Impacts of Climate Change on Dry Season Flow of Gorai River, Bangladesh Using SWAT Model

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Abstract

The Gorai River is one of the main distributaries of the Ganges and the primary source of fresh water in the southwestern part of Bangladesh. The dry season (Nov-May) flow of the river decreases due to climate change, shifts in land cover, and upstream diversion. In this research, SWAT (Soil Water Assessment Tool) has been used to assess the impact of climate changes on the dry season flow of the Gorai River. The model is calibrated and validated against the monthly flow from 1995-2013 for the gauging station at the Gorai Railway Bridge. Then it has been used under different climate change scenarios projected by multiple General Circulation Models (GCMs) by several Representative Concentration Pathway (RCP) scenarios of IPCC 5th Assessment (AR5) report for the 2030s and 2050s of the 21st century. A total of eight climate models under four RCPs have been selected for this study. Based on the projected monthly change in precipitation and temperature, four scenarios have been selected for this study: Wettest (BCC-CSM-1-1M RCP 2.6), Driest (MIROC-ESM RCP 6.0), Warmest (MIROC-ESM-CHEM RCP 8.5), and Coolest (GISS-E2-R RCP 2.6). The results show that the dry season flow decreases from the base periods (1995-2013) in all scenarios for the 2030's and 2050's. The highest reduction is found for the climate model MIROC-ESM (RCP 6.0), with a -46.37% decline in the dry season flow. The lowest drop in discharge is found under BCC-CSM-1-1M (RCP 2.6), with a -30.8% decrease. The reduction in the warmest and coolest scenarios are -43.37% and -42.42%, respectively. The model has also run for temperature change at 0, +2, +4, and precipitation change at -10%, 0%, +10%, and 20% to identify the most significant variable for dry season flow. The study infers the sensitivity of dry season flows to precipitation than temperature, which is linearly correlated. Results imply that sustainable planning of surface water resources is necessary to avoid shortages during the dry season.

Keywords: River Flow, Temperature, Rainfall, Hydrological model, RCPs.

Introduction

Water is one of the most significant natural resources on the earth's surface and relates to the earth's climate and ecosystem (Ghosh, 2016). The climate of a place can be attributed to the continuous phase of redistribution of water through the hydrological cycle. Regional water quantity and quality are affected by various natural and anthropogenic factors (UNEP/WHO, 1996). Among those factors, the climate is one of the most important agents for a basin's hydrology and water quality

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characteristics. Due to climate change, the dynamics of the basin's water quantity and quality are changing.

Bangladesh is one of the most vulnerable countries to climate change, where the river basin is the primary source of water (Billah et al., 2015). Around 700 rivers and their distributaries flow through Bangladesh and have formed the lifeline of this country (Chakraborty et al., 2016). They are now facing many problems like the deviation in the upstream flow, salinity intrusion, the excessive sedimentation that causes alterations of the navigability, and the consequent floods (Shamsad et al., 2014).

The Gorai River is one of the leading distributors of the Ganges in Bangladesh, and a vast network of rivers in the southwest region is dependent on the water supply of the Gorai River (Rahman et al., 2017). The availability of freshwater has become a significant problem in the region due to the complexity of this river (Huang et al., 2011). A decrease in the freshwater supply to the Gorai region has exacerbated many problems, especially the relative rise in salinity in the country's southwestern part. Research shows that increased salinity from saltwater intrusion poses an imminent threat to livelihoods and public health through its impacts on agriculture production and other fresh water-dependent sectors like infrastructures, fisheries, and small industries in that region (Dasgupta et al., 2018; Hussain, 2008). The nature conservation area of the Sundarbans, a vast mangrove forest consisting of a complex system of interconnected estuaries and channels, is also affected due to the increase in salinity. The salinity of the Nabaganga-Rupsha-Passur river system is highly influenced by the dry season flow of the Gorai River. It has been found that this reduction in flow has caused an eight-fold increase in maximum salinity at Bardia and a two-fold increase in Khulna in both cases (Islam and Gnauck, 2011).

River flow is also susceptible to climatic variables and climate-induced changes, which can shift the dynamic of the flow. It has been reported that several parts of the country often face water shortages while others are experiencing overflowing (Di Baldassarre et al., 2018). These changes in the flow have a multidimensional impact on various sectors of society like rapid urbanization and industrialization, population growth, and accessibility to quality water (DoE, 2006). Thus, the attempts to integrate climate change with river flow have become crucial to investigate optimal planning, especially for the southwestern part of Bangladesh, to attain sustainable water resources and management.

Hydrological models play an essential role in creating reference characteristics and long-term derivation effects challenging to calculate (Lenhart et al., 2002). Integrated hydrological modeling considers complex relations between the climatic parameter and water resource, making it an effective tool to study the dynamic interactions among multiple climatic variables and watershed parameters (Beven and Kirkby, 1977; Schultz, 1993; Cheng et al., 2002). General Circulation Models (GCMs) development is one of the most remarkable advances in climate change research. These models are utilized to simulate the climate system's response to the overall changing atmospheric composition (Shackley et al., 1998; Griggs and Noguer, 2002). Different hydrological models have been used to predict climate change on large-scale basins with these advancements in climate models. SWAT (Soil and Water Assessment Tool) has been used to determine the impact of climate change on river flow (Pervez and Henebry, 2015; Alam et al., 2016; Anand et al., 2018;

Mohammed et al., 2018). SWAT simulates the hydrological cycle within a watershed using a land phase and water phase to predict the impact of land management practices on water, sediments, and agricultural chemical yields in large complex basins with different soil, land use, and management conditions over long periods (Neitsch et al., 2005). SWAT is a physically-based hydrological model, and it is capable of being used on ungauged watersheds, which makes it an efficient tool for determining the impact of climate change on small-scale basins (Uniyal et al., 2015).

