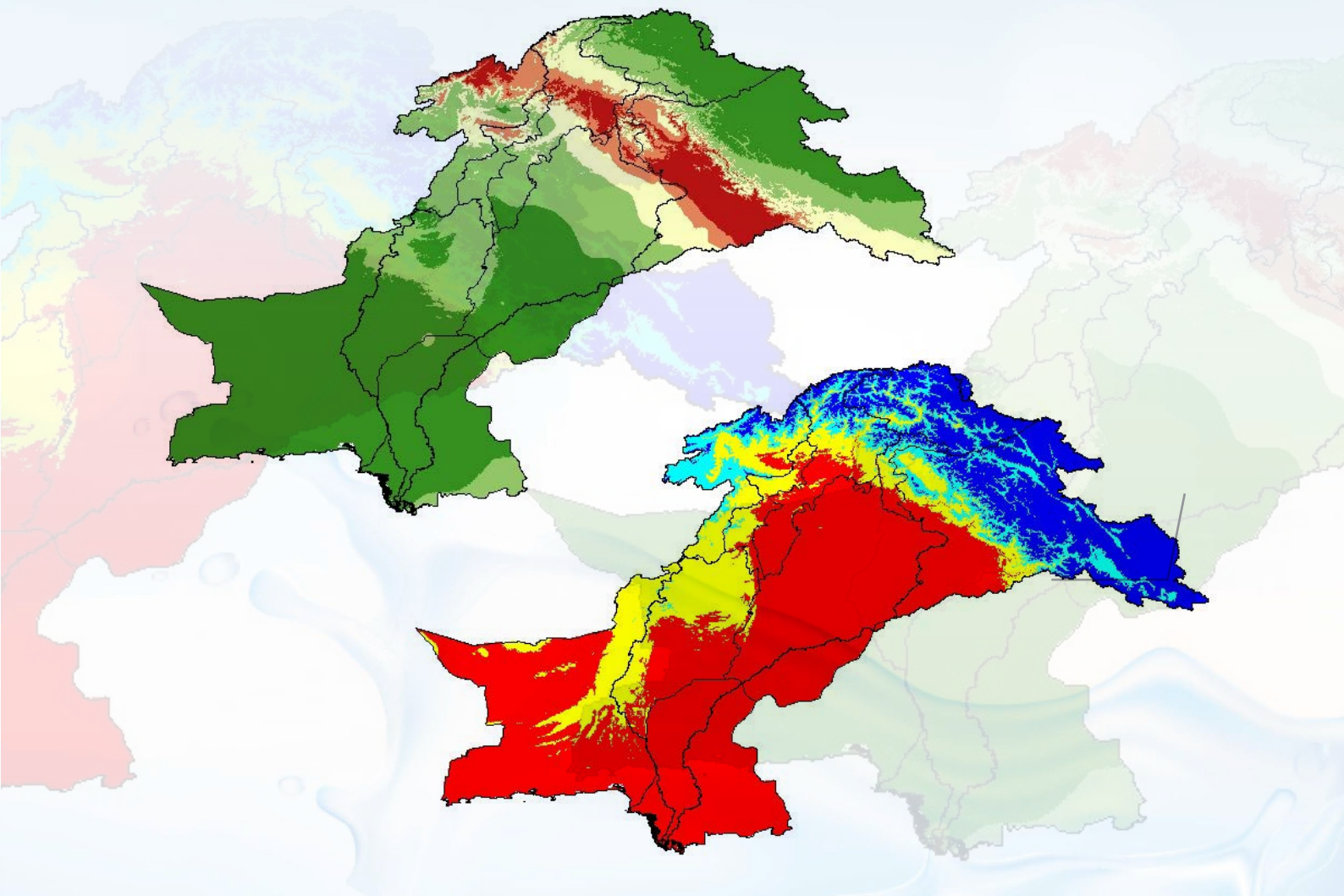
U.S.-Pakistan
Centers for Advanced Studies in Water

Managing Uncertainties in Projected Impacts of Climate Change on Precipitation Patterns in Pakistan

Final Report 2018



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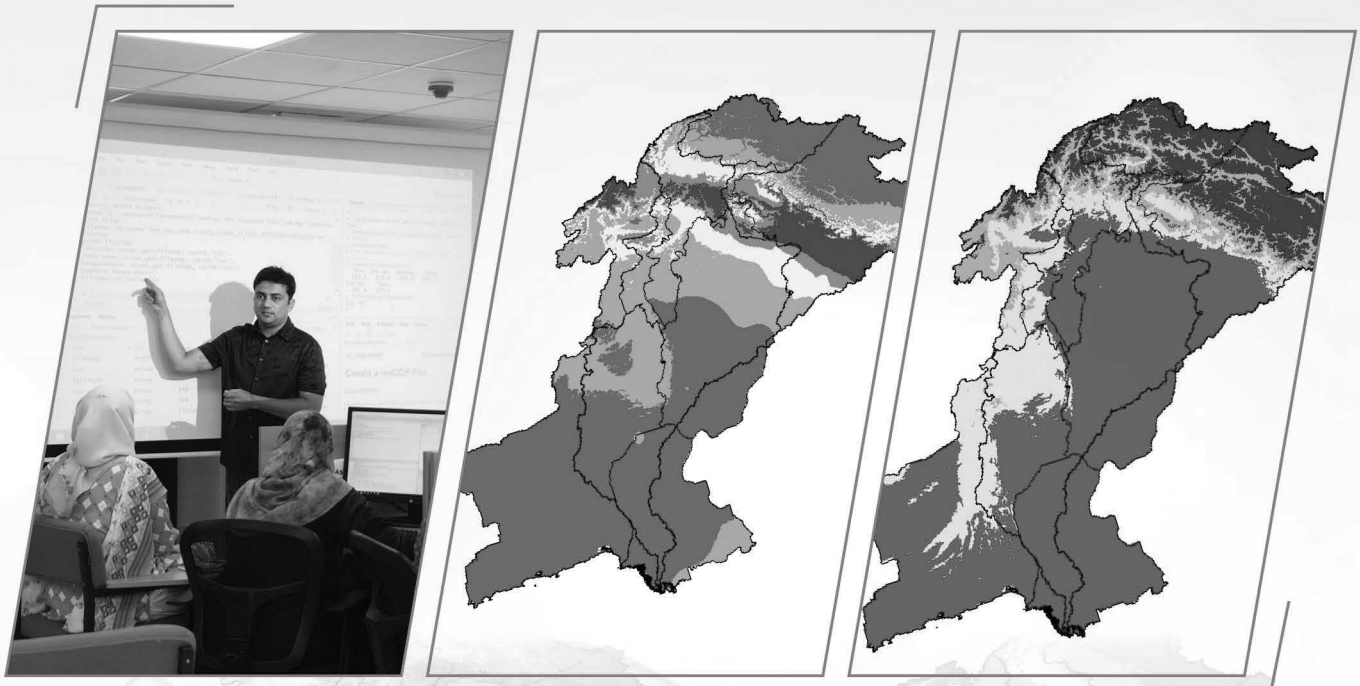

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LIST OF ABBREVIATIONS

ACCESS 1.3	Australian Community Climate and Earth-System Simulator version 1.3
BCC-CSM1-1	Beijing Climate Center Climate System Model version 1.1
CanESM2	Canadian 2nd generation Earth System Model
CCCma	Canadian Center for Climate Modeling and Analysis
CCSM4	Community Climate System Model version 4.0
CESM1-BGC	Marine Ecosystem Dynamics and Biogeochemical Cycling in the Community Earth System Model
CMIP5	Climate Model Inter-comparison - Project Phase 5
CRU	Climate Research Unit
CSIRO-MK-3.6.0	Commonwealth Scientific and Industrial Research Organization (CSIRO)
CO2	Carbon dioxide
DJF	December January February
ESGF	Earth Science Grid Federation
GEV	Generalized Extreme Value
GHCN	Global Historical Climatology Network
GCM	Global Climate Model / Global Circulation Models
GFDL-CM3	Geophysical Fluid Dynamics Laboratory - Coupled Physical Model version 3
GPCC	Global Precipitation Climatology Center
INM-CM4	Russian Institute for Numerical Mathematics Climate Model Version 4
IBIS	Indus Basin Irrigation System
IPCC-AR	Intergovernmental Panel on Climate Change Assessment Report
JJAS	June July August September

MAE	Mean Absolute Error
MIROC5	Model for Interdisciplinary Research on Climate (MIROC) version 3.2
MPI-ESM-LR	Max Planck Institute for Meteorology (MPI-M) Earth System Model
NCAR	National Center for Atmospheric Research
PCMDI	Program for Climate Model Diagnosis and Inter-comparison
QMD	Quantile Mapping Delta
RCP	Representative Concentration Pathway
SDSM	Statistical Downscaling Model
W/m2	Watts per square meter

EXECUTIVE SUMMARY

Climate change is a change in the statistical properties of the climate system that persists for several decades or longer usually at least 30 years. Climate change is due to natural processes, such as changes in sun's radiations, volcanoes or internal variability in the climate system or due to human influences such as changes in the composition of atmosphere or land use. Nowadays climate is affecting almost every sector of life all around the globe. Most recently, the city of Cape Town which is one of the most populous cities of Africa and world's renowned tourist place is running out of water after three years of continuous droughts. Likewise, Pakistan is one of the most vulnerable countries to the adverse impacts of climate change because of its topography and geographical location. According to a story published in a national newspaper Daily Nation on March 30, 2018, the spokesman for Indus River System Authority (IRSA), Khalid Rana briefed that the Indus River will receive water shortage by 11 MAF during Kharif season of 2018 due to less snowfall. Furthermore, the regional issues on the allocation of water of the state's share have not been resolved for past century, thus various times Sindh has protested about that.

Pakistan depends upon one of the major contiguous irrigation systems known as Indus Basin Irrigation System (IBIS) for its water supply. The Indus River gets about more than 65 percent of total average flow from snow and glacier melt in the HKH (HinduKush-Karakoram-Himalayan) region (Sheikh *et al*., 2009). Monsoon precipitation contributes in the remaining flows in the Indus River Basin (IRB).

Pakistan ranks at the sixth most populous country in the world and has an area of 796,000 km^2 with significant spatial variation in precipitation and temperature (Chaudhry, 2017). The southern parts of Pakistan gets the most of precipitation in the summer monsoon season (June to September), whereas northern parts gets highest precipitation in the winter season through western weather disturbances (December to March). According to a research by Chaudhry (2017), the monsoon precipitation contributes about 60% of the total annual precipitation in Pakistan. The northern parts of the country hosts the highest mountain peaks including K-2 and thousands of glaciers including Baltoro and Siachen which feed the Indus River Chaudhry, 2017. The temperature also varies from - 50°C in the winter to 15-20 °C in the summer season in northern parts of Pakistan, while southern parts experience the temperature of around 40-50 °C in June & July. The variability in the frequency and intensity of precipitation and temperature may be amplified by climate change, eventually impacting the country's limited freshwater resources.

Water resources managers and policy-makers need reliable projections of hydro-climatic conditions to develop sound water management policies. Global climate models (GCMs) are the primary basis for projecting how the climate may change over the coming decades. Yet, GCMs have low spatial resolution and inherent biases that limit their direct utility for understanding localized climate change impacts. These limitations are particularly pronounced in mountainous areas, where the terrain varies at a much finer resolution than GCMs. In this study, precipitation and mean temperature simulations from an ensemble of 10 GCMs that participated in the Climate Model Inter-comparison Project Phase-5 (CMIP5) under two Representative Concentration Pathways (RCP4.5 and RCP8.5) are downscaled to a 30 arc second spatial resolution (approximately 1 km) through bias correcting the simulations using quantile mapping and downscaling them with the delta method over Indus River Basin (IRB) and Pakistan for the period of 2040-2070. The GCM processing is carried out using the Global Climate Data (GCD) package. The results show that for all seasons and most of the Indus basin and Pakistan, future precipitation is highly uncertain. However, there is higher confidence that annual precipitation will increase in the higher elevation areas i.e. Upper Indus basin (UIB). As widely identified, there is also a high confidence that temperature will continue to rise over the Indus Basin and Pakistan.

Moreover, monsoon precipitation and temperature increases in the UIB region could bring huge flood disasters in the low plains of the IRB. Therefore, Pakistan needs to focus more on building reservoirs so that it can capture water when it is in excess and utilize it accordingly.

1. INTRODUCTION

1.1 Background

Climate change is an undeniable reality and its severe impacts are observed in every sector all around the globe. The climate is mainly driven either by natural or by anthropogenic factors. Changes in the components of hydrologic cycle such as precipitation, temperature, and runoff at the regional and global scales are attributed to anthropogenic factors (IPCC, 2007; Najafi *et al*., 2017).

The Indus River Basin (IRB) is a transboundary river basin covering an area of 1.12 million square km, which is distributed across four countries: Pakistan (47%), India (39%), China (8%), and Afghanistan (6%) (FAO, 2011). The Indus River is often referred as the "lifeblood" of Pakistan because it provides water for the country's irrigation system, which is one of the world's largest irrigation systems. The IRB stretches from the Himalayan-Karakoram-Hindu Kush (HKHK) mountain headwaters to the low-lying plains of Sindh province (Qureshi et al., 2010). While the Indus River delivers large volumes of precious water, much of the IRB is relatively arid to semi-arid. Annual precipitation varies from 1500 to 2000 mm in the Upper Indus Basin (UIB) and 100 to 500 mm in the southern plains in Sindh Province (Qureshi et al., 2010 FAO, 2011).

