UNIVERSITI PUTRA MALAYSIA

POTENTIAL IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES OF HARO RIVER WATERSHED IN PAKISTAN

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By

SAIMA NAUMAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To my lovely daughter and beloved family; without their confidence, encouragement and love, I would never have been able to reach this milestone.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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March 2019

Chairman : Zed Diyana binti Zulkafli, PhD
Faculty : Engineering

Climate change has resulted in changes in the hydrological fluxes and water distribution across the globe. Pakistan, which is home to almost 200 million people, is a particularly vulnerable country due to poverty, population growth and lack of resources. However, studies quantifying future climate change on water catchment regions in the country are limited due to multiple issues with data and modelling uncertainty. This research aims to quantify projected changes in the climate and its consequent impact on the streamflows of Haro River, the source of water for Khanpur Dam. Firstly, the climate change input is obtained by selecting one out of five downscaled General Circulation Model (GCM) outputs based on the highest coefficient of determination (R^2) value from a regression against observed meteorological dataset. The baseline and future meteorological parameters from the selected GCM are then bias corrected using the observed meteorological dataset. For future climate, two Radiative Concentration Pathways (RCP) 4.5 and 8.5 are considered. at two stations, namely Murree (P-1) and Islamabad (P-2). Next, a hydrological model for the basin is developed using the Soil and Water Assessment Tool (SWAT) to integrate the meteorological data and produce simulation of streamflows for the baseline (1976-2005) and future periods (2006-2095). The calibration, validation, uncertainty analysis and the sensitivity analysis of the SWAT Model is conducted in Sequential Uncertainty Fitting 2 (SUFI-2) algorithm. Finally, the change in streamflows is projected through a relative comparison between baseline and future flows on monthly and seasonal scale. The study found that the maximum (minimum) temperature at P-1 is expected to increase by 3.1°C (3.2°C) under RCP 4.5 and 4.0°C (4.3°C) under RCP 8.5 in the future. Precipitation is expected to rise from 8.9% under RCP 4.5 to 14.3% under RCP 8.5. Similarly, at P-2, the maximum (minimum) temperature is anticipated to increase by 3.3°C (3.3°C) under RCP 4.5 and 4.1°C (4.2°C) under RCP 8.5. Precipitation is projected to increase between 15.4% (RCP 4.5) and 23.1% (RCP 8.5) compared to the baseline scenario. SWAT produced good model performance with Nash Sutcliffe Efficiency (NSE) and R^2 values of 0.80 (0.77) and 0.82 (0.77) respectively during the calibration (validation) period. Simulation of baseline and future streamflows using the calibrated SWAT indicates an increase from

average annual baseline streamflows of 7.7 m^3/s to 8.7 m^3/s (9.3 m^3/s) under RCP 4.5 (RCP 8.5). Maximum streamflows expected during the month of July, are projected to increase from baseline streamflow of 21.3 m^3/s to 28.2 m^3/s (32.6 m^3/s) under RCP 4.5 (RCP 8.5). In summer season, compared to baseline streamflows of 13.1 m^3/s, the streamflows are expected to be 4.2 m^3/s (6.8 m^3/s) higher under RCP 4.5 (RCP 8.5). This study will help the policy makers in conceiving prudent schemes for effective utilization of water supply throughout the year. The new policies may focus on increasing water storage capacity of the dam reservoir in the future resulting from projected increase in streamflows.

