur	Mr. Kamal Devkota, SIAS

1215-1230	Q/A and discussion	
1230-1235	Concluding remarks	Session Chair

Lunch: 1235-1330

<u>Agenda Workshop on</u>

Climate Change and Sustainable Water Resource Development in Karnali Basin

5 June 2017, Jumla HQ

Inaugural Session

0830-0900	Guests and participants arrival and registration [Breakfast included]
0900-0905	<u>Dignitaries on Dias</u> Chairperson: Dr. Madan Lall Shrestha, Academician, Nepal Academy of Science and Technology (NAST) Chief Guest: Mr. Narayan Prasad Sapkota, Chief District Officer (CDO), Jumla Special Guest: Mr. Hari Narayan Belbase, Local Development Officer (LDO), Jumla Special Guest: Mr. Nirajan Sapkota, Regional Chief, Department of Hydrology and Meteorology (DHM) Guest: Mr. Jeeban Panthi, Research Coordinator, The Small Earth Nepal (SEN) Guest: Mr. Krishna Bahadur Shahi, District Coordinator, MOPE/NCCSP Guest: Mr. Bhola Dhakal, Watershed Management Specialist, USAID/PANI
0905-0920	Welcome and Keynote address on Overview of Climate Change in Nepal, Dr. Madan Lall Shrestha, NAST
0920-0925	Highlights of the objective of the workshop, Mr. Jeeban Panthi, SEN
0925-0930	Address by Mr. Hari Narayan Belbase (LDO)
0930-0935	Award distribution (Art Competition) coordinated by NCCSP
0935-0945	Address by the Chief Guest: Mr. Narayan Prasad Sapkota
0945-0950	Concluding remarks by the Chairperson

Tea/Coffee break and group photograph: 0950-1030

Sharing Session

Chairperson: Mr. Nirajan Sapkota, Regional Chief, DHM

Note keeper: Jeeban Panthi, SEN

1030-1050	Climate and hydrological assessment in Karnali Basin: Past and Future, Piyush Dahal, SEN
1050-1105	An overview of Nepal climate change support program, Krishna B. Shahi, MOPE/NCCSP
1105-1120	PANI project activities in the Karnali basin, Bhola Dhakal

1120-1130: Tea/Coffee

1130-1245: Existing and potential adaptation measures in water sectors in Karnali basin [Consultation workshop]
1245-1300: Weather and Hydrological monitoring stations in Western Nepal, Nirajan Sapkota, DHM

1300-1400: Lunch

1400-1500: Demonstration of weather monitoring visiting a meteorological station [Akhalesh

Chaurasiya, DHM]
1500-1515: Workshop Wrap up and tea/coffee

Attendance Sheets of Workshops

Inception Workshop

Inception Workshop

Runoff Scenario and Water Based Adaptation Strategy in South Asia

23-24 November, 2013

Kiran Hall, Hotel Summit, Kathmandu, Nepal

Day I: 23 November, 2013

Registration Sheet

S.N.	Name	Organization	Contact	E-mail	Signature
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Inception Workshop

Runoff Scenario and Water Based Adaptation Strategy in South Asia

23-24 November, 2013

Kiran Hall, Hotel Summit, Kathmandu, Nepal

Day II: ~~25~~ 24 November, 2013

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Basin Level Workshop at Jumla

Workshop on

Climate Change and Sustainable Water Resource Development in Karnali Basin

कर्णालीमा दिगो जलस्रोत बिकास र जलवायु परिवर्तन

5 June 2015, Jumla HQ

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Workshop on

Climate Change and Sustainable Water Resource Development in Karnali Basin

कर्णालीमा दिगो जलस्रोत बिकास र जलवायु परिवर्तन

5 June 201~~5~~7, Jumla HQ

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Workshop on

Climate Change and Sustainable Water Resource Development in Karnali Basin

कर्णालीमा दिगो जलस्रोत बिकास र जलवायु परिवर्तन

5 June 2017, Jumla HQ

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River Basin Research Sharing Colloquium

Nepal National Water and Weather Week 2017
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Registration Sheet

Date: March 21, 2017
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Nepal National Water and Weather Week 2017
River Basin Research Sharing Colloquium
Registration Sheet

Date: March 21, 2017
Venue: Hotel Himalaya, Kupodole, Lalitpur

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Nepal National Water and Weather Week 2017
River Basin Research Sharing Colloquium
Registration Sheet