Water in the IRB is generated both by monsoon rainfall and melt water from glaciers and snow. Temperature varies substantially across the basin, with the lowest temperatures occurring in the northern Himalayan mountains and the highest temperatures recorded in the deserts covering the southern portion of the basin. The diverse climate and the factors contributing to the current water resources in the basin make the region particularly susceptible to changes in either precipitation or temperature (Mukhopadhyay and Khan, 2015). Furthermore, changes in water resources could have serious consequences for water, energy and food security in this region (Archer 2003), potentially deepening transboundary and interprovincial water disputes. In the future, a rise in temperature may cause rapid melting of the glaciers and affect the rainfall which could result in a huge runoff initially and decreased runoff thereafter (Ahmed, 2002). Similarly, spatial and temporal variability of precipitation may be intensified by climate change which may have implications for Pakistan's management of water resources. Therefore, future climate projections of major climatic variables are essential to project water resources and its management for various sectors.

Pakistan is one of the most vulnerable countries to the adverse impacts of climate change. According to the Global Climate Risk Index (CRI) 2018, Pakistan has been ranked seventh in the list of most affected countries (Eckstein *et al.,* 2017). The CRI 2018 categorizes countries according to their vulnerability to extreme weather events

such as storms, floods and heat waves as well as their socio-economic data for two decades i.e. from 1997 to 2016. Currently, the country is facing various climate-related challenges of which rising temperatures and frequent and intense weather events are critical. Among the climate-related issues, precipitation and temperature are significantly important in the climatic water balance (Najafi and Moazami 2016; Dars *et al*., 2017). Rising temperature is one of the most serious concerns which could affect the hydrological cycle, thereby deteriorating critical water conditions, and consequently affecting almost every sector of life. In the past five decades, the mean annual temperature in Pakistan has raised by approximately 0.5°C (Chaudhry, 2017). According to the IPCC AR5, climate models project that the global temperature is likely to incline from 0.3°C to 1.7°C under lowest emission scenarios; whereas, it is likely to rise from 2.6°C to 4.8°C for higher emission scenarios over this region. Moreover, precipitation in Pakistan has increased significantly over the past century, but future changes in precipitation patterns are not well understood (Sheikh et al., 2009).

Global climate models (GCMs) are the best available tools to simulate climate change. However, they have several limitations, including that they do a poor job of representing precipitation and that their low spatial resolution renders them unable to resolve the impacts of most topographic features. Downscaling is the process of refining the model spatial resolution so that it is suitable for evaluating local conditions (Fowler and Archer, 2006). The two categories of downscaling methods are statistical and dynamical. In dynamical downscaling, regional climate models are nested within boundary conditions provided by the GCMs. In contrast, statistical downscaling applies robust empirical relationships between local factors and large-scale climate predictors. An advantage of statistical downscaling methods is that they are computationally inexpensive. In many instances, their performance, particularly for predicting mean climate, is comparable to dynamical approaches.

Recently, various studies have been conducted on the IRB and Pakistan to project precipitation and temperature changes for the coming decades. These studies have either been conducted on small spatial scales (Kazmi *et al.,* 2015; Amin *et al.,* 2018) or used older data of Special Report on Emission Scenarios (SRES) (Farooqi *et al.,* 2005; Mahmood and Babel, 2013; Saeed and Athar, 2017). Some of the studies, such as Su *et al.* (2016), focused on downscaling the entire Indus Basin but their resolution is too coarse to be used in hydrological studies or crop water modeling. More importantly, only a few previous studies have looked at the uncertainty of climate model projections. Consideration of uncertainty is critical for policy makers and water managers to ensure the reliability of climate projections and to support their decision-making process.

This study examines projected changes in precipitation and mean temperature across a 31-year time period using the bias corrected and downscaled output of 10 CMIP5 (Climate Model Inter-Comparison Project Phase5) models over the IRB and Pakistan under Representative Concentration Pathway (RCP) 4.5 and 8.5. The GCM simulations are processed by their bias correction with quantile mapping and downscaling to 30 arc seconds (approximately 1 km) with the delta method using the Global Climate Data (GCD) package (Mosier et al., 2018). The study also examines the uncertainty in these projections, providing critical insights on the confidence of projections. This study will support policy-makers and experts in the development of sound policies by delivering more reliable projections of hydro-climatic variables. In addition, long-term data for both historical periods and future projections are critical inputs for performing hydrological studies, crop water modeling studies and other climate impact assessment studies. In case of the IRB and Pakistan, the availability of high-resolution downscaled data poses a significant challenge. To bridge this gap, the high-resolution downscaled data will be made available in order to advance the research in the field of climate impacts assessment.

1.2 Research Hypothesis

The ongoing increases in global temperature trends will substantially alter the regional precipitation variability in the Indus River Basin and Pakistan including increases in the frequency and intensity of extreme events.

1.3 Research Questions

i. Both precipitation and temperature in the Indus River Basin and Pakistan are increasing, but how they will vary in the future?

ii. What is the level of uncertainty in the CMIP5 projections over this region?

1.4 Research Objectives:

Following are the main research objectives:

i. To estimate the projected changes in the precipitation and temperature over IRB and Pakistan.

ii. To perform uncertainty analysis to determine the reliability of the projections.

iii. To estimate the extreme precipitation events using extreme value analysis.

iv. To develop a web portal for data dissemination of bias corrected and downscaled data.

v. To organize a workshop to disseminate the findings of this study to the government institutions, academia, and NGOs.

2. MATERIALS AND METHODS

2.1. Study Area

The spatial extent of this study is the IRB and Pakistan (Fig. 2.1). Except for the portions of mountain headwaters, this region has an arid to semi-arid climate. The Karakoram Mountains in the UIB contain vast long-term and seasonal water reserves in the form of glaciers and snow. Pakistan's topography consists of glaciers in its north and plain areas including deserts in its south. Average annual rainfall in Pakistan varies from 100 mm to 250 mm with mean summer monsoon rainfall of 133 mm which is approximately 59% of the annual rainfall, based on the data for the period of 1901-1990 (Sheikh *et al*., 2009). Furthermore, the temperature varies across the country, from one region to another, being lowest in the northern Himalayan Mountains and highest in deserts in the South. Pakistan is dependent on the Indus River, which is one of the longest rivers in Asia and also one of the most climate-sensitive rivers because its water resources are mainly generated by monsoon rainfall and melt water from glaciers and snow. Thus, its water resources may be potentially affected by any changes in either precipitation or temperature (Mukhopadhyay & Khan, 2015).

2.2. Datasets

Four gridded weather information sources were used in this study, including monthly time series of low-resolution CMIP5 GCM simulations, 0.5° resolution Global Precipitation Climatology Center (GPCC) observed gridded data (Becker *et al.,* 2013), 0.5° resolution CRU observed gridded temperature data (Harris et al., 2014) and the 30-arc second Worldclim climatology dataset (Hijmans *et al.,* 2005).

An ensemble of 10 GCMs that participated in the CMIP5 (Taylor et al., 2012) is used in this study (Table 2.1). The CMIP5 is the most up-to-date public repository of climate model simulations. CMIP5 uses four representative concentration pathways (RCPs) named as RCP2.6, RCP4.5, RCP6.0 and RCP8.5. These four RCPs are used to project how the climate may change based on different amounts of greenhouse gas emissions. These labels indicate the approximate radiative forcing at the end of the 21st century, meaning that RCP8.5 is the most severe climate change scenario and RCP2.6 is the least severe. The CMIP5 GCM simulations used in this study are obtained from the Earth Science Grid Federation (ESGF) archive data portal (http://esgf.llnl.gov). Thirty one years of model output has been chosen for the historical baseline (1960-1990) and the future period (2040-2070). For each GCM, we have analyzed the output of only one ensemble member "r1i1p1" under RCP4.5 and RCP8.5.

Table 2.1 The CMIP5 models used in this study

Model ID	Institution	Country	Resolution (Lon x Lat)	Reference
CCSM4	US National Center for Atmospheric Research	USA	1.25°×0.95°	(Gent *et al.*, 2011)
CESM1-BGC	Community Earth System Model	USA	1.25°×0.95°	(Hurrell *et al.*, 2013)
MIROC5	University of Tokyo, National Institute for Environmental Studies, and Japan for Marine-Earth Science and Technology	Japan	1.406°×1.406°	(Watanabe *et al.*, 2011)
ACCESS1-3	Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology	Australia	1.875°×1.25°	(Bi *et al.*, 2013) a partnership between CSIRO1 and the Bureau of Meteorology. It is built by coupling the UK Met Office atmospheric unified model (UM
INM-CM4	Russian Institute for Numerical Mathematics (INM)	Russia	2.0°×1.5°	(Volodin *et al.*, 2010)the results of which are to be used in preparing the fifth assessment report of the ntergovernmental Panel on Climate Change (IPCC
CSIRO-Mk3-6-0	Queensland Climate Change Center of Excellence and Commonwealth Scientific and Industrial Research Organization	Australia	1.875°×1.875°	(Rotstayn *et al.*, 2012)

MPI-ESM-LR	Max-Planck_Institut fur Meteologie	Germany	1.875°×1.875°	(Giorgetta *et al.*, 2013)
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory	USA	2.5°×2.0°	(Delworth *et al.*, 2006)
BCC-CSM1	Beijing Climate Center, China Meteorological Administration	China	2.8°×2.8°	(Wu *et al.*, 2010)
CanESM2	Canadian Center for Climate Modeling and Analysis	Canada	2.8°×2.8°	(Arora *et al.*, 2011)

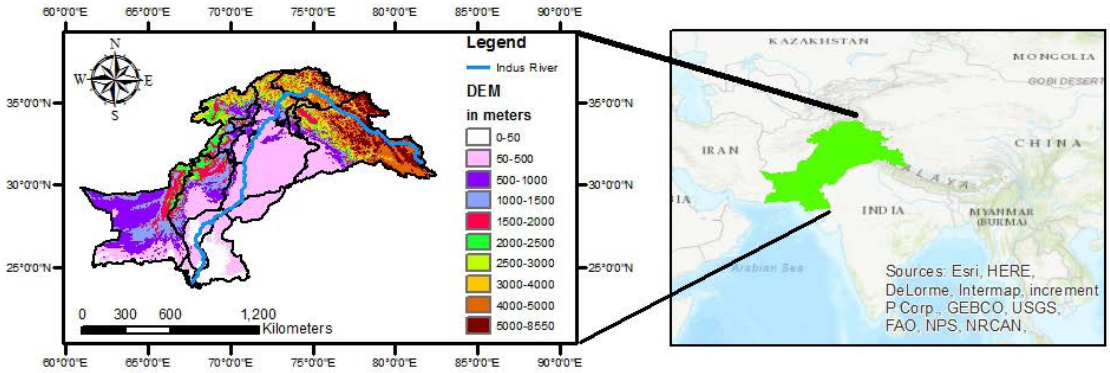

Fig. 2.1 Map of the Indus River basin and Pakistan

2.3 Methodology

2.3.1 Objectives 1 and 2: Temperature and Precipitation Projections

The GCM simulations are processed by bias correction, with quantile mapping and downscaling them to 30 arc seconds (approximately 1 km) with the delta method. The GCM simulations of precipitation and temperature variables have been downscaled using the 0.5° resolution of the GPCC observed gridded data (Becker et al., 2013) and the 0.5° resolution CRU TS 3.23 datasets (Harris et al., 2014), respectively. The research shows that the GPCC data is considered a "state of the art" and compares favorably with other observational precipitation data sets (Fekete et al., 2004). In this method, bias correction is performed by empirical quantile mapping (Piani et al., 2010; Themebl et al., 2012; Themebl et al., 2012; Mosier et al., 2018) which is a univariate bias correction technique. Using this method, empirical cumulative distribution functions (ecdf) are calculated for each GCM and observed gridded datasets. Mathematically, it can be represented as:

$$Y = ecdf^{-1}[P(Y)] \qquad \text{Equation 2.1}$$

where refers to the function which gives the non-exceedance probability, *mod* refers to modeled climate and *proj* refers to projection simulation.

Then, climate values corresponding to the given non-exceedance probability can be estimated by using the following formula:

$$Y = ecdf^{-1}[P(Y)] \qquad \text{Equation 2.2}$$

The bias correction can be done by developing transfer factors (TF) which are developed between observed gridded data and GCM simulation data over a similar historical period for all *P* in the CDF. Mathematically, it can be described by equations:

$$TF[P] = ecdf^{-1}{}_{obs,hist}\ [P] - ecdf^{-1}{}_{mod,hist}\ [P] \qquad \text{Equation 2.3}$$

where *obs,hist* refers to the historic observed data and *mod,hist* refers to the historic modeled data (GCM historic simulations).

Then, bias corrected value can be represented by:

$$Y' = Y + TF[P(Y)] \qquad \text{Equation 2.4}$$

The transfer factors are applied to future GCM simulations for downscaling on each grid. This method involves multiplicative perturbations for precipitation and additive for temperature variable for future projections. The WorldClim data (Hijmans et al. 2005) was used to spatially disaggregate to 30 arc-second resolution (1 km resolution).

The downscaled simulation data is then validated by comparing with Global Historical Climatology Network (GHCN) station records (Peterson and Vose 1997; Lawrimore et al., 2011). Two measures have been estimated to analyze the error i.e. Bias and Mean Absolute Error (MAE). The formulae for Bias and MAE are given below:

$$Bias = \frac{1}{n}\sum_{i=0}^{n}(P_i - O_i)$$ Equation 2.5

$$MAE = \frac{1}{n}\sum_{i=0}^{n}|(P_i - O_i)|$$ Equation 2.6

where is the downscaled value, is the GHCN value, and is the number of data points being compared.