Abstak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

IMPAK POTENSI PERUBAHAN IKLIM PADA SUMBER AIR LEMBANGAN SUNGAI HARO DI PAKISTAN

Oleh

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Perubahan iklim telah menyebabkan perubahan kitaran hidrologi dan taburan air di seluruh dunia. Pakistan yang dihuni hampir 200 juta penduduk, adalah sebuah negara yang paling terdedah kepada kesan perubahan iklim kerana kemiskinan, pertumbuhan penduduk dan kekurangan sumber asli. Walau bagaimanapun, kajian penyelidikan yang mengukur kadar perubahan iklim masa hadapan di kawasan tadahan air di negara ini adalah terhad disebabkan oleh pelbagai masalah dengan ketidakpastian data dan model. Penyelidikan ini bertujuan untuk mengukur anggaran perubahan iklim dan kesannya terhadap aliran Sungai Haro, sumber air untuk Empangan Khanpur. Pertama sekali, input perubahan iklim diperolehi dengan memilih satu daripada lima output General Circulation Model (GCM) yang telah diturunkan sekala berdasarkan koefisien penentuan (R^2) daripada regresi dengan dataset pemerhatian meteorologi. Bias dalam parameter meteorologi tempoh dasar dan masa hadapan dari GCM terpilih kemudiannya diperbetulkan dengan menggunakan set data meteorologi menggunakan. Untuk iklim masa hadapan, dua Radiative Concentration Pathways (RCP) 4.5 dan 8.5 dipertimbangkan. Prestasi pembetulan bias dinilai berdasarkan purata bulanan, persentil ke-10 dan ke-90, dan sisihan piawai di dua stesen, iaitu Murree (P-1) dan Islamabad (P-2). Model hidrologi untuk kawasan tadahan air dibangunkan menggunakan Soil and Water Assessment Tool (SWAT) untuk mengintegrasikan data meteorologi untuk menghasilkan simulasi aliran sungai untuk tempoh dasar (1976-2005) dan masa hadapan (2006-2095). Kalibrasi, pengesahan, analisis ketidakpastian dan analisis kepekaan model SWAT dijalankan menggunakan algoritma Sequential Uncertainty Fitting 2 (SUFI-2). Akhir sekali, perubahan aliran aliran dijangka melalui perbandingan relatif antara tempoh dasar dan masa hadapan pada skala bulanan dan bermusim. Kajian mendapati suhu maksimum (minimum) di P-1 dijangka berubah sebanyak 3.1°C (3.2°C) di bawah RCP 4.5 dan 4.0°C (4.3°C) di bawah RCP 8.5 pada masa akan datang. Hujan dijangka meningkat daripada 8.9% di bawah RCP 4.5 hingga 14.3% di bawah RCP 8.5. Begitu juga pada P-2, suhu maksimum (minimum) dijangka berubah sebanyak 3.3°C (3.3°C) di bawah RCP 4.5 dan 4.1°C (4.2°C) di bawah RCP 8.5. Hujan dijangka meningkat daripada 15.4% (RCP 4.5) kepada 23.1% (RCP 8.5) berbanding dengan

senario dasar. SWAT menghasilkan prestasi model yang baik dengan Nash Sutcliffe Kecekapan (NSE) dan nilai R^2 masing-masing 0.80 (0.77) dan 0.82 (0.77) semasa tempoh penentukuran (pengesahan). Simulasi baseline dan arus aliran masa depan menggunakan SWAT yang ditentukur menunjukkan peningkatan purata tahunan arus aliran dasar dari 7.7 m^3/s ke 8.7m^3/s (9.3 m^3/s) di bawah RCP 4.5 (RCP 8.5). Aliran maksimum yang dijangkakan pada bulan Julai, dijangka meningkat dari aliran dasar 21.3 m^3/s ke 28.2 m^3/s (32.6 m^3/s) di bawah RCP 4.5 (RCP 8.5). Pada musim panas, berbanding arus aliran dasar 13.1 m^3/s, arus aliran dijangka menjadi 4.2 m^3/s (6.8 m^3/s) lebih tinggi di bawah RCP 4.5 (RCP 8.5). Kajian ini akan membantu penggubal dasar yang terlibat untuk merangka skim yang berhemat bagi penggunaan bekalan air secara berkesan untuk sepanjang tahun. Dasar-dasar baru mungkin boleh memberi tumpuan kepada peningkatan kapasiti simpanan air empangan di masa depan berikutan daripada peningkatan aliran aliran yang dijangka.