Date: March 21, 2017
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Muhammad Hasan Mustafa Pakistan	hasan9206@gmail.com	Research intern – data editing for modeling.
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Kabi Raj Khatiwada: “It was great working at one of the projects of APN. I worked for the project "Runoff Scenario and Water Based Adaptation Strategies in South Asia" and it was awesome experience. I sincerely appreciate and provide especial thanks to Dr. Madan Lall Shrestha (Project Leader, The Small Earth Nepal-SEN) and Jeeban Panthi (Project Collaborator, SEN), for their invaluable help, expertise, enthusiasm and providing this opportunity to be part of the project. I personally enjoyed a lot being part of the project and it was great learning about the different aspects of climatic data, hydrological dynamics and water based adaptation strategies. Being a part of the project, I was able to learn different dimensions of professionalism at the same time share the work that has been done. This platform provided a great connection for motivation, engagement, and improvement at my personal and professional life. Thank you all for this exciting experience.”

Inception workshop and research approach finalization (23-24 November 2013, Kathmandu, Nepal)

The workshop was attended by more than thirty national and international participants representing the collaborating institutions, national meteorological and hydrological services, academia and other research communities. The formal opening session of the workshop was chaired by Dr. Kedar Lal Shrestha, former Vice Chancellor of Nepal Academy of Science and Technology (NAST) and President of Institute for Development and Innovation (IDI-Nepal). Dr. Shrestha, in his remarks, quoted the situation of water, “when we need it, it is not there and when we don’t, it’s too much.” In the session, Mr. Sudarshan Rajbhandari, Vice President of SEN, welcomed all the participants and guests. Dr. Madan Lall Shrestha, the project leader, shared the project objectives and its ultimate goals. Dr. Shrestha further encouraged exploring adaptation measures as the output should be hooked up in the development process of the country. He insisted that the results should be streamlined in national context. Er. Gautam Rajkarnikar, Deputy Director General from Department of Hydrology and Meteorology (DHM), the government of Nepal, wished the project team for the successful and implementable outcomes from the project which will be beneficial for the policy makers. Prof. Narendra Man Shakya from Institute of Engineering, Tribhuvan University addressed the session with his key note speech on the constraints of hydrological modelling in the steep and rugged topography of mountain countries like Nepal. Prof. Shakya shared that Regional Climate Model (RCM) outputs were not realistic and consistent to Himalayan region. Er. Waji Ullah from CEGIS, in his key remarks, emphasized on the challenges assessing the impacts and consequences of climate change in the South Asia region. Mr. Jeeban Panthi, project collaborator from SEN, presented the inception report for the feedbacks and suggestions.

The participants suggested for using two approaches for hydrologic modelling: Soil and Water Assessment Tools (SWAT) and coupling of Snowmelt Runoff Modelling (SRM) with University of British Columbia (UBC) hydrologic model. Participants also suggested that the national policies and programmes like National Adaptation Programme of Action (NAPA), Climate Change Policies, and Water Resource Strategies etc. should be reviewed for developing the adaptation strategies.

Dr. Ailikun from Monsoon Asia Integrated Regional Study (MAIRS)/Chinese Academy of Sciences (CAS) shared about the climate data availability for South Asia. She shared that various remote sensing and gridded datasets like TRMM, APHRODITE and climate model data like CORDEX were available for South Asia, but special attention is to be given while using those datasets as they may not properly capture the weather parameters in the high altitudes. Dr. Tarendra Lakhankar from NOAA/City University of New York provided a lecture about the remote sensing application to hydrological modelling.

Training on GrADS and MODIS-MRT (November 24, 2013, Kathmandu, Nepal)

We organized few hands-on training for the project collaborators and other young scientists of the participating countries in November 2014. Among the training programs, the GrADS software (The Grid Analysis and Display System) which is an open source for analysing the gridded datasets widely used in climate researches especially in modelling aspects was quite interesting and the training was instructed by Dr. P. Suneetha, one of the collaborators for this project. The same software has been used for the project in analysing the gridded dataset.

Another interesting training was on MODIS-MRT tool was also introduced which is used for processing the remote sending (MODIS) snow cover datasets. The training was instructed by Ms. Qurat ul Ahmad from GCISC – Pakistan. We are now mapping the snow cover and its statistics in Nepal and Pakistan using the same software, which is free and easy to handle.