The mean change in the precipitation and temperature has been calculated by the following equations:

$$Mean\ change\ (Precip) = (Projection\ MMM - Historic\ MMM)/Historic\ MMM$$

Equation 2.7

$$Mean\ change\ (Temp) = Projection\ MMM - Historic\ MMM$$ Equation 2.8

where *MMM* represents multi-model mean.

The uncertainty between the models has been calculated by the following equations:

$$Uncertainty\ (Precip) = \ Projection\ SD\ /\ Historic\ MMM$$ Equation 2.9

$$Uncertainty\ (Temp) = \ Projection\ SD$$ Equation 2.10

where *SD* is Standard Deviation between the model's outputs.

2.3.2 Objective 3: Extreme value analysis

Extreme value analysis plays an essential role in detecting the adverse impacts of climate change. Changes in the spatiotemporal variation of precipitation patterns and stream flow patterns will have serious effect on our socio-economics, aquatic species, hydrological infrastructures and human lives. Therefore, the evaluation of future changes in stream flow patterns has now become an essential part of water resources planning studies. The research shows that the Generalized Extreme Values (GEV) distribution is capable of simulating nearly accurate historical extreme events and predicting future extreme events (Tyhorn and DeGaetano, 2011, Halmstad *et al*., 2013). The GEV distribution is one of the most frequently used distributions in determining extreme events all over the world (Stedinger, 1993; Katz *et al*., 2002;

Ekström *et al*., 2005; El-Adlouni *et al*., 2007; Cooley, 2009).

In this study, GEV distribution (Fisher & Tippet, 1928) comprising three extreme value distributions have been adopted to analyze the extreme precipitation in terms of return values. These three distributions are named Gumbel, Frechet and Weibull distributions. The CDF of the GEV distribution is as follows:

$$F(x,\mu,\delta,\xi) = \exp\left[\left(-\frac{x-\mu}{\delta}\right)\right] \text{when } \xi = 0$$

$$Y = ecdf^{-1}[P(Y)]$$

where μ is the location parameter, ξ is the shape parameter and δ is the scale parameter. According to Katz *et al*. (2002), shape parameter can be used to describe the tail behavior of the distribution. If ξ = 0, GEV is called Type-I or Gumbel distribution. If ξ > 0, GEV distribution is called Type-II or Frechet distribution. If ξ < 0, GEV distribution is termed Type-III or Weibull distribution.

A return value is a threshold that is exceeded by an annual extreme in any given year with the probability p=1/T. Return values are the quantiles obtained from GEV distribution at every grid of the data. According to some studies, the GEV distribution works best on sufficiently large annual maximum data of at least more than 25 years (Coles, *et al*. 2001, Halmstad *et al*., 2013). After fitting the GEV distribution to the annual maximum values, the T-year return levels are obtained by the inverse of the cumulative distribution function.

2.3.3 Objective 4: Develop a web portal for data dissemination

The sharing of the downscaled data is a significant component of this study. For this purpose, a data archive has been developed under world wide web protocols; http://www.ccipp.water.muet.edu.pk. All precipitation data for whole IRB has been kept in this data archive. The website requires user registration to download precipitation data. Once the user is registered, then he/she will be able to download data. When the researchers use the data, they will be responsible to cite the source of the data which is very important for academic ethics.

2.3.4 Objective 5: Organize a seminar for knowledge dissemination

The goal of the organizing the workshop was to disseminate the findings of this study to the stakeholders and to advance the understanding of engineers, scientists, water managers and experts in the area of climate change impacts on system performance with particular reference to changes in temperature and precipitation. The workshop

stimulated interest among the participants training strength in the area of climate impact studies by using different tools such as R statistical language and WEAP decision support tool. The detailed concept note of the seminar has been attached in Appendix-A.

The participants from Provincial and Federal Government actively participated in the workshop. The participants' detailed contacts with their organizational background are attached in Appendix-B.

3. RESULTS AND DISCUSSION

In this section, we present and discuss downscaled observed gridded datasets, validation statistics, projected temperature changes and projected precipitation changes.

3.1 Downscaled Gridded Historical Datasets

The diverse historical climate of the IRB and Pakistan is evident in Fig. 3.1 and 3.2. Precipitation is highest at the transition between the lowlands and HKHK mountains. In addition, low plains (Sindh, Punjab, southern Baluchistan and some parts of KPK) have higher temperature whereas the UIB has low temperature.

The downscaled historical data has been validated by comparing it with GHCN station records. There are 183 GHCN stations with data in the study area for precipitation and 67 for temperature (Fig. 3.3). Bias and MAE were calculated between the downscaled and station records. The downscaled data are highly correlated with the GHCN stations records (Table 3.1). The aggregated bias and MAE values for downscaled CRU temperature data were estimated to be 0.98 °C and 2.42 °C, respectively. In addition, the aggregated bias and MAE values for downscaled GPCC precipitation data were estimated to be 26.69 mm and 42.56 mm, respectively. The performance of the Quantile Mapping Delta (QMD) method in downscaling precipitation and temperature is thus quite satisfactory as the aggregated bias and MAE values for both precipitation and temperature are quite low.

Table 3.1 Evaluation of the downscaled temperature (CRU) and precipitation data (GPCC) related to GHCN stations.

Model	CRU (°C)	GPCC (mm)
Bias	0.98	26.69
MAE	2.42	42.56
R	0.98	0.94

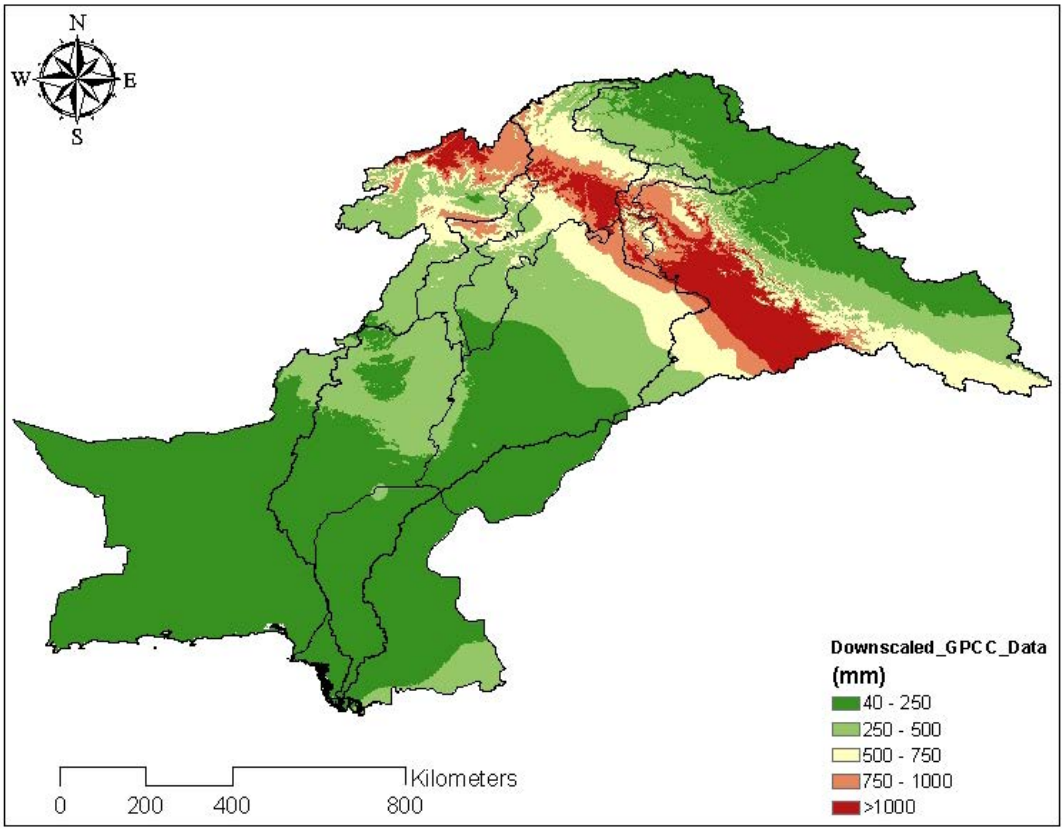

Fig. 3.1 Downscaled GPCC gridded precipitation for 1960-1990

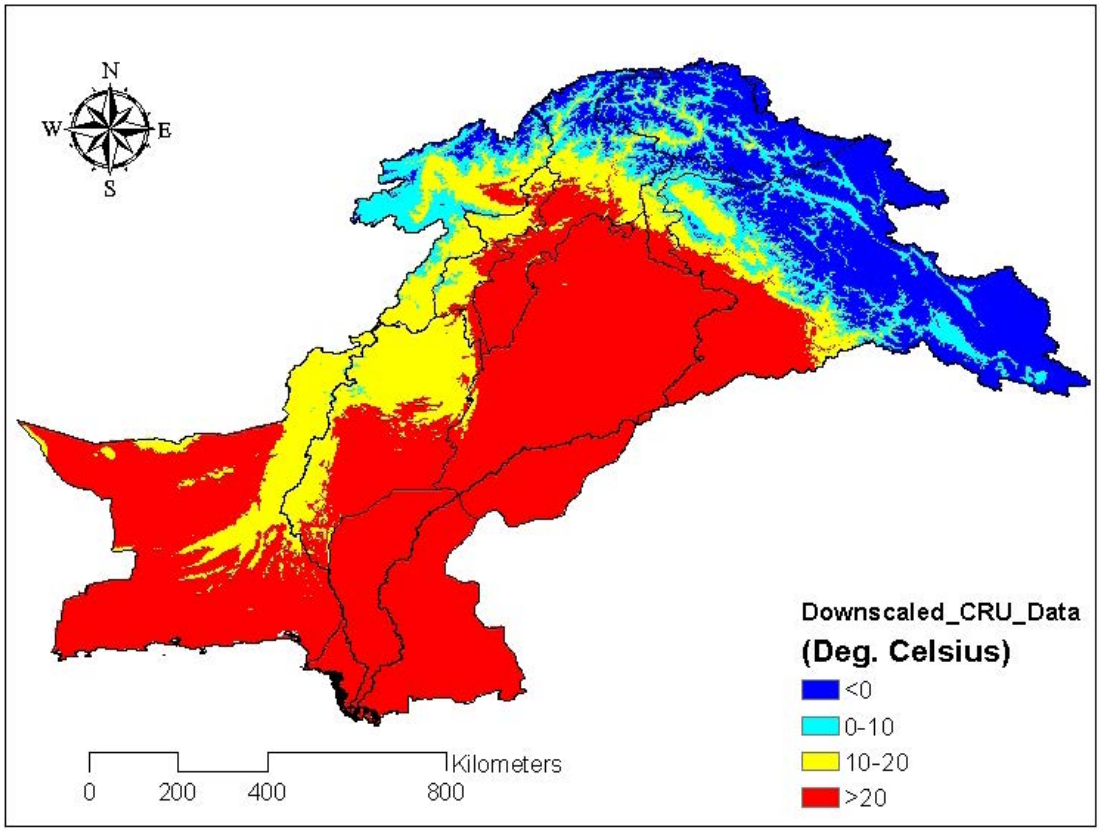

Fig. 3.2 Downscaled CRU gridded temperature for 1960-1990.

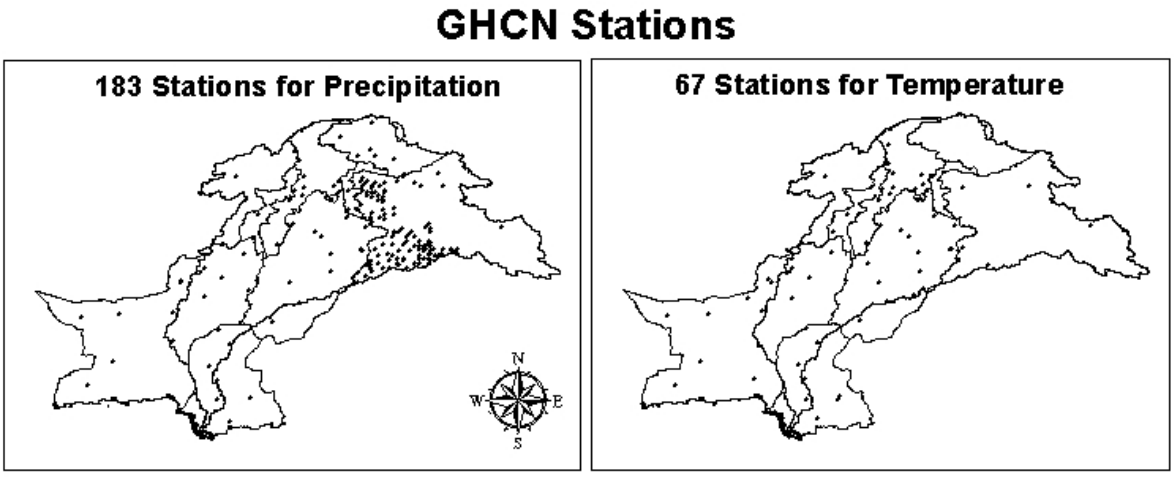

Fig. 3.3 GHCN stations reporting precipitation (Left) and temperature (Right) in the Indus River basin

3.2 Projected Temperature Changes

The changes of spatial patterns of annual mean temperature for the future period relative to the historic baseline period are given in Fig. 3.4. The projected changes in temperature are confident almost everywhere over the Indus Basin and Pakistan. It can be observed that the annual mean temperature has a consistent increasing trend throughout the basin. The annual mean temperature in the IRB is projected to increase by 2.02 °C under RCP4.5 and 2.65 °C under RCP8.5. Similarly, annual mean temperature in Pakistan is also projected to increase by 2.14 °C under RCP4.5 and 2.8 °C under RCP8.5 scenario.