In this study, hydrological model SWAT (Soil Water Assessment Tool) is used to evaluate the impact of climate change on the dry season flow of the Goria river under different climate change scenarios projected by multiple GCMs by several RCP scenarios of IPCC 5th Assessment (AR5) report for the 2030s and 2050s of the 21st century. Total eight climate models: BCC-CSM-1-1, BCC-CSM-1-1M, GISS-E2-H, GISS-E2-R, HADGEM2-ES, MRI-CGCM3, MIROC-ESM, MIROC-ESM-CHEM under four RCPs has been selected. From these models, four scenarios (wettest, driest, warmest, and coolest) are selected based on average monthly precipitation and temperature change for the overall understanding of the climate change impacts on the dry season flow. The SWAT model is also used to determine the sensitivity of the model to temperature and precipitation change. Incremental analysis has been done for temperature change at 0, +2, +4, and precipitation change at -10%, 0%, +10%, 20%. The model will help to determine the effects of these variables on river flow. The specific objectives of this study are to develop and calibrate a hydrological model of the Gorai River using the Soil Water Assessment Tool (SWAT), to identify the future extreme and moderate climate scenarios and corresponding GCMs for Gorai River, and to investigate the impacts of climate change on the future flow of the Gorai River basin for the selected station.

Materials and Methods

Study Area

The Ganges has entered Bangladesh at Chapai Nawabganj and takes the name "The Padma", river Gorai takes off from the Padma at Talbari of Kushtia. Gorai river is used for various purposes such as navigation, fisheries, agriculture, and household activities. Moreover, the freshwater flow of the river is also significant for many economic activities. The ecology of the mangrove forests situated along the coast is also greatly influenced by the Gorai river flow (Baki, 2014). It provides the last significant freshwater supply to the southwest corner of Bangladesh; therefore, this river flow is also crucial in controlling salinity intrusion and maintaining the mangrove forests, especially in the dry season. Due to the implementation of the Farakka Barrage in 1975, the dry season flows in the Ganges River have started to decline subsequently, which results in a reduction of flow in other related rivers. There has been no natural dry season flow in the Gorai since 1988 (Islam and Gnauck, 2008, 2009). The case study for this report has taken the Gorai River and its surrounding areas. The study area contains Chapainawabganj, Rajshahi, Natore, Pabna, Kushtia, Rajbari of Bangladesh, and some border areas of India to cover the entire length of the river route.

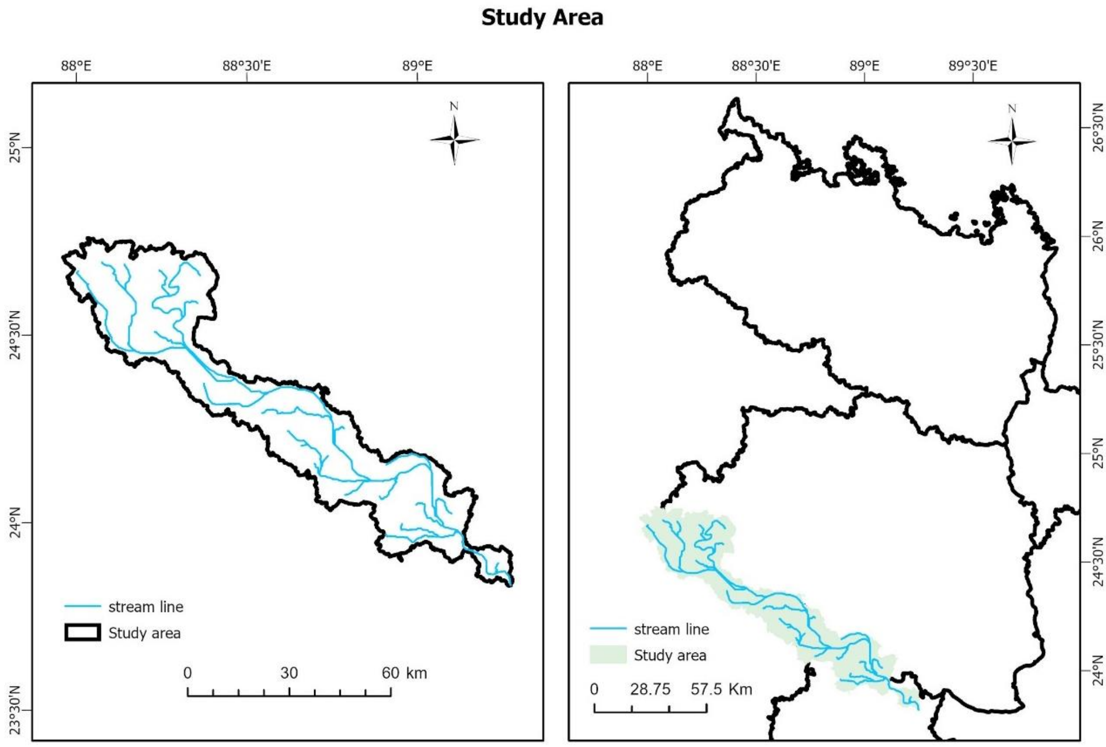

Figure 1: Overview of the Study Area.

Description of SWAT Model

Based on the physical processes involved in the modeling, a hydrological model can be divided into two groups: conceptual and physically-based (Refsgaard and Abbott, 1990). In the conceptual model, observations of a catchment are represented in a simplified mathematical relationship. On the other hand, in a physically based model, mass, momentum, and energy conservation are represented in a deterministic way. SWAT stands for Soil and Water Assessment Tool, which the United States Department of Agriculture - Agricultural Research Service (USDA- ARS) has developed. SWAT is a physically, conceptually, and efficiently based model capable of operating on daily time steps on a basin scale (Arnold et al., 1998, 2000; Neitsch et al., 2001). It can predict the impact of land management practices on water, sediments, and agricultural chemical yields in large complex basins with different soil, land use, and management conditions over long periods (Neitsch et al., 2005). Drainage basins combine all features of the hydrological cycle in a defined area, which is studied to quantify runoff that flows to a common point. SWAT divides a basin into a series of sub-basins based on the digital elevation model, where other models mostly use regression equations to describe the input-output relationship. Drainage basins combine all features of the hydrological cycle in a defined area, which is studied to quantify runoff that flows to a common point. Soil maps and land use overlap to create a series of unique hydrological response units (HRU) within each sub-basin (Yang et al., 2007). This HRU helps the SWAT model simulate surface and underground processes, representing vadose processes (i.e., infiltration, evaporation, absorption of plants, lateral flows, and percolation in the different stratum). The water balance used in SWAT can be expressed as in equation:

$$SWt = SWo + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw) \quad (1)$$

Where,

SWo is the initial soil water content, and SWt is the final soil water content on a day i. All other measurements are taken in millimeters, and time (t) is in days. The equation subtracts all forms of water losses from precipitation in a day I (Rday), including surface runoff (Qsurf), evapotranspiration (Ea), loss to vadose zone (Wseep), and return flow (Qgw) (Neitsch et al., 2011).