Training workshop on UBC hydrological modelling (27-28 April 2015)

As a series of capacity building activities under this project, the project team organized a training workshop in Islamabad, Pakistan called 'The Application of University of British Columbia (UBC) Watershed Model for Hydrological Studies'. The training was on UBC hydrological modelling and was organized by GCISC, Pakistan project partner. Initially, the international level workshop was planned for three countries participants viz Pakistan, Nepal and Bangladesh, but due to the massive earthquake that happened on 25th April in Nepal, Nepalese participants could not make it. Therefore, the training was organized only among Pakistan and Bangladesh partners.

The objective of this workshop was to train relevant regional institutions/scientists in the hydrological modelling to ascertain river flows availability under future climatic condition. Thirty participants from Pakistan from national and international meteorological and hydrological services, academia and other research communities this training workshop.

Training Workshop was formally inaugurated by Dr. Amir Muhammed, APN SPG Member & Rector FAST National University in Islamabad. In the beginning of the inaugural session, all training workshop participants, guests and invited speakers observed one minute silence before the start of formal proceedings to share the grief of loss of life and infrastructure in Nepal due to the devastating earthquake of 7.8 Richter scale. Dr. Mohsin Iqba, Head Coordination, GCISC opened the inaugural session with welcome remarks and Mr. Motaleb Hussain Sarker, Director - Ecology, Forestry and Biodiversity Division, Centre of Environment and Geographic Information Services (CEGIS), Dhaka, Bangladesh gave a brief overview of the project. He talked about project objectives, methodologies to be adopted, expected outcomes and project activities status. Dr. Muhammed shared his long term collaborative work/research experience with APN team and the journey to his achievements under the APN umbrella. He appraised his acknowledgement to the workshop organisers for holding regional training workshop and encouraged the young scientists and students to focus on the climate change research.

During the first technical Session, five invited speakers from different institutions presented their work on climate change related studies in HKH Region including watershed modelling, application of remote sensing and GIS tools and techniques and downscaling techniques to get high resolution future climate data. Second technical Session was reserved for the lectures from Resource Person (Eng. Daniyal Hashmi, Project Director: Glacier Research Monitoring Centre (GMRC), WAPDA, Lahore, Pakistan) on the introduction to University of British Columbia (UBC) Watershed Model and its application in the mountainous region. In his lectures, he explained about the model structure, its salient features, required input parameters and their format, how to run UBC model and analysis of model output.

Second and third days of the workshop were dedicated for the hands on exercises on the UBC model install. At the end of third day, five groups were formed and were assigned to work on actual study basin with real hydro-climate data. Participants also discussed their queries with the facilitators regarding model errors, problems in the input data preparation and analysing model output. On the fourth day, participants worked in groups and presented short presentations. Dr. Arshad M. Khan, Executive Director, GCISC formally closed the session with his acknowledging remarks. He appreciated the workshop organizers team for successfully holding the targeted training workshop under stressed situation.

Regional level sharing workshop (18 February 2017)

The Small Earth Nepal (SEN) along with project partners Center of Environment and Geographic Information Services (CEGIS) based in Dhaka and Global Change Impact Studies Center (GCISC) based in Islamabad organized a regional level sharing workshop in Dhaka, Bangladesh on 18th and 19th February 2017. The workshop was organized to share the project findings from each of the participating countries: Nepal, Bangladesh and Pakistan. The workshop was organized as a part of two years research project 'Runoff Scenario and Water Based Adaptation Strategies in South Asia' supported by Asia Pacific Network for Global Change Research (APN) under its Annual Regional Collaborative Project (ARCP) program.

During the formal inauguration session chaired by Engr Waji Ullah, Executive Director of CEGIS, Dr. Madan Lall Shrestha, the project Leader shared the ideas and objectives of the ongoing project. Dr. Shrestha highlighted on the three case study sites taken in each of the partnering countries. Dr. Shrestha also spoke some of the flagship programs of the APN. Dr. Zafar Ahmed Khan, Senior Secretary, Ministry of Water Resources, Government of Bangladesh, as a chief guest of the inaugural session, appreciated the project team for organizing the high-level meeting including the policy makers, decision makers and scientists for sharing the findings, which are indeed essential for decision support system.

Following the inaugural session, the technical session was chaired by Professor Dr. Ainun Nishat, Professor Emeritus at BRAC University in Dhaka in which three papers were presented by the delegates each from Nepal, Bangladesh and Pakistan. We used the advanced ICT tool, skype teleconference, for connecting the delegates from Pakistan as they were not able to join the meeting in-person due to some administrative reasons.