The uncertainty between ensemble projections estimated in Fig.3.5 shows that under RCP4.5, the uncertainty in most of the Indus Basin is low except western parts (Kabul River Basin, FATA, Baluchistan and KPK provinces of Pakistan) whereas in some eastern parts (SW Tibetan Plateau) the uncertainty is comparatively high. Similarly, under RCP8.5, the uncertainty in the middle belt of the IRB (Sindh, Punjab and middle belt of UIB) is low except in western parts and some eastern parts where the uncertainty is comparatively high.

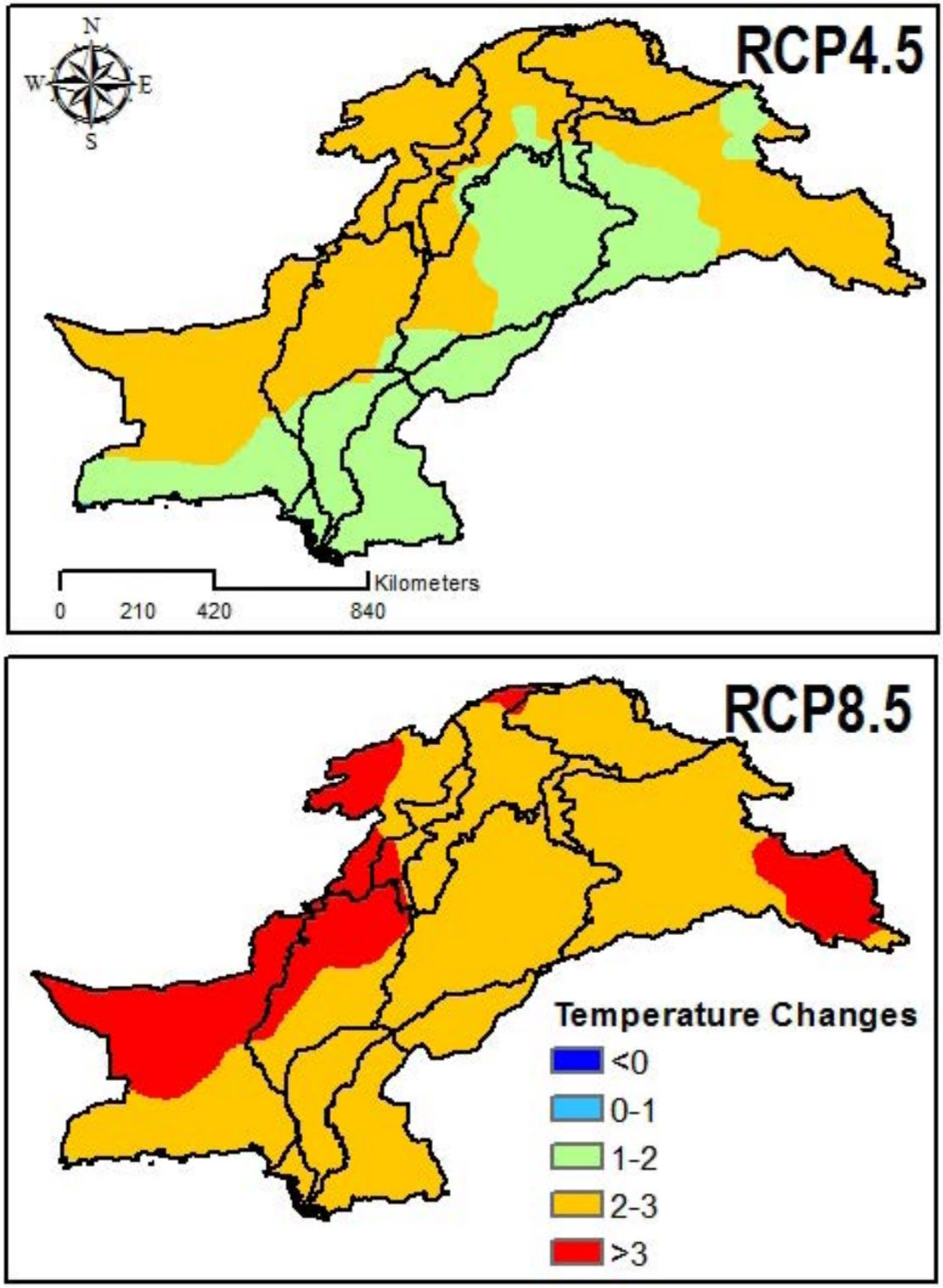

Fig. 3.4 **Projected changes in temperature (oC) for 2040-2070 relative to the historic time period (1960-1990). Gray grid cells specify the locations where the absolute uncertainty between ensemble projections is greater than the projected changes.**

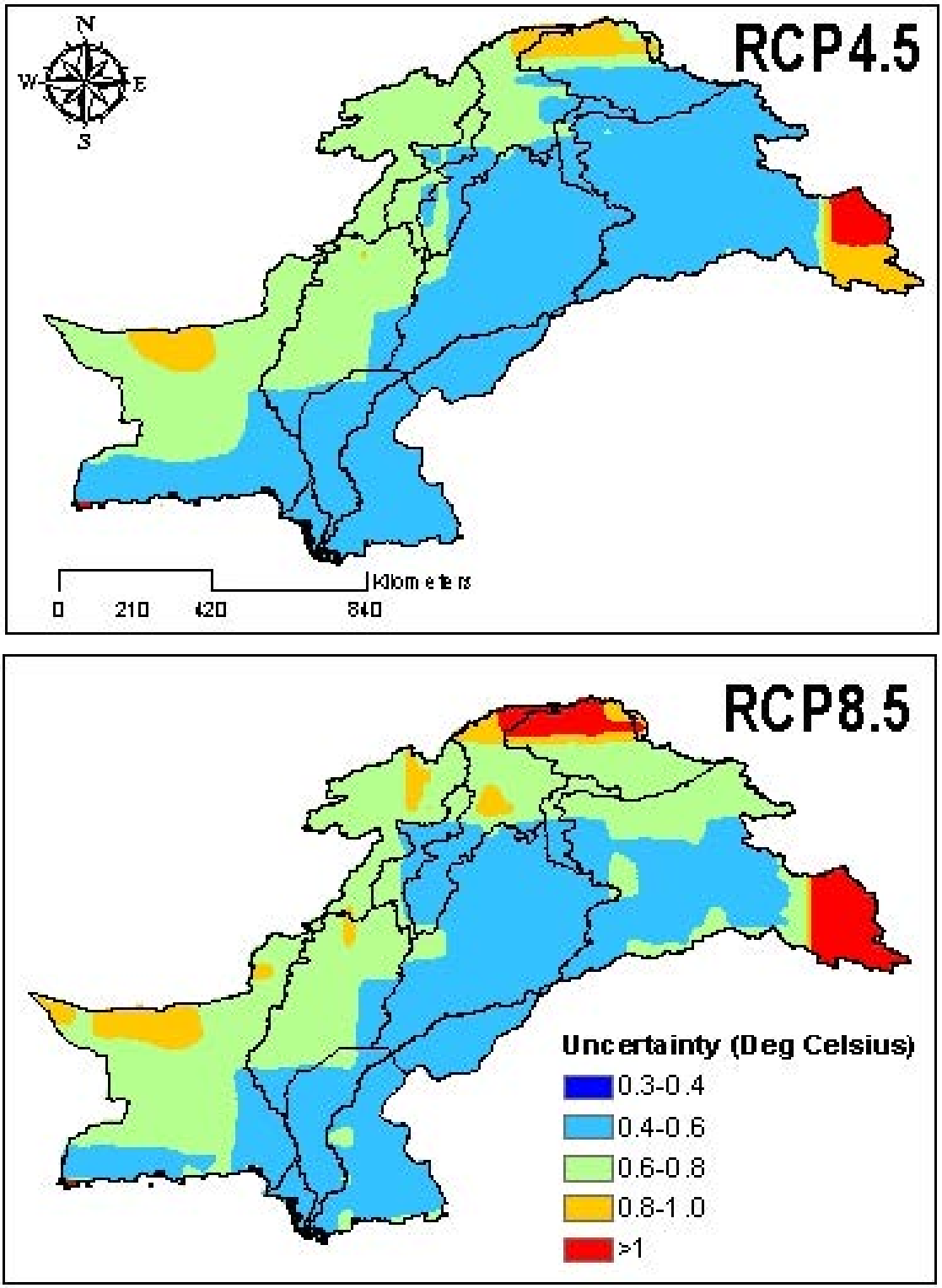

Fig. 3.5 **Uncertainty in projected temperature changes (°C) for 2040-2070 relative to the historic time period (1960-1990)**

The changes of spatial patterns of seasonal mean temperature for the future period relative to the historic baseline period are given in Fig 3.6. The winter (i.e. December, January, February, DJF) temperature in the IRB is projected to increase by 2.13 °C under RCP4.5 and 2.76 °C under RCP8.5. Similarly, the summer (i.e. June, July, August, September, JJAS) temperature is also projected to be increasing by 1.89 °C under RCP4.5 and 2.50 °C under RCP8.5. Likewise, the autumn (i.e. October, November, ON) temperature is also projected to increase by 1.97 °C under RCP4.5 and 2.59 °C under RCP8.5. The spring (i.e. March, April, May, MAM) temperature in the IRB is projected to increase by 2.11 °C under RCP4.5 and 2.77 °C under RCP8.5. The winter temperature in Pakistan may increase by 2.3 °C under RCP4.5 and 2.9 °C under RCP8.5 scenario. Similarly, the summer temperature is also projected to be increased by 2.06 and 2.76 °C under RCP4.5 & RCP8.5 scenarios, respectively. However, the projections for change in summer temperature in Sindh and Punjab are relatively lower compared to that of the northern parts under RCP4.5 scenario.

In the UIB, the mean temperature is projected to increase by 2 to 3 °C under both RCP4.5 and RCP8.5 by 2040-2070 except for the eastern parts of the UIB (SW Tibetan Plateau - where the Indus River originates), where more than 3 °C increase in the mean temperature is predicted under RCP8.5. In Sindh and Punjab provinces, the mean temperature is projected to increase by 1 to 2 °C under RCP4.5 and 2 to 3 °C under RCP8.5 by 2040-2070. In northern and western parts of Baluchistan province, the mean temperature is projected to increase by 2 to 3 °C under RCP4.5 and more than 3 °C under RCP8.5 by 2040-2070 whereas in southern and eastern parts of Baluchistan province, the mean temperature is projected to increase by 1 to 2 °C under RCP4.5 and 2 to 3 °C under RCP8.5 by 2040-2070.

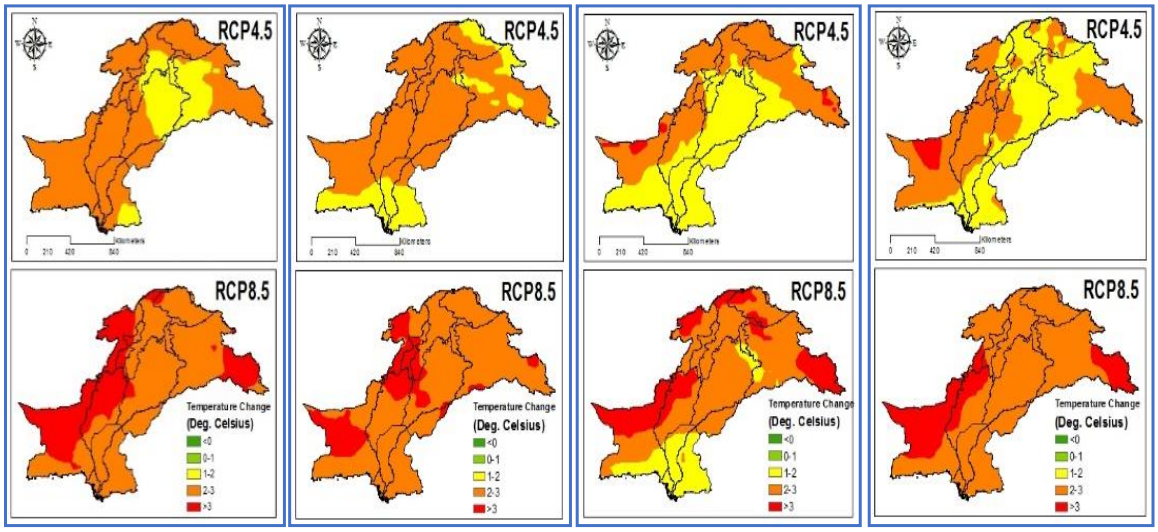

Fig 3.6. Projected changes (°C) in temperature for 2040-2070 relative to the historic time period (1960-1990). from left to right the figure represents winter, spring, summer and autumn seasons

3.3 Projected Precipitation Changes

The projected changes of the annual mean precipitation in 2040-2070 relative to the baseline period (1960-1990) are given in Fig. 3.7. Gray grid cells specify the locations where the absolute uncertainty between ensemble projections is greater than the projected changes. It shows that there is low confidence in how precipitation will change over most of the region. The results show that for all seasons and most of the Indus Basin, future precipitation is highly uncertain. However, the climate models are confident that precipitation will increase in the UIB. The UIB has a great significance regarding hydrological features and hosts thousands of glaciers and high peaks. Therefore, precipitation and temperature changes will greatly impact the flow of Indus River. Furthermore, the results show that the mean annual precipitation over the UIB is projected to increase by 8% under RCP4.5 and 14% under RCP8.5 (Fig. 3.7 and 3.8).