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The thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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a.m.s.l	above mean sea level
AAT	All-at-a-time Sensitivity Analysis
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
ARS	Agriculture Research Services
BCSD	Bias Corrected Spatial Disaggregation
CCS	Climate Change Signal
CFSR	Climate Forecast System Reanalysis
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CSI	Consortium for Spatial Information
CV	Coefficient of Variance
DC	Delta Change Approach
DEM	Digital Elevation Model
DM	Distribution Mapping
DSMW	Digital Soil Map of the World
ET	Evapotranspiration
FAO	Food and Agriculture Organization
GCM	General Circulation Model
HBV	Hydrologiska Byrans Vattenbalansavdelning
HRU	Hydrologic response Unit
HWSD	Harmonized World Soil Database
IIASA	International Institute for Applied System Analysis

IPCC	Intergovernmental Panel on Climate Change
JGCRI	Joint Global Change Research Institute
LOCI	Local Intensity Scaling
LS	Linear Scaling
MAE	Mean Absolute Error
NASA	National Aeronautics And Space Administration
NCEP	National Centre for Environmental Prediction
NESPAK	National Engineering Services Pakistan
NEX-GDDP	NASA Earth Exchange Global Daily Downscaled Projections
NIES	National Institute for Environment Studies
NPS	Non Point Sources
NSE	Nash Sutcliffe Efficiency
OAT	One-at-a-time Sensitivity Analysis
P_{BIAS}	Percent Bias
PMD	Pakistan Meteorological Department
PT	Power Transformation
QM	Quantile Mapping
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SCS-CN	Soil conservation Service Curve Number
SDG	Sustainable Development Goals
SHE	Systéme Hydrologique Européen
SRES	Special Report on Emission Scenarios
SRTM	Shuttle Radar Topography Mission

SSP	Shared Socioeconomic Pathways
SUFI-2	Sequential Uncertainty Fitting version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Program
SWHP	Surface Water Hydrology Project
SWM	Stanford Watershed model
TAR	Third Assessment Report
TOP MODEL	TOPography based Hydrologic Model
UNEP	United Nations Environment program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department for Agriculture
UTM	Universal Transverse Mercator
VS	Variance Scaling
WAPDA	Water and Power Development Authority
WARMF	Watershed Analysis Risk Management Framework
WGCM	Working Group on Coupled Modelling
WGS	Word Geodetic System
WMO	World Meteorological Organization
WYLD	Water Yield

LIST OF NOTATIONS

X_{10}	10th Percentile
X_{90}	90th Percentile
μ	Mean
σ	Standard Deviation
n	Total number of observations
P_o	Observed Precipitation
P_m	Model simulated precipitation
S	Mann Kendall test statistic
V(S)	Variance for the test statistic
Z_s	Standard test statistic
H_O	Null hypothesis
H_a	Alternative hypothesis
α	Significance level
$P_{sim(bc)}$	Bias corrected monthly precipitation
$T_{sim(bc)}$	Bias corrected monthly temperature
P_{sim}	Raw RCM simlated precipitation
T_{sim}	Raw RCM simlated temperature
P_{obs}	Observed precipitation
T_{obs}	Observed temperature
P_{his}	RCM simulated historical precipitation
T_{his}	RCM simulated historical temperature
SW_t	Final soil water content
Swo	Initial soil water content

R_{day}	Amount of precipitation
Q_{surf}	Amount of surface runoff
E_a	Amount of evapotranspiration
w_{seep}	Amount of water entering the vadose zone from the soil profile
Q_{gw}	Amount of return flow
I_a	Initial abstarctions
S_t	Retention parameter
CN	Curve Number
q_{peak}	Peak runoff rate
α_{tc}	Fraction of daily rainfall occuring during time of concentration
A	Area of subbasin
t_{conc}	Time of concentration for the subbasin
t_{ov}	Time of concentration for the overland flow
t_{ch}	Time of concentration for the channel flow
λ	Latent heat flux density
Ea	Depth rate evaporation
Δ	Slope of the saturation vapor pressure-temperature curve
H_{net}	Net radiation
G	Heat flux density to the ground
ρ_{air}	Air density
c_p	Specific heat at constant pressure
e_z^o	Saturation vapour pressure of air at height z
e_z	Water pressure of air at height z
Γ	Psychrometric constant

r_c	Plant canopy resitance
r_a	Diffusion resistance of the air layer
V_{in}	Inflow volume
V_{out}	Outflow volume
ΔV_{stored}	Change in storage volume
TT	Travel time
V_{stored}	Storage volume
q_{out}	Discharge rate
SC	Storage coefficient
Δt	Length of time step
$q_{out,1}$	Outflow rate at the beginning of time step
$q_{out,2}$	Outflow rate at the end of of time step
$q_{in,avg}$	Average inflow rate during the time step
G	Value of objective function
α_r	Regression constant
B	Coefficient of parameters
R^2	Coefficient of determination
Q_m	Measured discharge
Q_s	Simulated discharge