The case study site in Nepal is Karnali basin, Gilgit basin in Pakistan and Ganges-Padma basin in Bangladesh. All the countries are using the Coordinated Regional Downscaling Experiment (CORDEX) data for developing the climate scenarios for the future. The country papers described the status of the past and future climate and its impacts to the river runoff scenarios. It has been identified that the rate of increase of temperature is higher in high altitude regions and the dry season and the regions are becoming even drier in the future. The next plan is to develop the water based adaptation strategies on the basis of the runoff scenarios in each of the case in study basins. There were some constructive comments on selection of the case study sites and harmonization in hydrological modelling along with other suggestions and comments. The research team will incorporate the relevant comments and suggestions that came up during the workshop in producing the final report.

River Basin Research Sharing Colloquium (March 21, Kathmandu, Nepal)

A colloquium on the river basin in Nepal was organized on 21 March 2017 at the Himalayan hotel. The main objective of the program was to share the activities and the research findings from the major river basins in Nepal. Several projects related to climate change and variability, water resource management integrating with other key sectors such as agriculture, public health, disaster management have been carried out in different basins of Nepal but there is a severe lack of coordination among the projects. This program was designed to provide a common platform to policy makers and scientists to share the state of the art findings from the river basin and discuss the potential policy implications. As some supplementary outcomes, young researchers working in the water and related sectors got an opportunity to identify the research and knowledge gaps in the river basins and they can plan research projects to those river basins accordingly.

Technical Session: Focus of Recent Research in Water Sector

Second technical session was chaired by Dr. Madan Lall Shrestha, Academician, Nepal Academy of Science and Technology (NAST). There were five papers in the session.

Climate and hydrological assessment in Karnali Basin, Nepal

Jeeban Panthi, The Small Earth Nepal

In his presentation, Mr. Jeeban Panthi mainly discussed current and future climate and hydrological scenarios of Karnali Basin. The basin is one of the most vulnerable basins in Nepal in terms of climate change. Analysing the historical climate data it has been found in the basin that the upper region has received low rainfall. Mr. Panthi further presented his research findings that the whole basin receives about 89% of the annual rainfall in the four months of monsoon. Historical records also show that the numbers of rainy days are decreasing. Future climate prediction for the region shows that temperature in the region will increase up to 6 ^{o}C by 2080 in worst case scenario. Future climate models have also shown that pre-monsoon rainfall will increase in the region while post monsoon will rainfall will decrease. Future discharge scenarios also show that pre-monsoon season flow will increase. As the rainy days are decreasing, it is likely that drier days in the future are getting drier. Similarly, warming will be higher in the winter and rainfall variability will be high.

Livelihood vulnerability assessment due to climate change in Gandaki Basin, Nepal

Piyush Dahal, The Small Earth Nepal

Mr. Piyush Dahal presented climate change scenarios in Gandaki River Basin and livelihood vulnerability due to changing climate in the area. His analysis of observed climatic data in the basin shows that warming trend in the basin is higher in the high elevation and precipitation is much variable spatially, Duration of the monsoon has been increasing but quantity of the precipitation has not changed significantly. Similarly, consecutive dry days are increasing and, as a result, rainy days are decreasing in the basin. He further presented that agriculture land in the basin is decreasing, mainly due to unavailability of water. Also, livestock diseases in the basin are increasing. Similarly, he further discussed that livestock sector in future is likely to get more stressed as the fodder production is decreasing and invasive species are increasing.

WWF's experiences on implementing river basin management approach in ground

Dr. Shalu Adhikari/Dr. Jagannath Joshi, WWF Nepal

Dr. Shalu Adhikari presented the experiences and learning of the project activities carried out by WWF Nepal in the Koshi River basin. The main objective of the project was to sustainably manage Koshi River Basin water resources and reduce climate risk vulnerability. The project had also supported the Koshi River Basiin Strategic Plan.

The project mainly worked in water, food, energy, conservation education and awareness, capacity building and strengthening of people. The major impact of the project was it enhanced capacity and knowledge of Integrated Resources Management Committees (IRMC), and also improved water access of the people in the rural areas as well. Dr. Adhikari further highlighted that proper water management increased agriculture productivity and also raised awareness among the people. Major lesson learning of the project highlighted was working in an integrated approach in resources management provides better and sustainable changes.