The uncertainty between ensemble projections estimated in Fig. 3.8 shows that, under both scenarios, more uncertainty exists in the eastern parts of the UIB (Karakoram Range and Tibetan Plateau) and the coastal regions of Sindh and Baluchistan provinces.

The changes of spatial patterns of seasonal precipitation for the future period (2040-2070) relative to the historic baseline period (1960-1990) are given in the Fig. 3.9. The winter precipitation over UIB will increase by 3% under RCP4.5 and 8% under RCP8.5. The spring precipitation over UIB is projected to decrease by 4% under RCP4.5 and 0.1 % under RCP8.5. The precipitation in the summer season is likely to increase by 14% and 18% under RCP4.5 and RCP8.5 scenarios, respectively. The precipitation in the autumn season is projected to increase slightly by 5% under RCP4.5 and 24% under RCP8.5.

Several studies have evaluated the downscaled data over this region. Amin et al., (2010) have applied SimCLIM model to compute the projected changes over southern Punjab under RCP4.5, RCP6.0 and RCP8.5 for two years i.e. 2025 and 2050. They found that precipitation projected by ensemble models is highly uncertain while temperature projections showed 95% confidence for increase in temperature in this region. Saeed and Athar (2017) have analyzed 22 raw GCMs for precipitation and temperature projections over Pakistan region for three future time periods of 2025-2049, 2050-2074, and 2075-2099 under three SRES scenarios; A2, A1B, and B1, respectively. Their study showed that both temperature and precipitation are projected to be increase, and that the precipitation projections are not certain for winter season. In another study, Su et al. (2016) statistically downscaled 21 GCMs to 0.5° resolution for the IRB under three RCP scenarios for monthly precipitation and temperature and found that both are projected to increase in the future. Kazmi et al. (2015) have

employed the Statistical DownScaling Model (SDSM) to downscale daily minimum and maximum temperature data of 44 gage stations based on A2 and B2 scenarios. They concluded that the temperature would be increasing with more changes in the UIB. Likewise, Mahmood and Babel (2013) also applied SDSM tool to downscale maximum temperature, minimum temperature and precipitation in the upper Jhelum river basin under A2 and B2 scenarios and reported a significant increase in all the three variables in the future. A study conducted by Farooqi et al. (2005) assessed projected changes in Pakistan for the second half of the current century and found that spatially averaged precipitation will decrease in the future over most of Pakistan with slight increases over northern parts.

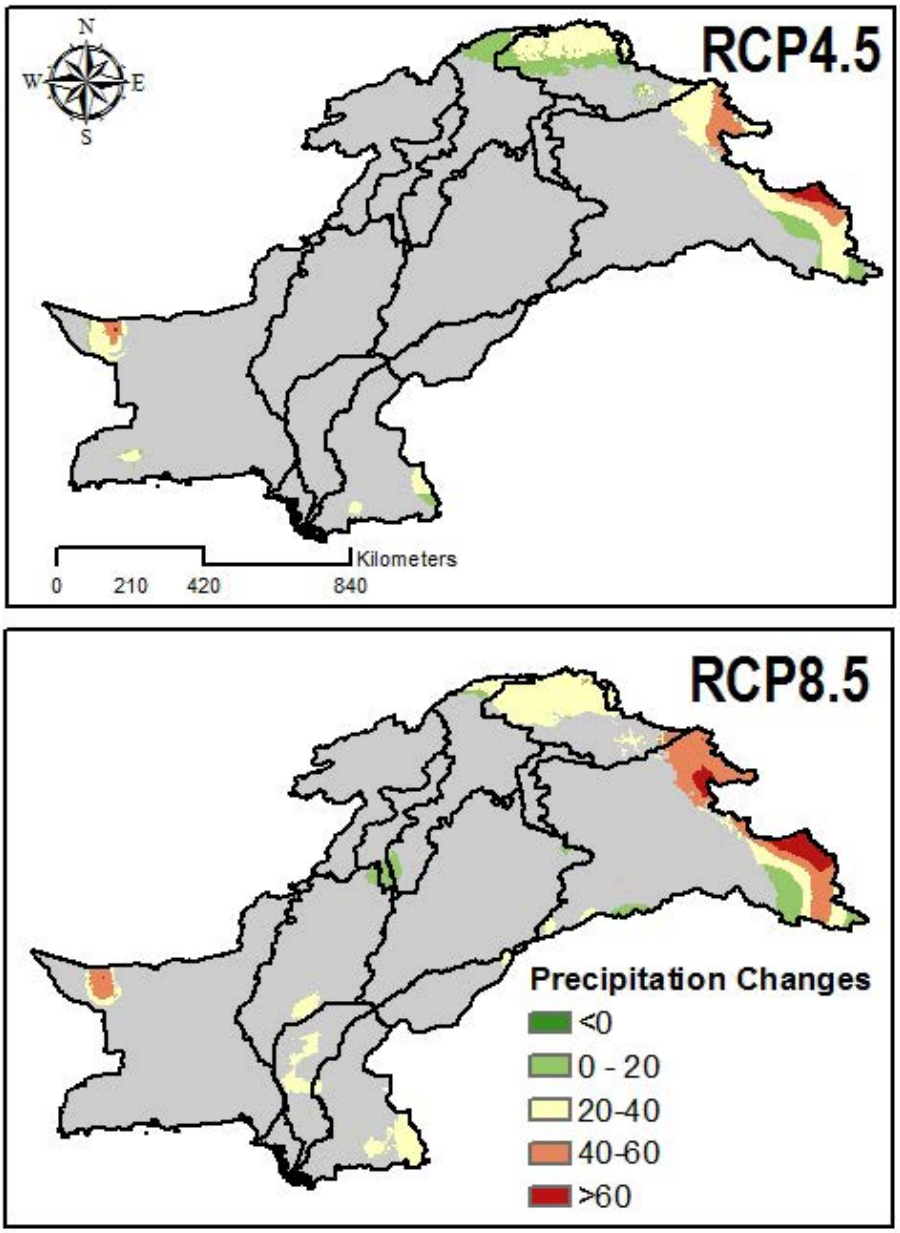

Fig. 3.7 Uncertainty in projected precipitation changes (%) for 2040-2070 relative to the historic time period (1960-1990)

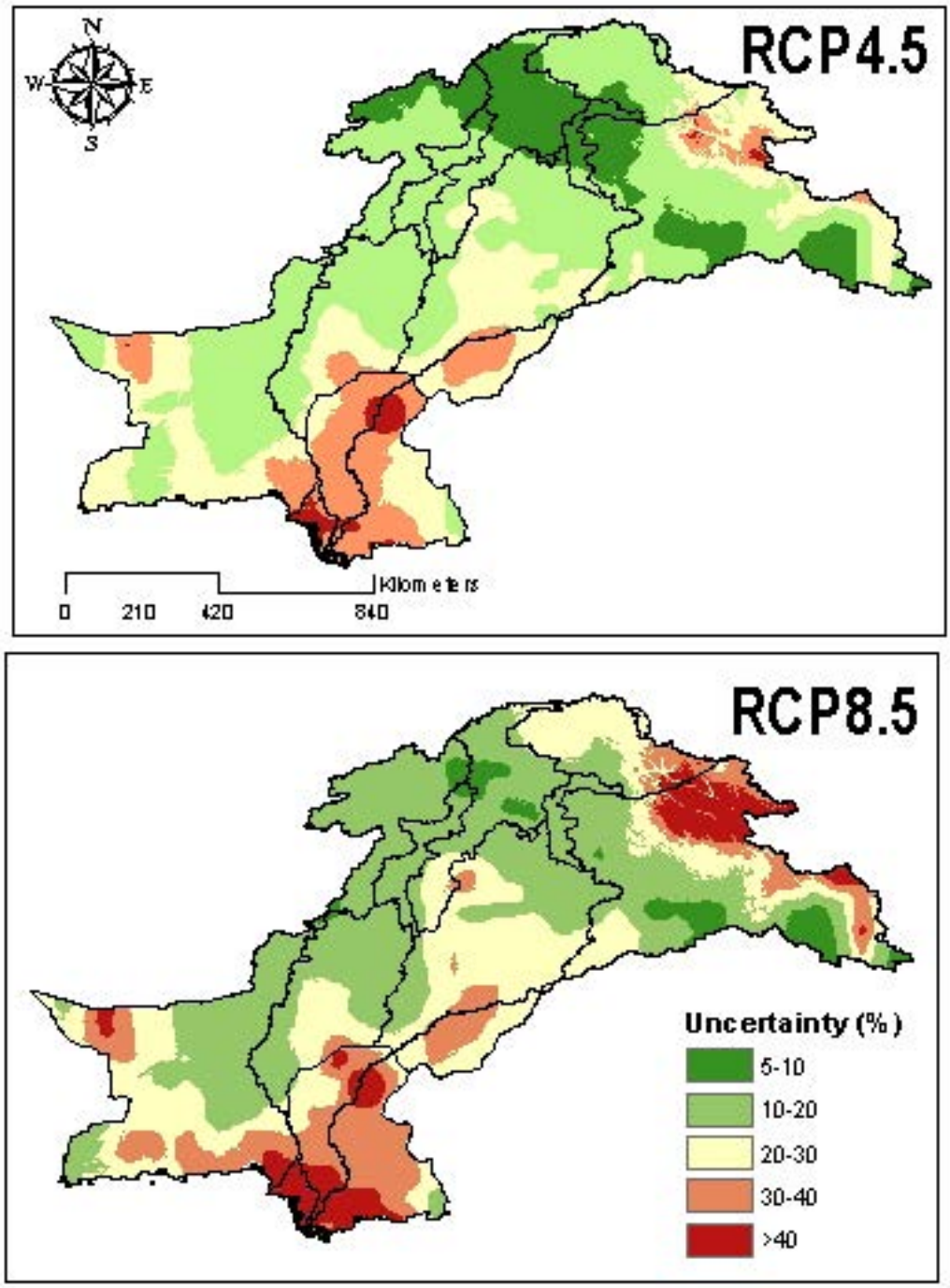

Fig. 3.8 **Projected changes in precipitation (%) for 2040-2070 relative to the historic time period (1960-1990).**

3.4 Results of Objective-3: Extreme Value Analysis

In this study, three return levels (10, 25, and 50years) have been chosen. The maps showing spatial distribution of the return levels are shown in the Fig. 3.10, 3.11and 3.12, respectively. Under 10, 25, and 50-year return periods, the extreme precipitation are estimated to be 600, 800, and 1000 mm/month, respectively. The results show that the extreme precipitation will occur at some eastern parts of the Indus Basin (includes Indian held Kashmir, Himachal Pradesh, a province of India), northern parts of IRB (includes Hunza Basin), upper arid regions of Punjab (includes Narowal, Sialkot, Gujrat, Jhelum, and Rawalpindi), some districts of Sindh Province (including Badin, Sujawal, Thatta, Tando Mohammad Khan, Khairpur and Sukkur), and eastern parts of Balochistan province.

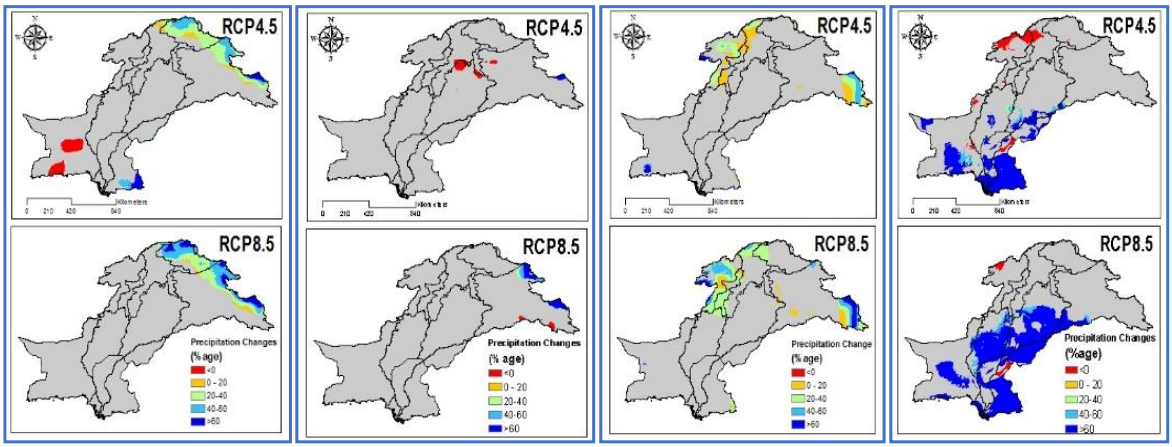

Fig. 3.9 Projected changes (in percentages) in precipitation for 2040-2070 relative to the historic time period (1960-1990). The first column from left shows winter, second column shows spring, third column shows summer and last column shows autumn seasonal changes. Gray grid cells specify the locations where the absolute uncertainty between ensemble projections is greater than the projected changes.