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the past few decades, multiple factors have contributed in damaging the earth's natural cycle. Overall, the global energy balance is facing disruption due to an alarming increase in urbanization, higher rate of population growth and unplanned exhaustion of non-renewable resources (Khattak , Babel and Sharif, 2011; Chu, Xia, Xu and Singh, 2010). These changes have, in turn, impacted the natural climatic cycle (Merritt, Alila, Barton, Taylor, Cohen and Neilsen, 2006). During the last century, the atmospheric concentration of greenhouse gases (GHGs) due to anthropogenic activities has increased significantly. This will lead to a considerable rise in Earth's temperature in the upcoming years (Chu et al., 2010; Wentz, Ricciardulli, Hilburn and Mears, 2007; Merritt et al., 2006). As per report of IPCC (2013), the earth's temperature has increased successively in the past three decades compared to previous records, with the decade of 2000 being the warmest.

As stated in United Nations Report on World Water Assessment Programme (2015), a change in climatic conditions will amplify the risk of natural disasters, particularly those related to water resources, which are the most hazardous economically as well as socially. Excessive global warming will upset the present hydrological systems. It will lead to a variation in water availability and will cause increment in the intensity and frequency of precipitation (Mahmood, Jia and Babel, 2016b). In the present scenario, where the rise in global warming is inevitable, there is a dire need to evaluate its possible effects on the hydrological cycle and to comprehend the threats posed to water resources due to these changes (Meenu, Rehana and Mujumdar, 2012). The impacts of climate change on hydrological systems are region dependent (Khattak et al., 2011).

A number of studies carried out by Azim , Shakir and Kanwal (2016); Mahmood and Jia 2016a ; Mahmood et al., 2016b; Ahmad, Hafeez and Ahmad (2012); Khattak et al., 2011; Bocciola et al. (2011); Shakir, Rehman and Ehsan (2010); and Akhtar, Ahmad and Booij (2008) have focused on the climate change impacts on various water resource related projects in Pakistan. The rapidly changing climatic scenario is highly alarming for Pakistan, with its growing population and natural-resource-dependent economy (Khattak et al., 2011).

The assessment for annual change in hydrological parameters is usually carried out by incorporating 30 year historical climatic data (Morrison, Quick and Foreman, 2002). For hydrologic modeling and climate change assessment, a physically based continuous time model; the Soil and Water Assessment Tool (SWAT) developed by Dr Jeff Arnold for United States Department for Agriculture (USDA) Agricultural Research Services

(ARS); is commonly used (Garee, Chen, Bao, Wang and Meng, 2017; Kundu, Khare and Mondal, 2017; Xu, Wang, Kalcic, Muenich, Yang and Scavia, 2017; Nyeko, 2015; Narsimlu, Gosain and Chahar, 2013 and Abbaspour, Faramarzi, Ghasemi and Yang, 2009). SWAT incorporates input data, including weather, topography, soil, land management practices and vegetation present in the watershed and directly models the physical processes related to movement of water, sediment, plant growth, and nutrient cycling.

The outputs extracted from General Circulation Models (GCMs) are incorporated in the hydrological model to assess the changes in water resources due to future climate. GCM uses multiples GHG emission scenarios and can be employed to make projections about climatic condition in the future. GCM outputs provide scientific evidence to perform necessary steps according to the predicted conditions for future hydrological changes in the basin. However, small basins require very fine spatial resolutions, while the spatial resolution of GCM is very coarse (about 200-500 km) (Mahmood et al., 2016b). Therefore, it is necessary to downscale the information from large scale to local scale. NASA's Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset, launched in June 2015, comprises of the downscaled global climatic scenarios obtained from runs of Global Circulation Models covered in Coupled Model Intercomparison Project Phase 5 (CMIP5). The CMIP5 GCM runs were developed to feed into the Fifth Assessment Report of Intergovernmental Panel on Climate Change (IPCC, 2014). These projections are available at spatial resolution of 25x25 km under two Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5.