Curve Number Method calculates the output volume (Mishra et al., 2003), and results are generated daily or annually. In SWAT, the soil conservation curve (SCS) number method determines the surface runoff. In the SCS-CN method, soil and land use properties are combined to a single parameter (White et al., 2009). Antecedent Moisture Condition is defined based on the Curve-Number Antecedent moisture condition (CN-AMC) (NRCS, 2004). Antecedent moisture condition (AMC) is the initial moisture content in the soil at the start of the rainfall-runoff event under consideration, and it governs infiltration and initial abstraction. The retention parameter, S, is calculated using the daily CN value.

$$S=25.4(1000/CN -10) \quad (2)$$

CN lies in the range of $100 \geq CN \geq 0$. Where 100 indicates zero potential retention, i.e., impervious catchment, 0 corresponds to an infinitely abstracting catchment with $S=\infty$.

The direct runoff is calculated by combining the above empirical equation with the SCS runoff equation.

$$Qsurf= (Rday - Ia)2/ (Rday - Ia + S) \quad (3)$$

Qsurf is accumulated rainfall excess (runoff), Rday is rainfall depth for that day, Ia is the initial abstraction, S is the retention parameter.

Data Collection and Model Setup

Geospatial Data

SRTM Processed 90m Digital Elevation Data Version 4 can be downloaded from the International Consortium for Spatial Information (CSI) website (http://srtm.csi.cgiar.org/). The data are in ARC GRID format, in decimal degrees, and datum WGS84. They are derived from the USGS/NASA SRTM data. CIAT has processed this data to provide seamless continuous topography surfaces (Leon, 2009). Land use is one of the most critical factors that affect surface erosion, runoff, and evapotranspiration in a watershed. The land use data has been collected from USGS (United State Geological Survey) - Global Land Cover 2000 database. The study area is available from the South-Central Asia dataset using the WGS84 datum. There are seven types of land use data in the Gorai River catchment area. The soil data is provided by Dr. Karim Abbaspour of Eawag, Switzerland. The soil map is produced by the United Nations Food and Agriculture Organization (FAO). Almost 5000 types of soil have been differentiated with a spatial resolution of 10 kilometers, and some soil properties are provided for two layers (0-30 cm and 30-100 cm depth). All the GIS inputs are in the same UTM projections. The study area falls in zone UTM north 45. The selected areas are masked together and projected to WGS-84 UTM North 45.

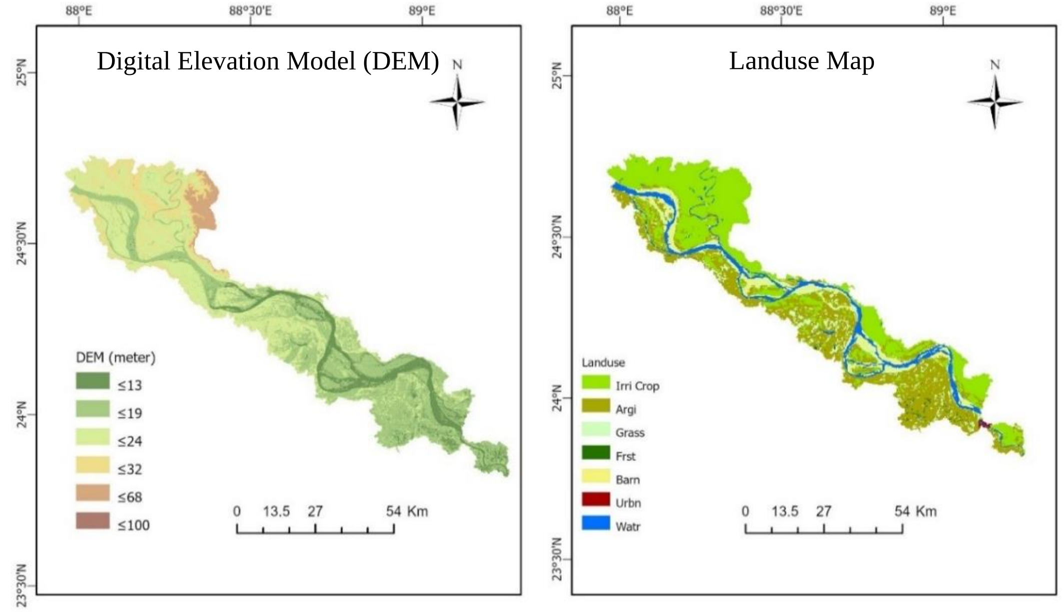

Figure 2: Digital Elevation Model (DEM) and Landuse map.