UBC modeling in Gilgit basin, Pakistan: Potentially replicable to Nepal

Dr. Muhammad Zia Hashmi, GCISC, Pakistan

Dr. Muhammad Zia Hashmi presented his research on modelling Gilgit basin in Pakistan and discussed its potential replication to Nepal's river basin since topography and river basin characters are similar to some extent. Dr. Hashmi discussed about the retreat of glaciers in the Himalayan region and stressed on water resources planning in transboundary approach.

Water security in rapidly urbanizing mid hill towns in Koshi and Gandaki Basins: Cases from Dhulikhel and Bidur

Kamal Devkota, SIAS

Mr. Kamal Devkota from Southasia Institute of Advanced Studies (SIAS) presented his case studies from mid hill towns. Dhulikhel and Bidur, on how urbanization is threatening water security. He highlighted some of the observations as current efforts of community are largely focused on getting access to water resources and distribution than its conservation and sustainable management. It has led to rapid trend of water resources capture and is likely to lead to serious conflict. Some of the conflicts have been already observed in the local level and if they are not addressed properly, may lead to serious level in future. Mr. Devkota further discussed that local political vacuum is leading to problem in water resources management as there is huge diversity of institutions concerning water resources but lack of coordination among them. He also discussed that decrease in rainfall and discharge has been neglected in water planning and decision-making system.

Basin Level sharing workshop (5 June 2017, Jumla, Nepal)

A workshop on 'Climate Change and Sustainable Water Resource Development in Karnali Basin' was organized at the Jumla of the Karnali basin in western Nepal on the auspicious occasion of the World Environment Day 2017. The workshop was attended by 75 people representing the district administration office, district coordination committee, relevant government line agencies from Jumla, Kalikot and the Mugu districts of the basin including civil society groups, journalists, and academic institutions. The workshop was jointly organized by The Small Earth Nepal (SEN) and Department of Hydrology and Meteorology (DHM) with the support of Asia Pacific Network for Global Change Research (APN), USAID PANI project and Nepal Climate Change Support Program (NCCSP).

Presenting as a keynote speech to the opening ceremony of the workshop, Dr. Madan Lall Shrestha, APN Project Leader and Academician at Nepal Academy of Science and Technology (NAST) shared some of the research findings on climatic trends in Nepal. He highlighted that the warming rate is higher in high mountain areas. He also mentioned that as water is the part and parcel of the Nature, the theme “Connecting People to Nature” of the World Environment Day-2017 is more relevant with the present workshop, which mainly deals with the water issues in the Karnali River Basin. Mr. Narayan Prasad Sapkota, Chief District Officer (CDO) of Jumla, appealed to the people to conserve the water sources and adapt their lifestyles with the changing condition of climate, but not harming the nature. He urged the research community to come up with some substantial solutions to mitigate the climate change impacts. Speaking at the session, Mr. Hari Narayan Belbase, Local Development Officer (LDO) commented on the unplanned infrastructure development that has ruined the forest and water resources of the Karnali basin. Mr. Jeeban Panthi, Research Coordinator at SEN, highlighted the need of collaborative action to address the environmental problems the country is facing in recent years. Mr. Piyush Dahal, Program Coordinator at SEN, presented the research finding that SEN has been carrying out in the Karnali basin with the support APN. The major results of the project are available here. Mr. Bhola Dhakal from USAID PANI project and Mr. Krishna Bahadur Shahi from NCCSP shared their project activities related to water resource management in the Karnali basin. The available hydro-meteorological stations in the Karnali basin and the basic of the weather monitoring science were shared by Mr. Nirajan Sapkota, Regional Chief of Department of Hydrology and Meteorology (DHM). Finally, participants discussed in group the existing and potential water based adaptation strategies and presented to the forum.

Karnali River Basin in western Nepal is a trans-boundary basin involving China, Nepal and India, and it is the largest basin (45,000 sq. km) in terms of the total area lying within Nepal. Asian Development Bank (2012) ranks the basin the most vulnerable to climate change mainly due to increasing climate extreme and low capacity of people to cope with the changes. In recent years, there are some climate change research and water resource management projects being carried out by government as well as other development partners. Therefore, it’s time to share the outcomes and results to the field level stakeholders in a way that they understand and will be able to implement in their work. In addition, the workshop also provided a platform to those knowledge and development partners to come together and share their project information, which is very instrumental in avoiding the duplicity, if any, and build on the project activities based on the available knowledge.