1.2 Problem Statement

The study aims to assess the impacts of increasing level of carbon dioxide and variation in rainfall and temperature on the streamflows of Haro River watershed in the future. Previously, Hagras and Habib (2017) carried out a similar hydrological modeling study at Haro River watershed using SWAT. However, their study was limited to hydrological modeling using manual calibration without further assessment of the future impacts of climate change. Moreover, the limit in prior study was the downstream Khanpur Dam, which prevents quantification of changes in the water resources contributing to the dam without interference of human controls. To achieve this, the limits of the modeling in this study are moved upstream of the dam at Dhartian gauging station.

GCMs provide information that is used to define climate change under present and future conditions. For impact studies, these models incorporate climate processes and greenhouse gas emissions to simulate changes in large-scale global climate systems (Tshimanga and Hughes, 2012). Uncertainties arise within the GCMs due to inaccurate or inadequate representation of main physical processes (Raneesh and Thampi, 2013). Furthermore, the uncertainties in climate change impact assessment studies may also occur due to difference in downscaling techniques, emission scenarios as well as hydrological models (Vetter, Reinhardt, Flörke, Griensven, Hattermann, Huang, Koch, Pechlivanidis, Plötner, Seidou, Su, Vervoort and Krysanova, 2016). The combined effect of uncertainty and variability in future climate changes is considered challenging for planning of water resources (Bharati, Gurung, Jayakody, Smakhtin and Bhattarai, 2014). These uncertainties result in biases in climate representation of the baseline period, which may or may not be systematic. In impact assessment, particularly for mountainous regions, there are also uncertainties due to a mismatching scale between the climate and the hydrological model (Bennett, Werner and Schnorbus 2012).

These uncertainties are addressed using multiple strategies that include using an ensemble of model runs and applying spatial downscaling techniques to GCM models (Nover, Witt, Butcher, Johnson and Weaver, 2016). It is also pertinent to remove the systematic bias in the GCM output before application for climate impact studies (Teutschbein and Seibert, 2012). To study future streamflows in Haro River due to climate change, the model uncertainty was abridged in the present study by initially assessing five GCM models and then choosing one model after bias correction for assessing future climate impacts. The GCM outputs were obtained from recently launched NASA Earth Exchange Global Daily Downscaled Projection (NEX-GDDP) dataset, which is not yet frequently used for climate studies in Pakistan.

In addition to climate modeling uncertainty, climate impact assessment is further complicated by uncertainties in hydrological modeling pertaining to data, conceptualization, and parameterization. Hilly areas especially in developing countries are highly susceptible to climate change impacts (McDowell, Ford, Lehner, Berrang-Ford and Sherpa, 2013). Yet these same areas are commonly associated with meteorological and hydrological data scarcity due to limitations in temporal as well as spatial extents of weather station networks and rain gauges (Remesan and Holman, 2015). However, alternative observational and parameterization datasets e.g. reanalysis datasets are increasingly available to overcome these challenges (Nkiaka, Nawaz and Lovett, 2017). Furthermore, there are also developments within the hydrological modeling community for models applicable in data scarce watersheds, such as SWAT, HBV and TOPMODEL (Wakigari, 2017). The study, therefore, aims to address the issue with data scarcity by using multiple data sources to parameterize, drive and calibrate SWAT. The subsequent calibration and validation using robust generic interface known as SWAT Calibration and Uncertainty Program (SWAT-CUP) limits the uncertainty in the input parameters by propagating it in the model output in the form of parameter ranges.

With increasing level of global warming, poor management of the water resources in Pakistan may endanger water security, instigating an energy crisis and affecting food supply in the future (Akhtar, 2015). Managing water resources in dams is considered as the best strategy to overcome the challenges posed by climate change (Akhtar, 2015). Hence, the study on effects of future climate change on the water resources of Haro River watershed is essential as it has a direct effect on Khanpur Dam located downstream. The results of the study will be useful for effective management of the water resources of this watershed in the future, as the dam is used for supplying drinking water to the population of twin-cities of Islamabad and Rawalpindi, and for fulfilling the irrigation requirements for Khyber Pakhtunkhwa and Punjab Province. Outcomes of the study will also help the policy makers and authorities in devising proper strategies for Khanpur Dam and Haro River watershed in future.