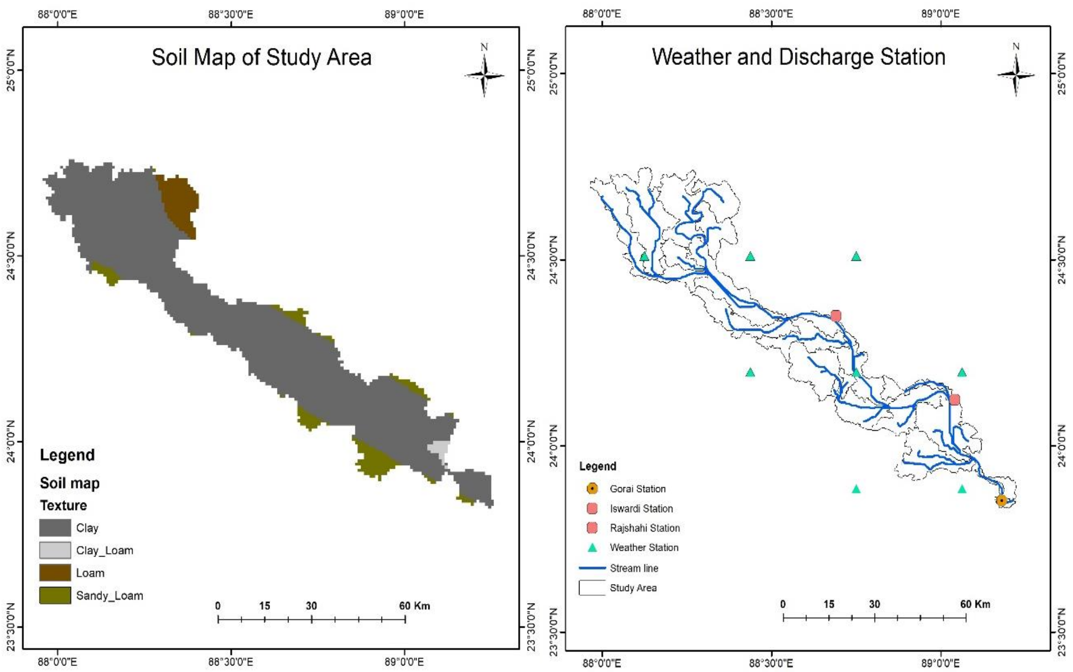

Figure 3: Soil map and Weather station location of the Study area.

Weather and Discharge data

The SWAT model requires precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed data to simulate the hydrological processes. Weather data were collected from GLOBAL WEATHER DATA FOR SWAT (https://globalweather.tamu.edu/). Weather data was collected from 8 Weather stations. For bias correction, the precipitation data from 1993-2013 of the Rajshahi and Iswardi station were collected from BMD (Bangladesh Meteorological Department). Historical discharge data of Gorai River was collected from BWDB (Bangladesh Water Development Board). The station ID is SW99, and the Station name is GORAI RAILWAY BRIDGE.

Model Set-up

Biases CFSR Precipitation Data

Precipitation is the most important and sometimes uncertain variable of hydrological modeling (Islam and Gan, 2015). The lack of coincidence between observed rainfall and CFSR (Climate Forecast System Reanalysis) can cause more significant uncertainty and less reliable results from the hydrological assessment. So, a comparison of mean monthly precipitation between few observed stations and nearby CFSR grid points for the same period has been made to identify the extent of the deviation. Based on data availability, two points (Rajshahi and Iswardi station) have been selected within the Gorai River watershed. The ratio of the average monthly precipitation for the observed and corresponding nearest CFRS global weather station has been determined, and from this, the average ratio of each month is calculated. Finally, the average ratio is multiplied by all CFSR global weather stations.

Model Simulation

Delineation is creating a boundary, which depicts a contributing area for an outlet or control point. Delineation divides a watershed into discrete land and channel segments for analyzing the behavior of the watershed. In this study, ArcSWAT, an ArcGIS 10.3 extension, has been applied to set up the model. In Arc SWAT, DEM is used to delineate the watershed and to create subbasins. Stream definition is done based on the DEM data, which is further applied to generate flow direction and accumulation. Ultimately, with this, the stream network and outlets are created. All the watershed delineation steps, such as filling a sink, defining flow direction, and accumulation, have been done automatically through the user interface. After watershed delineation, the Gorai River watershed has been divided into 17 subbasins based on the threshold area of 1700 ha. A Hydrological Response Unit (HRU) is defined as a unique combination of various land use, land cover, soil, and slope classes (Ghosh, 2016). In HRU definition, 100% overlapping of the land use map and the soil map is done within the delineated watershed. Different slope classes are included to classify the HRU. A total of 97 HRUs are produced and included in the simulation. The discretization of the basin into HRUs allows a detailed simulation of the hydrological processes.

The meteorological data (i.e., precipitation, maximum, and minimum temperature) of the eight meteorological stations are selected in this study based on the nearness to the study area. The data are prepared in the SWAT format and integrated with the model using weather data input wizards. The wind speed, solar radiation, and relative humidity data for the stations are generated using the weather generator tool. SWAT Weather Database tool is used to generate the WXGEN file for SWAT input.

Model calibration and validation

It is vital to evaluate model consistency, adaptability, performance, and accuracy using any model for prediction (Goswami et al., 2007). The performance of the model can be assessed by comparing the simulated results to that of observed data. SUFI2 has been used to perform the calibration and validation of SWAT. The fitted value forms the SUFI2 is used as a guideline to select the parameters to calibrate. The model is calibrated from 1995-2004 and validated from 2005-2013. November to May is selected for calibration and validation, as this research focused on dry season flow. The model's performance has been evaluated by Nash–Sutcliffe Efficiency value (NSE) and Mean relative bias (PBIAS). The NSE value is 0.51 for the calibration period and 0.50 for the validation period. PBIAS value is 19.5 for calibration and 20 for the validation period. These values indicate that the model result is satisfactory.

(According to Moriasi et al., 2007: NSE: “very good” if NSE > 0.75, “good” if 0.65 < NSE < 0.75 and “Satisfactory” if 0.64< NSE <0.50;)