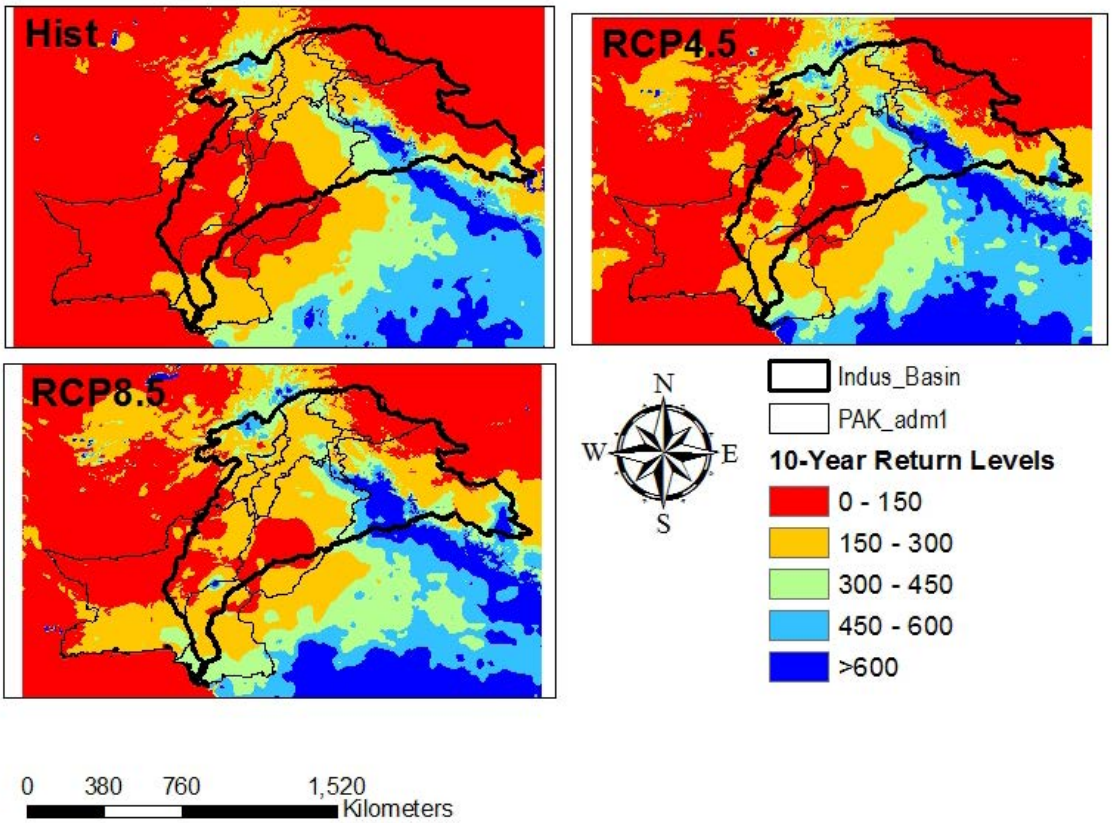

Fig. 3.10. Spatial distribution of 10-Year Return Levels over Indus River Basin and Pakistan for the historical, RCP4.5 and RCP8.5 scenarios.

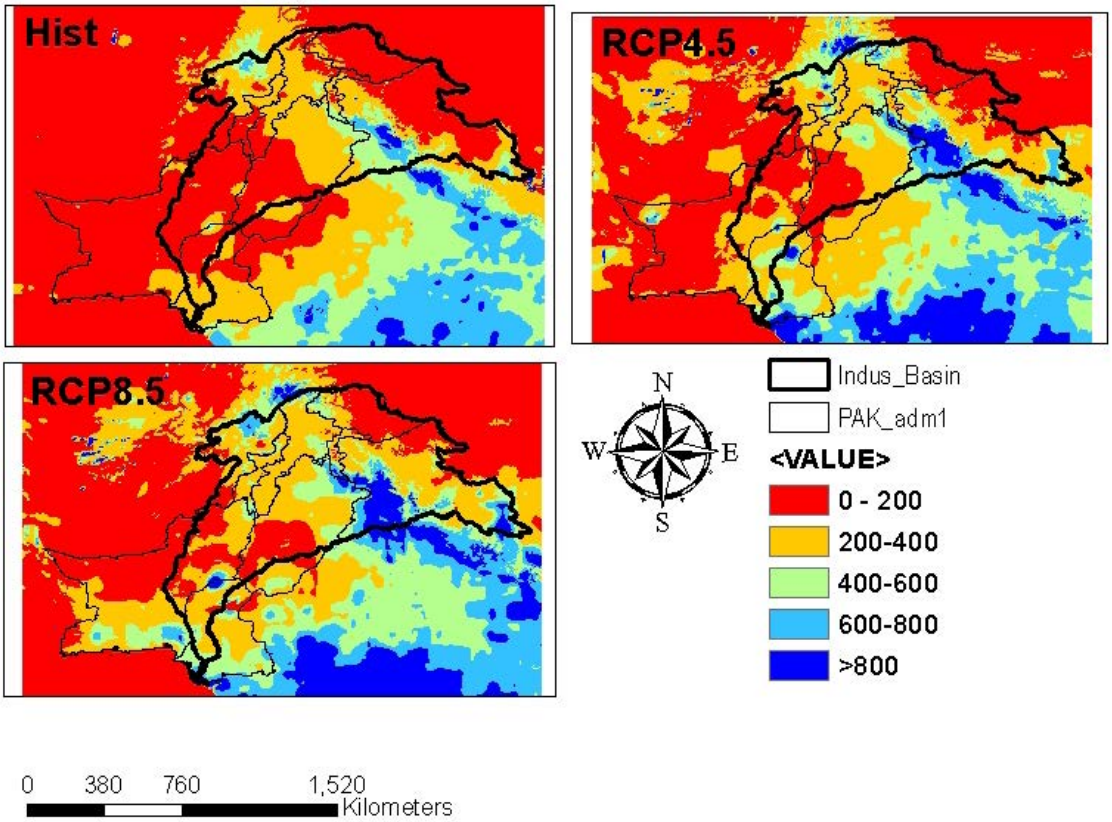

Fig. 3.11 Spatial distribution of 25-Year Return Levels over Indus River Basin and Pakistan for the historical, RCP4.5 and RCP8.5 scenarios.

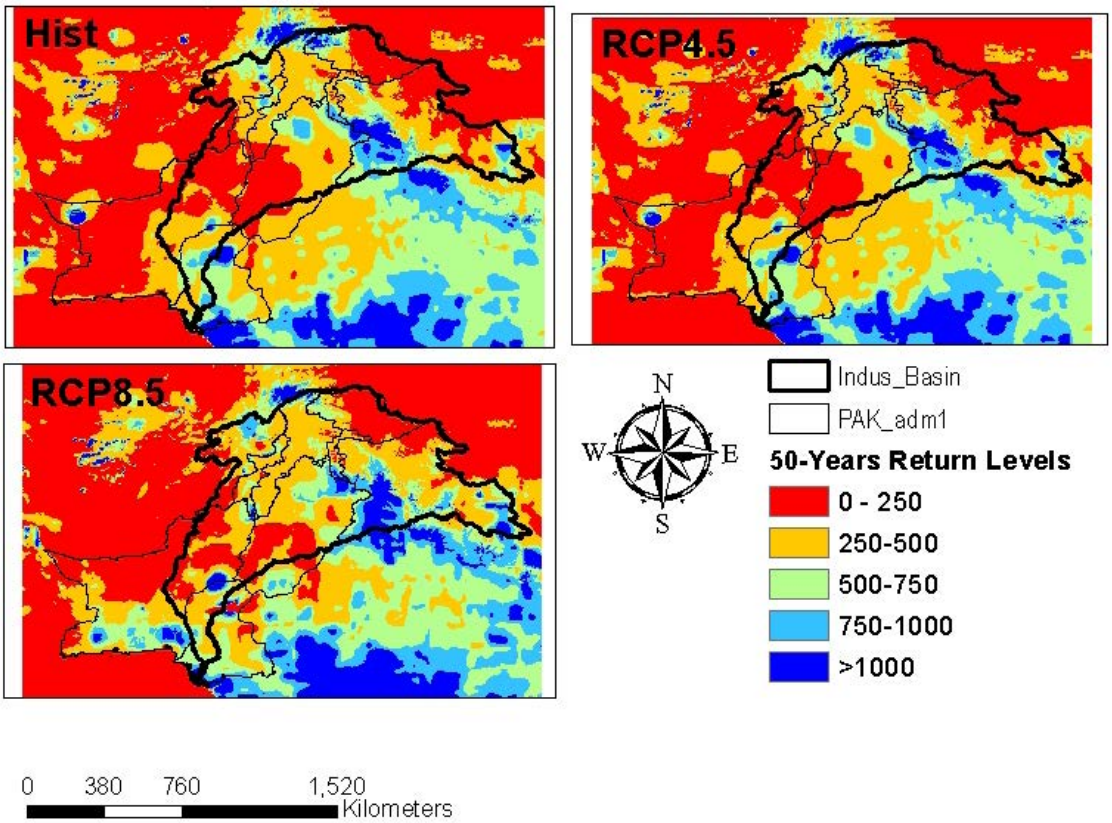

Fig. 3.12 Spatial distribution of 50-Year Return Levels over Indus River Basin and Pakistan for the historical, RCP4.5 and RCP8.5 scenarios.

3.5 Results of Objective-4: Web Portal

The sharing of the downscaled data is a significant component of this study. For this purpose, a data archive has been developed and it can be accessed through the following address:

http://ccipp.water.muet.edu.pk

3.5.1 User Registration:

The website requires user registration to download precipitation data of whole Indus Basin (Fig. 3.13).

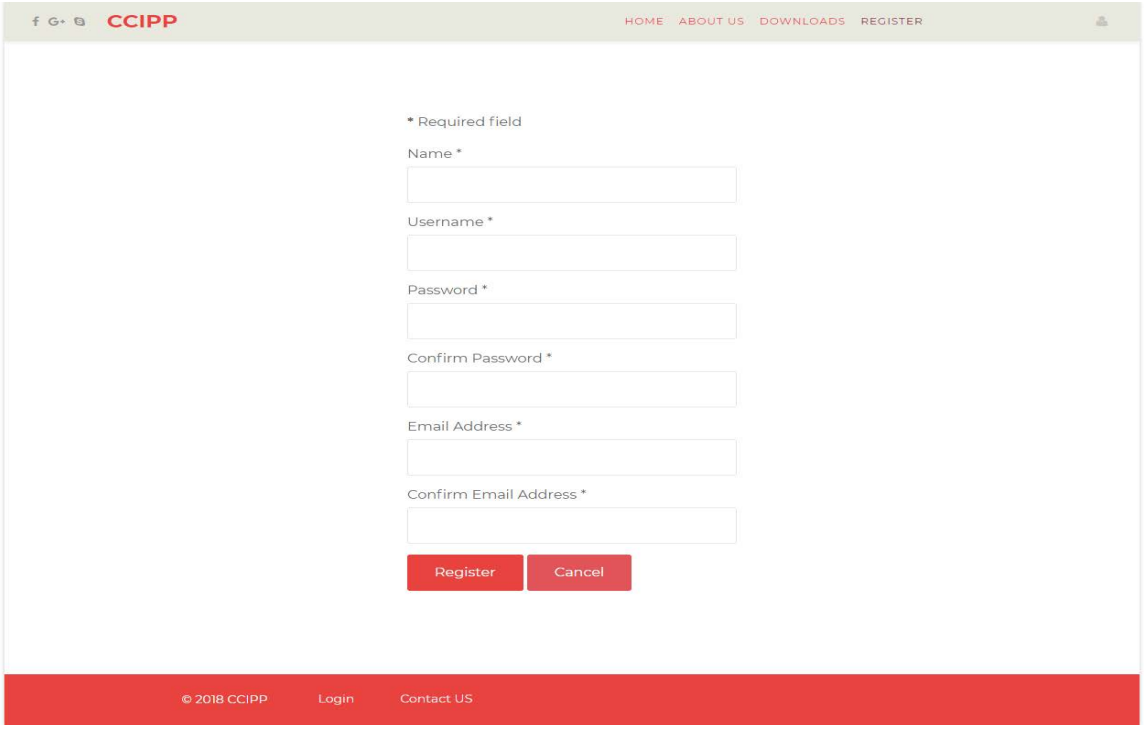

Fig. 3.13 Registration Portal

After submitting a user registration form, the user will receive an account activation email. Once a user account is activated, the user can download precipitation data from the website (Fig. 3.14 and 3.15).