1.3 Objectives of Research

The aim of the study is to quantify the future impacts of climate change on the streamflows of Haro River. The specific objectives of the study are:

1) To evaluate climate output from five downscaled General Circulation Models from the NASA Earth Exchange Global daily Downscaled Projections (NEX-GDDP) product against observed precipitation data from national meteorological stations and reanalysis dataset; additionally, to quantify the performance of bias correction of the selected GCM output using linear scaling method for baseline and future periods.

2) To quantify future climate change by comparing the bias corrected future climate projections against the baseline period under two emission scenarios.

3) To perform hydrologic simulation of Haro River watershed in SWAT using observed records of meteorological variables and subsequent calibration and validation of model using Sequential Uncertainty Fitting version-2 (SUFI-2).

4) To quantify the impact of future climate change on the streamflows of Haro River watershed under two emission scenarios using the calibrated SWAT Model and bias corrected GCM output.

1.4 Scope of the study

The study focuses on assessing the variation in the historical and future climatic projections and evaluating the potential climatic change impacts on water resources of Haro River watershed in Pakistan. Climate model data for five General Circulation Models: ACCESS 1.0, CCSM4, CNRM-CM5, MIROC ESM and MPI-ESM-LR under two Representation Concentration Pathway (RCP) scenarios, RCP 4.5 and RCP 8.5 is attained from bias corrected and spatially downscaled NEX-GDDP data at 25 x 25km resolution, and bias corrected using observed precipitation and temperature. Due to time limitations, only a single model is selected for assessment of future climate change impacts. This limitation is addressed based on assessing the regression analysis of GCM model outputs against the observed meteorological data from weather stations and reanalysis dataset. The observed precipitation and temperature data is obtained at two stations: Murree (P-1) located inside the catchment area and Islamabad (P-2) located outside the catchment area. The reanalysis meteorological data is obtained from the co-located pixel to P-1 and P-2 (C-1 and C-2).

The observed meteorological data is available only for 19 years i.e. from 1987 until 2005. To cater for this limitation in data availability, the absence of trend in the data was assessed before applying the computed bias corrected factors from 19 years of observation to the full historical period of 30 years. The bias corrected factors obtained from the historical period is then applied to the future climate period. The bias corrected thirty years historical data (1976-2005) for precipitation, maximum temperature, and minimum temperature is utilized for SWAT simulation of the baseline period. The future climatic projections are ascertained by using future bias corrected GCM data for three time periods, each of 30 years i.e. 2006-2035, 2036-2065 and 2066-2095.

The scope of the study also includes the hydrologic simulation of the watershed in the SWAT Model and subsequent calibration and validation of the model using SUFI-2. For hydrological modelling, the solar radiation, relative humidity and wind speed data at daily time scale is obtained from reanalysis data due to absence of observed data. The discharge data is only available from 1989-1991 and 1996-1998 (7 years total), which makes the calibration and validation challenging. The discharge data from the former period is used for calibration and from the later period is used for validation of the hydrological model. The baseline and future bias corrected projections are used to run the calibrated SWAT to investigate the effect of climate change on the water resources of Haro River watershed under emission scenario RCP4.5 and RCP 8.5.

In short, the outcomes of this study need to be interpreted in the context of all the limitations identified throughout the data collection and modelling stages. Nevertheless, the limitations have been addressed to the extent defined in the scope of study.

1.5 Significance of the study

1) The current study is carried out to assess the likely effects of climate change on a localized river basin.

2) Khanpur Dam, which is located on the downstream side of the study region, is the main source of supplying drinking water and fulfilling the irrigational water requirements. Therefore, it is pertinent to predict the impact of climate change in future upon the flows, precipitation and temperature.

3) The results of the study will provide necessary information related to expected future seasonal streamflow changes, which will provide the basis for better policymaking.

4) The study will prove helpful in planning strategies to mitigate drastic changes in the hydrology, if projected by the study.

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