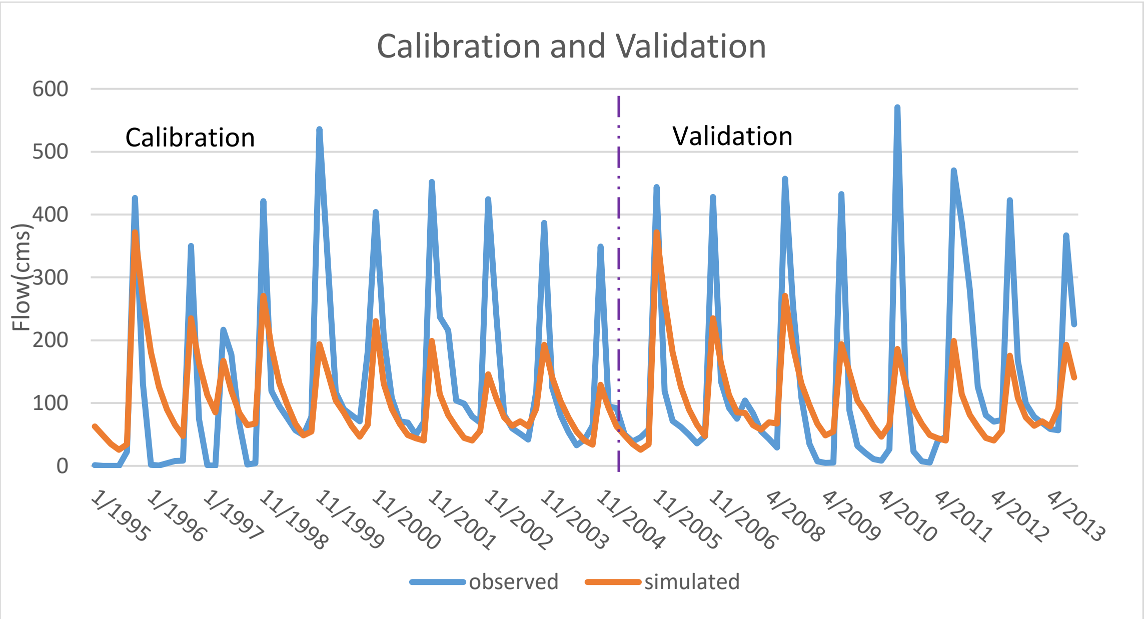

Figure 4: Monthly flow for Calibration and validation period 1995-2013.

Selection of Climate Change Scenarios

There are different approaches to generating climate change scenarios for hydrological impact studies. They can be classified in general terms like synthetic approach, analog approach, and climate model-based approach. Arbitrary quantities gradually modify future climate variables (mainly precipitation and temperature) in the synthetic approach. These changes can be made on annual, seasonal, or monthly scales. Determining the impact of climate on water resources are based on this approach has been done in many research (Xu, 2000; Semadeni-Davies, 2004; Jiang et al., 2007). In an analog approach, recorded climate regimes that can resemble the future are used to construct climate change scenarios. It does not consider its source or boundary conditions; instead, it focuses on the change of unity of the climate drivers. In a temporal analogical approach for a given place, the past climate is investigated to resemble the projected future climate (Islam, 2011). Using the analog approach in water resources is also found in the literature (Bouraoui et al., 2004; Yao et al., 2009; Orlowsky et al., 2010). General Circulation Models (GCMs) are the most advanced tools currently available to simulate climate change (Griggs and Noguer, 2002). The new scenarios are called Representative Concentration Pathways (RCPs), categorized into four pathways: RCP8.5, RCP6, RCP4.5, and RCP2.6. Emissions and concentrations, forcing, and temperature anomalies of each Representative Concentration Pathway (RCP) define a specific emissions trajectory and subsequent radiative forcing. Based on spatial resolution and data availability, eight suitable GCMs for four RCPs are selected for this study. They are BCC-CSM-1-1, BCC-CSM-1-1M, GISS-E2-H, GISS-E2-R, HADGEM2-ES, MRI-CGCM3, MIROC-ESM, MIROC-ESM-CHEM.

Calculating the temperature and precipitation of the whole watershed for all the GCMs and RCPs are very difficult and tedious work. Two points are selected over the watershed to better understand temperature and precipitation under 4 RCP scenarios. Marksim tool was used to generate the temperature and precipitation data of those two points. Temperature and precipitation change of the eight GCMs are analyzed under two periods: viz 2010-2039 (2030s), 2040-2059 (2050s). Monthly precipitation and temperature data for each model were averaged and compared with the base period data (1995-2013). The tables show the changes in precipitation (%) and temperature for eight GCMs.

Table 1: Change in precipitation (%) for eight GCMs

	RCP 2.6		***RCP 4.5***		***RCP 6.0***		***RCP 8.5***	
Model	**pcp_2030**	**pcp_2050**	**pcp_2030**	**pcp_2050**	**pcp_2030**	**pcp_2050**	**pcp_2030**	**pcp_2050**
BCC-CSM-1-1	8.395	8.995	2.02	3.029	8.37	8.12	6.342	5.574
BCC-CSM-1-1M	6.474	8.983	5.49	1.25	3.21	6.35	4.999	4.383
GISS-E2-H	7.644	3.579	6.61	6.652	3.67	3.24	5.379	5.746
GISS-E2-R	7.216	5.018	6.29	4.657	4.64	4.01	3.585	4.832
HADGEM2-ES	4.968	2.373	2.32	1.893	6.45	5.28	1.233	4.159
MRI-CGCM3	5.408	1.528	3.85	1.726	3.82	0.86	4.272	4.384
MIROC-ESM	3.987	3.121	5.34	2.65	6.59	8.02	4.884	6.589
MIROC-ESM-CHEM	7.787	4.246	6.3	2.411	4.41	5.63	6.125	7.491

Table 2: Changes in temperature for eight GCMs

	RCP 2.6		*RCP 4.5*		*RCP 6.0*		*RCP 8.5*	
Model	**tmp_2030**	**tmp_2050**	**tmp_2030**	**tmp_2050**	**tmp_2030**	**tmp_2050**	**tmp_2030**	**tmp_2050**
BCC-CSM-1-1	0.12	0.79	0.913	1.19	0.58	0.84	0.81	1.19
BCC-CSM-1-1M	-0.12	0.71	0.91	1.19	0.68	0.89	0.71	1.13
GISS-E2-H	-0.14	0.44	0.51	0.75	0.78	1.28	0.08	0.89
GISS-E2-R	-0.15	-0.01	0.17	0.28	0.39	0.65	0.11	0.46
HAD-GEM-ES	0.28	1.28	0.96	1.83	-0.01	0.19	1.03	2.2
MRI-CGCM	0.06	0.45	0.86	1.45	0.29	0.77	0.57	1.63
MIROC-ESM	0.11	0.99	2.25	2.43	0.75	1.13	1.23	2.73
MIROC-ESM-CHEM	0.3	1.19	0.45	0.76	0.35	0.38	0.38	1.07