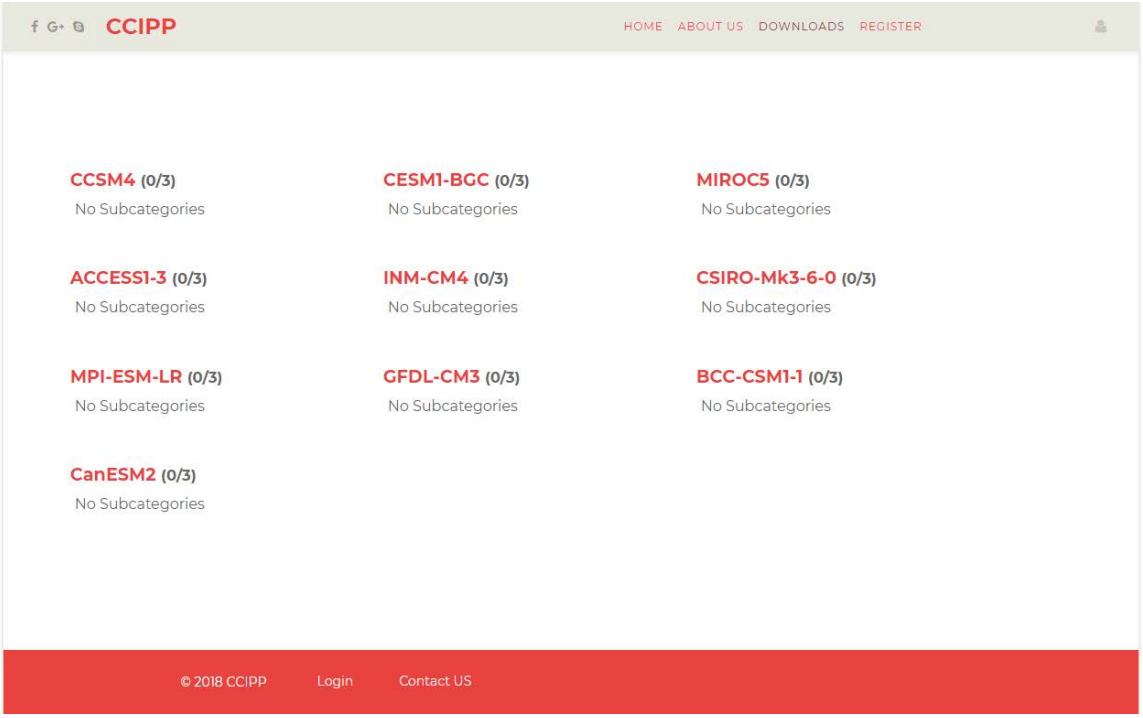

Fig. 3.14 Category view for downloads

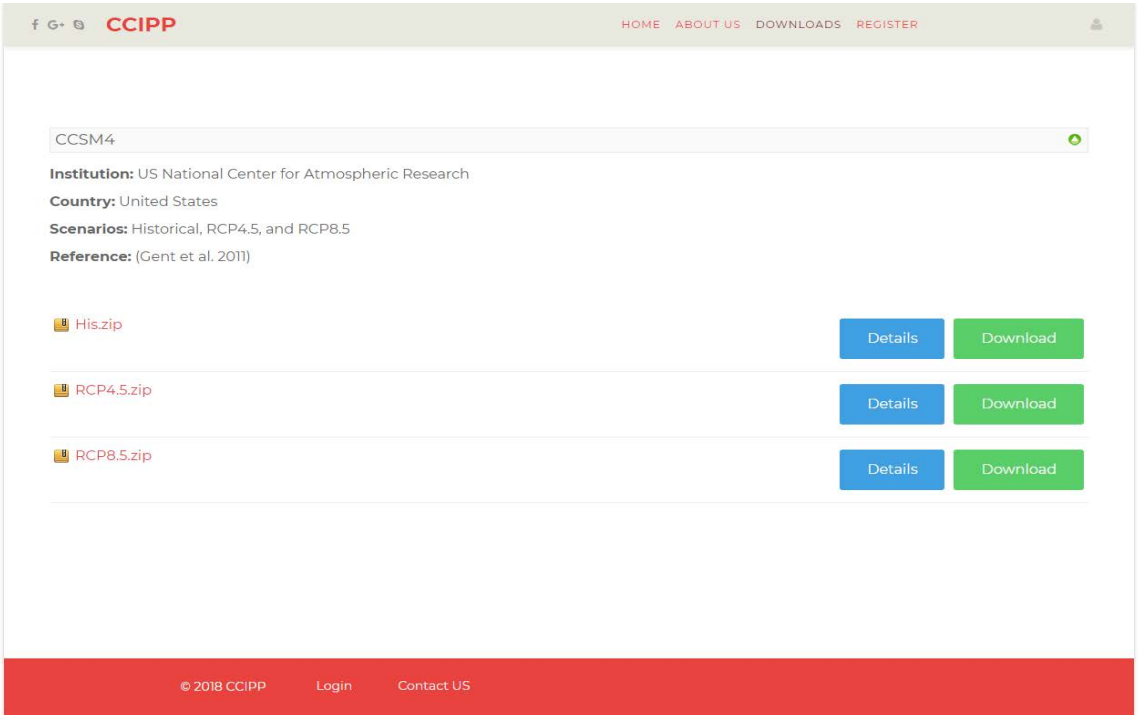

Fig. 3.15 File view for downloads

3.6 Dissemination of Research Results

A two-day national training workshop titled “Climate Change Projections and its Impact on Water System Performance” was organized on August 17-18, 2017 at the Center to disseminate the findings of this study, and advance engineers, scientists, water managers and experts’ capacity related to climate change impacts on system performance. The workshop was attended by stakeholders from different government and non-government organizations such as Pakistan Meteorological Department (PMD) Lahore, BUITEMS Baluchistan, PMAS Arid Agricultural University Rawalpindi, LUMS Lahore, Karakoram International University Gilgit, PCRWR, NED University Karachi, SIDA, WAPDA, Sindh Agricultural University Tandojam, QUEST Nawabshah, Civil Engineering Department MUET, Mechanical Engineering Department MUET, MUET Campus Khairpur Mirs, and USPCAS-W, MUET.

The workshop also stimulated innovation and build participants’ training strength in the area of climate impact studies by using different tools such as R statistical language and WEAP decision support tool. The detailed concept note of the workshop is attached in Appendix-A, and the list of participants is attached in Appendix B.

In addition, I also participated in a KTN (a local TV) talk with Faiz Khoso on Climate Change in Sindh through telephone.

3.7 Research Output

1. Research papers

One research paper titled **"Study of multi-model ensemble high-resolution projections of major climatic Variables over the Indus River Basin and Pakistan"** is under review in the Mehran University Research Journal of Engineering and Technology.

2. Ph.D. /M.Sc. thesis completed

Two students participated in this project and completed their MS degrees. Titles and research objectives of their thesis are given in the Appendix-C.

3. Presentations in the national or international conferences

I presented a paper on **"Analyze Future Rainfall Variations in All over Pakistan Based on Downscaled Climate Scenarios"** in the International Conference on "Science-Policy Conference on Climate Change (SP3C)", dated December 18-20, 2017 at Marriott Hotel, Islamabad.

4. Articles published in the Magazines/Newspapers

One article published in the Farming Outlook magazine under joint authership with Waqas Ahmed. Its title is "Integrated Management of Water Resources for Sustainable Growth".

3.9 Building Research Partnerships

This research project provided an opportunity to work in collaboration with Dr. Mohammad Reza Najafi, Assistant Professor, Department of Civil and Environmental Engineering, Western University, Canada, Dr. Courtenay Strong, Associate Professor, Department of Atmospheric Science, University of Utah, and Dr. Adam Kochanski, Research Assistant Professor, Department of Atmospheric Science, University of Utah. Court, Adam and Dars have sustained this research partnership to analyze the climate change impacts on water resources using more robust tools and models. Their partnership was able to secure more funds for research over the Indus River Basin (IRB) and Pakistan. They won two research projects titled "Changing climate in Pakistan: Food Security and Water Management Implications (provide high resolution climate simulations for complex terrain") and "Improved hydro-meteorological forecasts under changing climate using robust model techniques".

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Water resource managers and policy-makers need reliable projections of hydro-climatic conditions to develop sound water management policies. In this study, precipitation and mean temperature simulations from an ensemble of 10 GCMs that participated in the CMIP5 under two RCPs i.e. RCP4.5 and RCP8.5 are downscaled to a 30 arc second spatial resolution (approximately 1 km) through bias-correcting the simulations using quantile mapping and downscaling them with the delta method over IRB and Pakistan for the time frame of 2040-2070.

Many of the previous studies focus on projecting the climate variables but they do not explore the uncertainty of the projections. This study has explored both long-term average changes and the uncertainty of the projections. The analysis finds that the temperature changes are much more certain than precipitation. The projected changes in temperature are confident across the IRB and Pakistan. The projected changes in temperature are confident almost everywhere over the Indus Basin and Pakistan. Relative to the baseline period (1960-1990), the annual mean temperature in the IRB is projected to rise by 2°C under RCP4.5 and 2.6°C under RCP8.5. The changes are projected to be largest during the summer season in the UIB and Northern Western parts of Balochistan under both scenarios. However, projected changes in precipitation are highly uncertain, indicating that GCMs are not confident whether precipitation will increase or decrease over the region in the future. However, the climate models are confident that precipitation will increase in some areas of the UIB. The GCMs are also confident that the precipitation will increase in the lower Indus Basin (most of the areas of Sindh and Punjab) in the autumn season under RCP8.5. Computational resources limited this study to 10 GCMs. Studying the full set of models in the future would provide a more robust estimate of the ensemble statistics, but this 10-GCM subset suggests large uncertainty exists across the ensemble for precipitation. Moreover, dynamic downscaling may be performed for the UIB to provide more physically based outcomes for orographic precipitation and to explore the extent to which future climate change may depart from the historically derived empirical relationships utilized in statistical downscaling. This may be particularly informative where uncertainty in precipitation is higher, specifically southern parts and extreme northern areas of the region.

The potential changes in the precipitation and temperature are likely to affect the hydrological cycle, with serious implications on water resources and extreme events. In the UIB where both precipitation and temperature are consistently increasing, this

could cause glaciers to retreat at a faster rate and cause flooding in the downstream of the Indus Basin at the initial level, but in the long term, the glaciers could melt away with serious implications for the Indus River. In the lower Indus Basin, where precipitation is highly uncertain and the temperature will significantly increase (as indicated in the results section), a major impact on the hydrologic cycle would be increasing evapotranspiration due to large irrigated agriculture, which would put immense pressure on already limited water resources (Ahmed et al., 2014). These changes in climate could also affect the sowing of crops and timing of harvest in this region. Therefore, policy makers and water managers need to incorporate consideration of climate change projections in their future policies, and emphasize climate adaptation strategies such as water-saving technologies and climate-resilient crops.

4.2 Recommendations

This study has provided some useful information about climate projections of precipitation and temperature over the IRB and Pakistan. However, it has some limitation as well. First, we used 10 GCMs due to available computational resources but addition of more models will provide reliable projections, and help the researchers in quantifying uncertainty or errors more in detail. In addition, GCMs cannot capture orographic precipitation which emphasizes upon using dynamical downscaling models in the complex terrains to provide more physically based outcomes for orographic precipitation and to explore the extent to which future climate change may depart from the historically derived empirical relationships utilized in statistical downscaling. This may be particularly informative where uncertainty in precipitation is higher, specifically southern parts and extreme northern areas of the region. Lastly, the multi-model ensemble methods such as Bayesian Model Averaging (BMA) may be used to quantify uncertainty in the models and get reliable predictions. Therefore, future studies are encouraged to incorporate one or all of the above recommendations, based on the available resources, to improve the projections and reduce the uncertainty of the models.

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Appendix A: Concept Note for the Training Workshop

Two Days Training Workshop on

Climate Change Projections and its Impact on Water System Performance

To be held at USPCASW, MUET

From August 17-18, 2017

Instructors:

Ghulam Hussain Dars, USPCAS-W, MUET

Waqas Ahmed, USPCAS-W, MUET

Rakhshanda Bano, USPCAS-W, MUET

Location: Geographic Information System Laboratory, USPCAS-W, MUET.

Goal and Objectives:

The goal of this workshop is to advance engineers, scientists, water managers and experts' capacity related to climate change impacts on system performance. The workshop will stimulate innovation and build participants' training strength in the area of climate impact studies by using different tools such as R statistical language and WEAP decision support tool. Foundational concepts, tools and methods, and case studies will be covered. Participants will also be engaged in hands-on activities leading to post-workshop.

The objectives of the workshop are:

- To Explore large climate datasets in R.
- Describe climate projections for different climate variables.
- Explain climate vulnerability assessment techniques and tools.
- Formulate and calculate water system performance measures and indicators using WEAP.
- Apply data and computational tools for climate vulnerability assessment and adaptation planning.

The outcomes of the workshop are expected to be:

- Improved comprehension of climate projections and vulnerability assessment and techniques across a range of applications.
- Increased knowledge of data sources and evaluation measures used in climate vulnerability studies.
- Awareness of data analysis, programming, modeling, computational and other tools for climate vulnerability assessment.