Results and Discussion

Evaluation of discharge under different scenarios

Under different RCPs, the dry season flow is simulated to see the changes within the GCMs and the changes in the future. The changes are analyzed in two periods: 2030s and 2050s. In all RCP scenarios, the average annual streamflow tends to decrease in the dry seasons. In RCP 2.6, the precipitation rate increases in both 2030s and 2050s but at the same time, the temperature increases. Temperature increases more in the 2050s. The box plots for RCP 2.6 show that the range is higher for the 2050s, but the mean is lower than the 2030s. The range between 75th and 25th percentile is relatively higher for the 2050s under the RCP 2.6. In RCP 4.5, there is a moderate increase in the precipitation in both 2030s and 2050s, but more increase in temperature than RCP 2.6. Like RCP 4.5, in RCP 6.0, the average annual streamflow tends to decrease in the dry seasons. For RCP 8.5, the range of flow varies significantly for the 2030s. The mean flow in GCMs under all RCPs ranges from 70 to 85 cms (cubic meters per second) for the 2030s and 70 to 80 cms for 2050s. In the future, the number of extreme precipitation events will increase, contributing to the flow of the river for a short period.

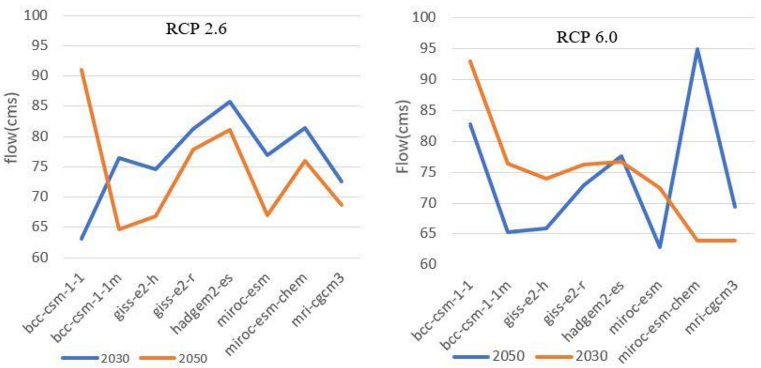

Figure 5: Average dry season flow (cms) in RCP 2.6 and RCP 6.0 scenarios.

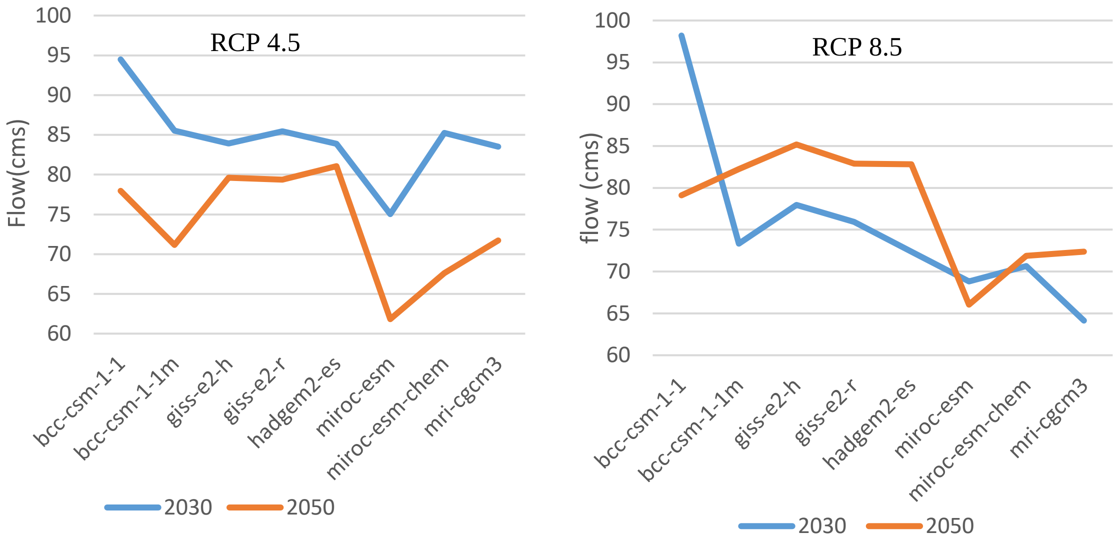

Figure 6: Average dry season flow (cms) in RCP 4.5 and RCP 8.5 scenarios.

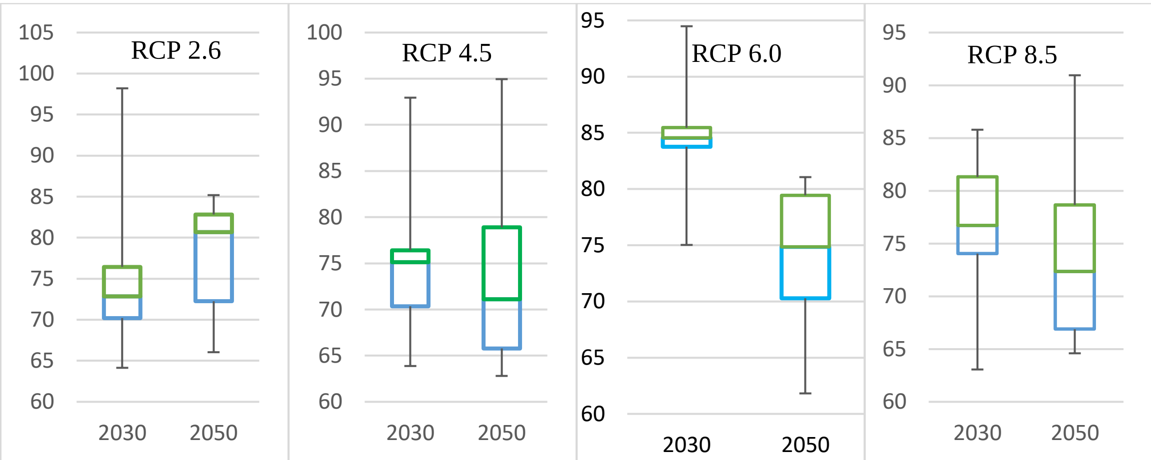

Figure 7: Box plot of dry season flow in four RCP scenarios.

Climate Change Impact on Flow

The GCMs result of the 2050s is analyzed to obtain the warmest, coolest, driest, and wettest scenarios for the watershed. Wettest and driest scenarios are BCC-CSM-1-1 RCP 2.6 and MIROC-ESM RCP 6.0, which give the highest and lowest percentages of precipitation changes, respectively. On the other hand, MIROC-ESM-CHEM RCP 8.5 and GISS-E2-R RCP 2.6 show the maximum and minimum temperature changes, respectively. These four periods are used to determine the final climate changes impact on the flow of the watershed.

Table 3: Selection of Climate Change Scenario

BCC-CSM-1-1	RCP 2.6	8.95% change in pcp	Maximum (wettest)
MIROC-ESM	RCP 6.0	0.86% change in pcp	Minimum (driest)
MIROC-ESM-CHEM	RCP 8.5	2.73^0 Celsius	Maximum (warmest)
GISS-E2-R	RCP 2.6	-0.01^0 Celsius	Minimum (coolest)

Different GCM model is compared with the base period (1995-2013) to see the changes inflow. SWAT simulated the mean monthly streamflow of dry seasons (Nov-May) for four climate change scenarios in response to these projected changes to the primary climatic factors. It has been found that in all scenarios for the 2030s, the dry season flow will decrease. Though the overall precipitation increases in different GCMs in the dry season, the average flow decreases. On the other hand, in the warmest periods, there is a decreasing pattern in the flow. For the 2050s, the scenario is also the same. Dry season flow tends to decrease by 2050 and in terms of the wettest and warmest GCM model. The simulated model pattern of the 2050s is similar to the 2030s.

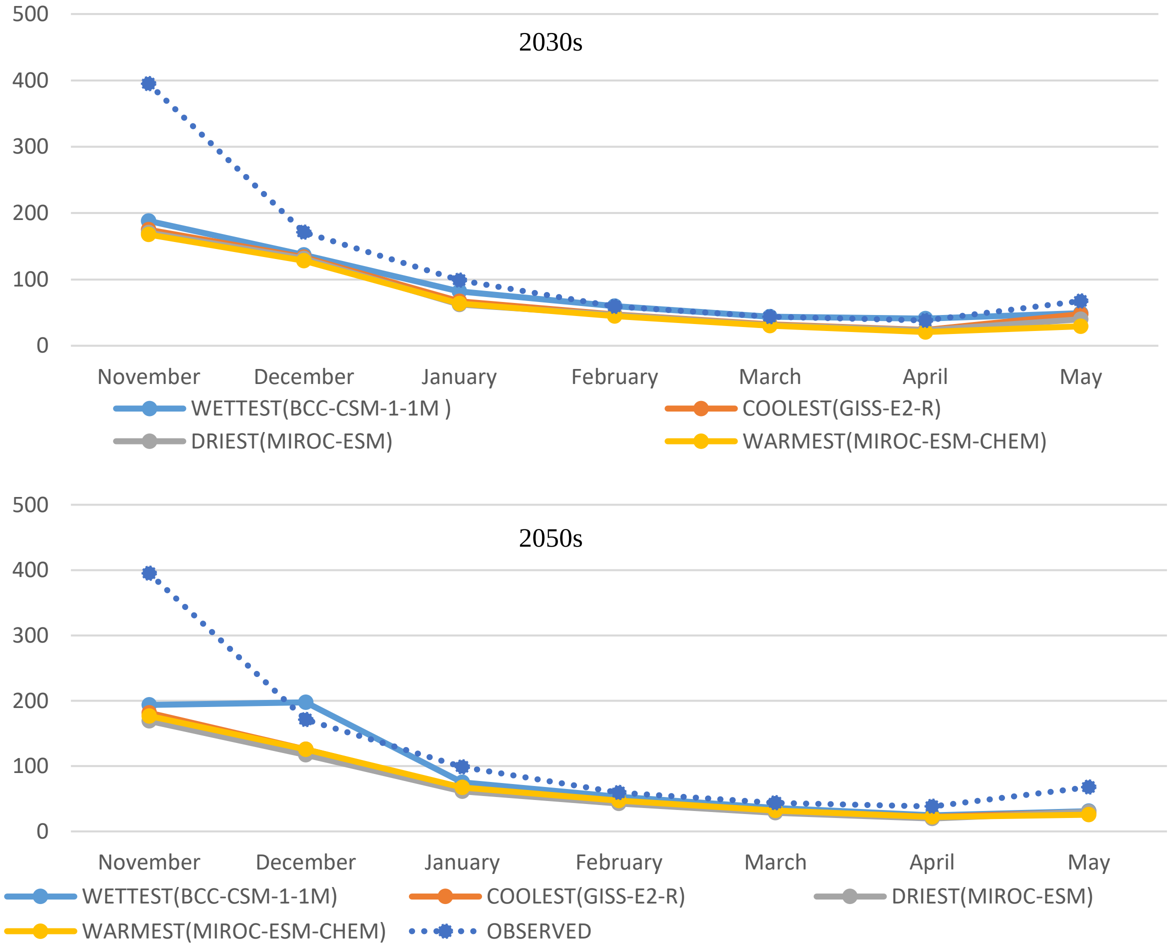

Figure 8: Dry season discharge (cms) for the 2030s and 2050s.

In the 2030s, the dry season flow shows a decreasing pattern. The highest decrease was found for MIROC-ESM-CHEM (RCP 8.5) with a -44.52% change. All other scenarios, viz BCC-CSM-1-1M RCP 2.6, MIROC-ESM RCP 6.0, and GISS-E2-R RCP 2.6, gave a decrease in flow with -31.16%, -42.17%, -39.79% changes, respectively. On the other hand, in the 2050s, the highest decrease was found for MIROC-ESM (RCP 6.0), with a -46.37% change. All other scenarios, viz BCC-CSM-1-1M RCP 2.6, MIROC-ESM-CHEM RCP 8.5, and GISS-E2-R RCP 2.6, gave a decrease in flow -30.08%, -43.19%, -42.42% changes, respectively.