Participanting Organizations:

PMD/Research Center

BUITEMS, Baluchistan

PMAS Arid Agricultural University, RWP

LUMS, Lahore

Karakoram International University

PCRWR

NED University

SIDA,

WAPDA

Sindh Agricultural University, Tando Jam

QUEST, Nawabshah

Civil Engineering Department, MUET

Mechanical Engineering Department, MUET

MUET Campus, Khairpur Mirs

USPCAS-W, MUET

Appendix B: Participants of the Workshop

Attendance Sheet of Participants with their Contact Details

Name	Designation	Organization	Mobile #	Email Address
Mr. G. H. Dars	Asstt. Professor	USPCAS-W, MUET	+92-333-2806506	ghdars.uspcasw@faculty.muet.edu.pk
Ms. Rakhshanda Bano	Asstt. Professor	USPCAS-W, MUET	+92-347 597 6468	rbano.uspcasw@faculty.muet.edu.pk
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Dr. Zehra Waheed	Asstt. Professor	SDSB, LUMS	+92-323-8862112	zehra.waheed@lums.edu.pk
Prof. Dr. Moazzam Nizami	Director IMARC	Karakoram Int. University Gilgit	+92-321-5029381	director.imarc@kiu.edu.pk
Dr. Noman Qadeer Soomro	Asstt. Professor	MUET, SZAB Campus	+92-331-3121638	nomansoomro@muetkhp.edu.pk
Dr. Arjumand Zaidi	Sr. Research Fellow	USPCAS-W, MUET	+92-333-2385185	arjzaidi@gmail.com
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Mr. Saad-Ul-Haque	Lecturer	IST, Karachi	+92-333-2385185	saad_haq@hotmail.com

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Dr. Kanya Lal Khatri	Associate Professor	MUET, Jamshoro	+92-308-3060990	Rajaln@yahoo.com
Mr. M. U. Mirjat	Asstt. Professor	SAU, Tandojam	+92-307-3713228	mumirjat@yahoo.com
Mr. Rajesh K. Soothar	Asstt. Professor	SAU, Tandojam	+92-331-3806525	rk_engr195@yahoo.com

Mr. Waqas Ahmed	Asstt. Professor	USPCAS-W, MUET	+92-303-3998170	wapathan.uspcasw@faculty.muet.edu.pk
Mr. Nabi Bux Bhatti	Ph.D. Scholar	USPCAS-W, MUET	+92-302-2707196	nabibux123@gmail.com
Mr. Syed Ahsan Ali	Electronic Engineer	PMD	+92-315-5145014	ahsan@pmd.gov.pk
Dr. Faheem Shaikh	Assistant Professor	MUET, Jamshoro	+92-333-7281311	engrfaheemshaikh@gmail.com
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Mr. S. Zohaib Habib	Assistant Director	DRIP	+92-332-1124723	s.zohaibhabib@gmail.com
Mr. Ali Akbar	Research Scholar	NUST	+92-334-2132785	aliakbarnust@gmail.com
Mr. Shan-e-Haider	MS Student	USPCAS-W, MUET	+92-300-9252564	shanhydersoomro@yahoo.com
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Hafiz Usama Imad	Ms Student	USPCAS-W	+92-345-9078157	usamaimad@yahoo.com
Muhammad Waqar Khan	Assistant Engineer	PHED	+92-300-93154515	Waqarkhan_65@yahoo.com
Zulfiqar Ali	Sub-Engineer	PHED	+92-300-3142990	

Syed Safdar Ali Shah	Sub-Engineer	PHED	+92-335-5499090	
Shakeel Ahmed	Sub-Engineer	PHED	+92-336-900909	
Ajaz Ali Malik	Assistant Engineer	PHED	+92-300-2682877	
Abdul Ghani Soomro	Phd Scholar S.S.O	USPCASW, MUET Jamshoro. PARC	+92-300-3041972	Ag2005parc@gmail.com
Aneela Memon	Phd Scholar	USPCASW, MUET Jamshoro. PARC	+92-333-2722273	aneelahameem@gmail.com

Workshop Program

Day 1		
Time	**Detailed Description**	**Instructor/Lead**
9:00 – 9:05	Recitation of Holy Quran	
9:05 – 9:20	Welcome Remarks	Dr. Bakhshal Lashari, PD, USPCAS-W
09:20 – 9:45	Overview of the USPCAS-W	Dr. Rasool Bux Mehar, DD Academics and Research
9:45 – 10:15	Workshop Introduction	Waqas Ahmed
10:15 – 11:00	Participants' Presentations describing their/Institutes' research agenda	Waqas Ahmed, Rakhshinda, Ghulam Hussain Dars
11:00 – 11:30	Networking/Tea Break	
11:30 – 13:30	Participants' Presentations describing their/Institutes' research agenda	Workshop participants
13:30 – 14:30	Lunch/Prayer Break	
14:30 – 15:00	Introduction to Climate Projections	G H Dars
15:00 – 16:00	Impact Lab-1 – Climate Change Projections – Use of web-based tools to analyze climate projections of various climate variables	G H Dars
18:00 – 21:00	Hyderabad Tour and Dinner at Hyderabad	W A, R Bano and G H Dars
Day 2		
09:00 – 10:00	Impact Lab-2 – Exploring large climate datasets in R	G H Dars
10:00 – 10:30	Climate Vulnerability Assessment Concepts and Approaches	Miss R Bano
10:30 – 11:00	Climate Vulnerability Indicators and Performance Metrics	W A, R Bano
11:00 – 11:30	Networking/Tea Break	
11:30 – 13:00	Impact Lab-3: WEAP in one hour	W A
13:00 – 14:00	Lunch/Prayer Break	
14:00 – 15:30	Impact Lab-4: System Analysis using WEAP	W A and Miss R Bano
15:30 – 16:00	Group Discussion – Data and Modeling need assessment for the water system under climate uncertainties	W A, R Bano and G H Dars
16:00 – 16:30	Concluding and Certificate award ceremony	G H Dars

Appendix C: Details of Students who participated in the Project

Two students did their MS while working for this project, as detailed below:

MS Student 1

Name	Muhammad Touseef (15-MS-IWRM-07)
Supervisor Name	Ghulam Hussain Dars, Assistant Professor, USPCAS-W, MUET, Jamshoro
Degree Program	MS in Integrated Water Resources Management
Email	engrtouseef3347@gmail.com
Research Project Title	Predicting the Climate Change Impacts on Future Precipitation Trends in Pakistan Using CMIP5 Climate Scenarios.
Research Objectives	
☐ To downscale 08 GCMs which participated in the CMIC-5 under two emission scenarios of RCP8.5 and RCP4.5. ☐ To estimate the projected seasonal rainfall i.e. Summer (JJAS) and Winter (DJF) precipitation patterns. ☐ To estimate the projected differences in future (2040-2070) and historic (1960-1990) simulations.	

MS Student 2

Name	Mehran Sattar (16-MS-IWRM-05)
Supervisor Name	Ghulam Hussain Dars, Assistant Professor, USPCAS-W, MUET, Jamshoro
Degree Program	MS in Integrated Water Resources Management
Email	Mehran4015@gmail.com
Research Project Title	Application of two statistical downscaling methods for future temperature projections in Pakistan.
Research Objectives	
☐ To bias-correct and downscale 08 GCMs for temperature variable of 31 years historical-period (1960-1990) for whole Pakistan. ☐ To bias-correct and downscale 08 GCMs for temperature variable for 31 years future period (2040-2070) under RCP4.5 & 8.5 scenarios for whole Pakistan. ☐ To evaluate the performance of two statistical downscaling methods i.e. QMD method and Delta Method (DM) over the complex terrain of Pakistan for temperature variable.	

Workshop Photos Gallery


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WATER
Thematic Research Areas
*Applied geology, Geohazards and Sustainable
Mineral source development
*Atmospheric Science & Climate Change
*Forestry & Climate Change
*Biodiversity Conservation
*Water Resource Management
*Soil Science


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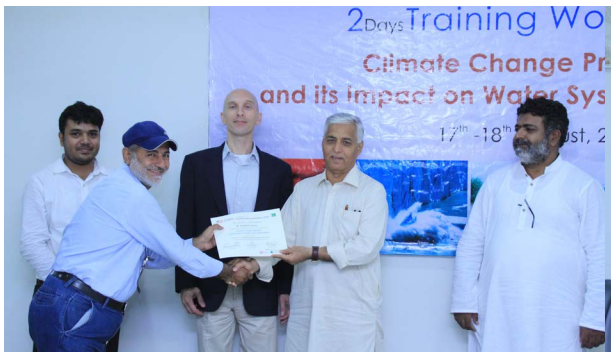
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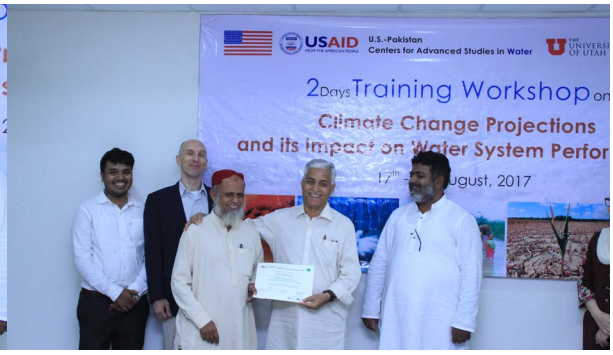
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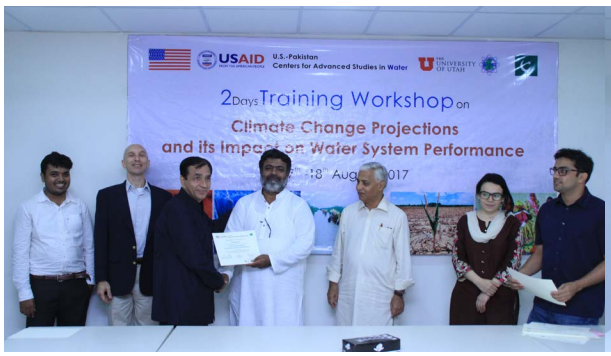
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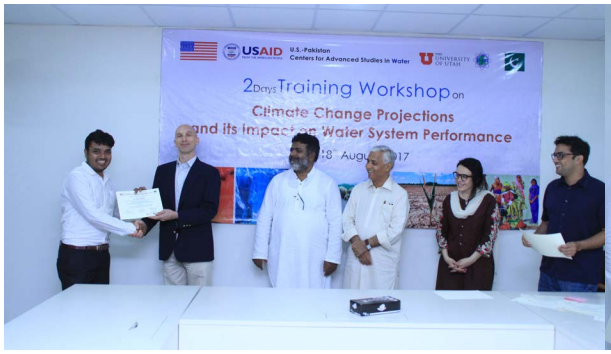
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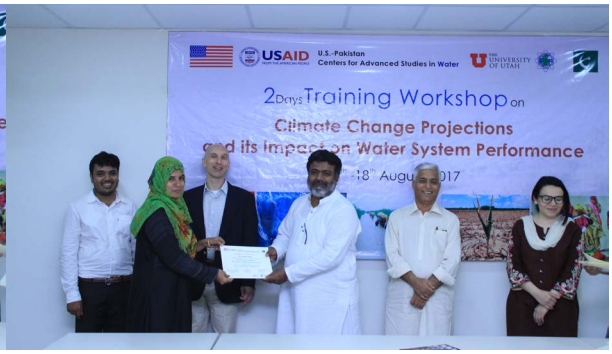
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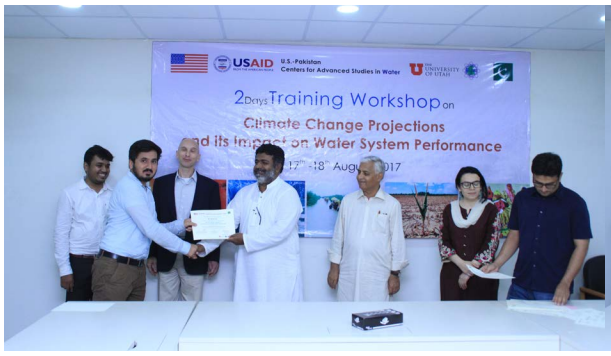
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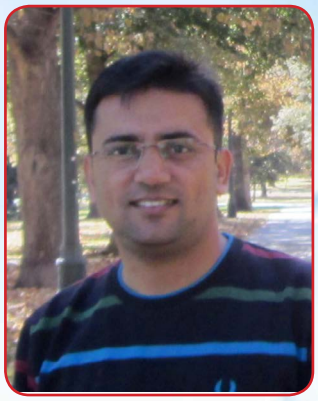
About the Authors



Ghulam Hussain Dars joined the U.S.-Pakistan Center for Advanced Studies in Water (USPCAS-W), Mehran University of Engineering and Technology, Jamshoro in May 2015 as Assistant Professor in Integrated Water Resources Management (IWRM) Department. Prior to this, he was working as Research Officer (now designated as Assistant Chief) in Water Resources Section, Planning Commission, Government of Pakistan, Islamabad. He has also worked as Water Management Officer (WMO) in the Agriculture Department, Government of Sindh. Mr. Dars is a professional engineer and an expert with 15 years experience in the planning, research in management of water resources systems, besides teaching Mr. Dars received a Fulbright Scholarship for MS degree in Civil and Environmental Engineering from Portland State University, Oregon, United States. His MS thesis focused on "Climate Change Impacts on Precipitation Extremes over the Columbia River Basin Based on Downscaled CMIP5 Climate Scenarios". Mr. Dars teaches various subjects at the USPCAS-W including Climate and Water, Hazards Planning and Risk Management and Catchment Hydrology. Moreover, he has published a number of research articles in national and international journals. He uses state-of-the-art tools (WRF-Hydro, SWAT, Matlab) to conduct research over Upper Indus Basin. His research interests include: Climate change impacts on water resources, statistical and dynamical downscaling, drought monitoring and forecasting, flood forecasting, uncertainty and risk analysis.

Dr. Mohammad Reza Najafi is currently Assistant Professor at the Department of Civil and Environmental Engineering, Western University, Canada. Previously, he has worked as Research Scientist, Sessional Instructor and Postdoctoral Fellow at the University of Victoria, BC. Besides, he has served as Postdoctoral Researcher at Byrd Polar Research Center, The Ohio State University, USA and Graduate Research Assistant at the Department of Civil and Environmental Engineering, Portland State University, USA. His research interests include Watershed Hydrology, Hydroclimatic Extremes, Climate Change Impact Assessment, Detection and Attribution, Infrastructure Risk and Resilience, Regional Frequency Analysis, Multi-Modeling and Uncertainty Assessment, Downscaling and Bias Correction, Hydrologic Forecasting, Remote Sensing, Machine Learning, Physical/Numerical Modelling and Design.

Main thrust of Applied Research component of the Water Center is to stimulate an environment that promotes multi-disciplinary research within the broader context of water-development nexus to support evidence-based policy making in the water sector. This is pursued using the framework provided by the six targets of the Sustainable Development Goal on Water i.e. SDG-6.

Contact:

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