Result of Synthetic Approach

The synthetic approach is also used to investigate the climate change impacts on the flow. Several synthetic approaches are applied to the climate base period (1995-2013) meteorological data. Incremental climate change scenarios are utilized for two variables: temperature and precipitation. The theoretical approach involves an increase in temperature by 0, +2, and +4. For precipitation, the scenario involves -10%, 0%, +10% and 20% changes in the values. The model result is analyzed to see the changes in the mean dry season flow of the Gorai River, and it is found that flow is more sensitive to precipitation than temperature. The results indicate that a 10 % change in precipitation would produce a 13.16 % change in streamflow for the Gorai River discharge.

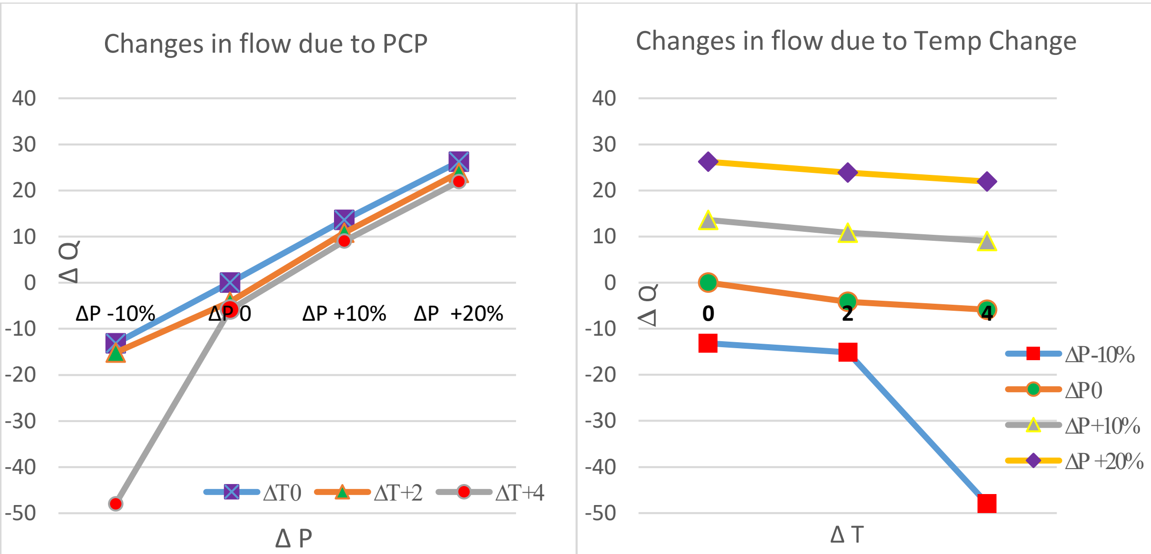

Figure 9: Changes in mean dry season discharge (%) due to the changes in precipitation and temperature.

On the other hand, a 10 % change in precipitation and a +2 degree increase in temperature would produce a -4.16 % change in the flow, and a +6 degree increase in temperature under a 10% increase in precipitation would decrease the flow for Gorai River by -6.86%. Changes in the mean annual precipitation may have significant impacts on the water availability of the watershed. An increase in the mean annual precipitation may significantly increase the streamflow, contributing to the surface runoff, lateral flow, and baseflow. Though the precipitation rate increases in the dry periods, at the same time, the temperature also increases, which contributes to evapotranspiration. Under different RCPs scenarios, it has been found that the average flow would decrease roughly by 39% in the 2030s, and 42% by the 2050s. The effect of climate change is already visible. The monthly dry season discharge is already decreasing in recent years. From 1995 to 2013, the average dry season flow was 124.79 cms, but from 2014-2018 the flow decreases to 78.19 cms. The later five-year flow is 37.34% lower than the previous period, which indicates that the flow will decrease over time.

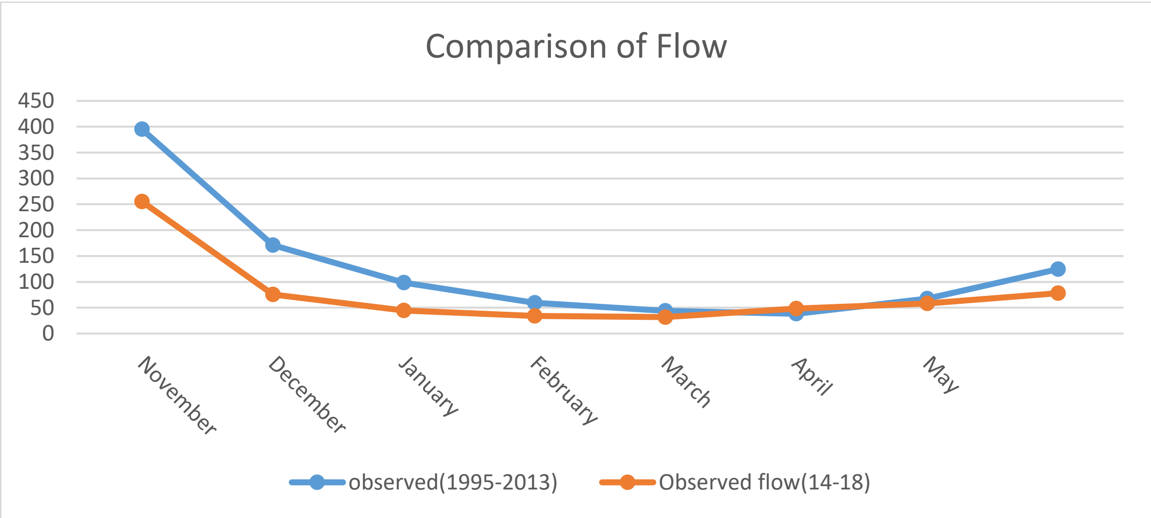

Figure 10: Comparison of the observed flow (cms) of Gorai River.

Conclusion

From this research, it is clear that the salinity problem will increase in the future due to the reduction in flow in the dry season. The observed reduction is close to 40% from the base period flow (1995-2013). So, sustainable planning of surface water resources is necessary to avoid shortages during the dry season.

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