American Journal of Water Resources, 2019, Vol. 7, No. 3, 95-105
Available online at http://pubs.sciepub.com/ajwr/7/3/2
Published by Science and Education Publishing
DOI:10.12691/ajwr-7-3-2

Potential Changes to the Water Balance of the Teesta River Basin Due to Climate Change

Imran Khan[1,*], **Dr. Mostafa Ali**[2]

[1]River Engineering Division, Institute of Water Modelling, Dhaka, Bangladesh
[2]Water Resources Engineering Department, BUET, Dhaka, Bangladesh
*Corresponding author: ikhan.buet@gmail.com

Received June 06, 2019; Revised July 14, 2019; Accepted August 05, 2019

Abstract This study is carried out to assess the potential changes to the water balance of the Teesta River basin due to climate change. A semi-distributed hydrological model of Teesta river basin has been developed using SWAT (Soil Water Assessment Tool). After assessing the results of GCM solutions for 2080s, four scenarios has been selected for detail analysis. They are: Wettest, Driest, Warmest and Coolest. Among the selected scenarios, for the wettest scenario the precipitation had increased by 11.71% while it decreased by 1.76% for the driest scenario. The increase in temperature for the coolest and the warmest scenario is found to be 2.24°C and 5.34°C. The developed hydrological model of 1998-2013 timeframe served as the base model output to be compared against climate change model results. Comparing the water balance of the climate change model with the base model, it has been found that the monsoon season will become more wetter (as much as 48% increase of precipitation) and the dry season become more drier (as much as 43% reduction of precipitation) due to climate change for all the climate change scenarios. The flow comparison at the Dalia point, upstream of Teesta Barrage for different climate change scenarios shows similar kind of trend to that of the water balance comparison. The general trend emerging from the flow analysis is that the Dalia point will experience a more severe shortage of water during the lean season where, as much as 25% decrease of flow has been found even without any upstream controls.

Keywords: *climate change, SWAT, water balance, Teesta river basin, Bangladesh*

Cite This Article: Imran Khan, and Dr. Mostafa Ali, "Potential Changes to the Water Balance of the Teesta River Basin Due to Climate Change." *American Journal of Water Resources*, vol. 7, no. 3 (2019): 95-105. doi: 10.12691/ajwr-7-3-2.

1. Introduction

South Asia is one of the most densely populated regions of the world, and also one of the most water scarce. With access to only 8.3 percent of the world's water resources, the region supports more than 21 percent of the world's population [1]. In recent decades, population expansion, urbanization, and changes in production and consumption patterns in the region have increased the demand for water, food, and energy. Simultaneously, variations in rainfall patterns and weather systems due to climate change have made the region highly susceptible to floods, droughts, and natural disasters.

The Himalayas, known as the "water tower" of Asia or the "third pole," supply the three major trans-boundary river systems of the Indus, the Ganges, and the Brahmaputra, which collectively support an estimated 700 million people [1]. In this region the annual southwest monsoons supply 70–90 percent of annual rainfall [2]. The majority of countries in South Asia rely on trans-boundary water flows to meet their domestic water needs. Bangladesh, for example, draws an estimated 91.3 percent of its water from trans-boundary river systems such as the Brahmaputra and the Ganges [1]

Meanwhile, water availability per capita in South Asia has declined by a staggering 70 percent since 1950 [2]. In addition, climate change studies of South Asia increasingly suggest that the effects of glacial melt and erratic monsoon patterns will significantly reduce the availability of water in river basins in the region. As the demand for water for agriculture, industry, and hydropower generation in these countries grows, water is increasingly a driver of tension and potential conflict in the region.

The Teesta River is one of the most important trans-boundary river of Bangladesh with only the Ganges and Brahmaputra have a higher annual runoff than the Teesta. It is a tributary of the Brahmaputra River and falls under the Brahmaputra sub-basin in the Eastern Himalayan region. Bangladesh has long argued that India's construction of the Gozaldoba Barrage upstream of Dalia (Teesta Barrage) has significantly reduced the availability of water in the dry season [3]. Water diversion at Gozoldoba and Dalia are used mainly for surface water irrigation and high rate flow diversion at Gozoldoba creates water scarcity for the Bangladesh part of the Teesta River. Furthermore, the release of water during the monsoon season causes flooding and bank erosion downstream. The availability of water for irrigation, particularly in the lean or dry season, has been at the crux of the longstanding dispute between the two countries.

And with the impending threat of climate change, the water balance of the Teesta Basin is going to become a more important factor in an already water stressed region. In recent years, Sikkim has experienced a number of sudden and devastating glacial lake outburst floods (GLOFs) [1]. Several potentially dangerous small and medium sized glacial lakes have been identified in the upper catchment of the Sikkim region [4]. These lakes are evidence of increasing glacial melt and retreat in the upper reaches of the basin due to climate change. It is predicted that the Himalayan river catchments will experience more extreme weather events such as cloudbursts and heavy rainfall, increasing the rate of soil erosion, landslides, and flash floods [2]. The general pattern of hydrological impact of climate change in the Brahmaputra river basin can be extrapolated to the Teesta to predict a future in which accelerated melting of the glaciers feeding the rivers will lead initially to more frequent and intense flooding, but subsequently, as the glaciers retreat ever further, to decreases and eventually drastic reductions in the Teesta's flow [5].

2. Teesta River Basin

The river Teesta is one of the main Himalayan rivers and originates from the glaciers of Sikkim in North at an elevation of about 5,280 m [4]. It is a perennial, rain and snow fed river. A number of glaciers and glacial lakes in the upper reaches of the basin in Sikkim supply the headwaters of the Teesta. In addition to glacial melt water, the Teesta is also fed by a number of tributaries as it journeys towards the plains. Flowing through the glacial mountains of the Northeast Indian state of Sikkim, it subsequently enters Bangladesh, flowing through Jalpaiguri and then the Rangpur Division, finally meeting with the Brahmaputra near Fulchari. A map of the Teesta River basin is shown in Figure 1.

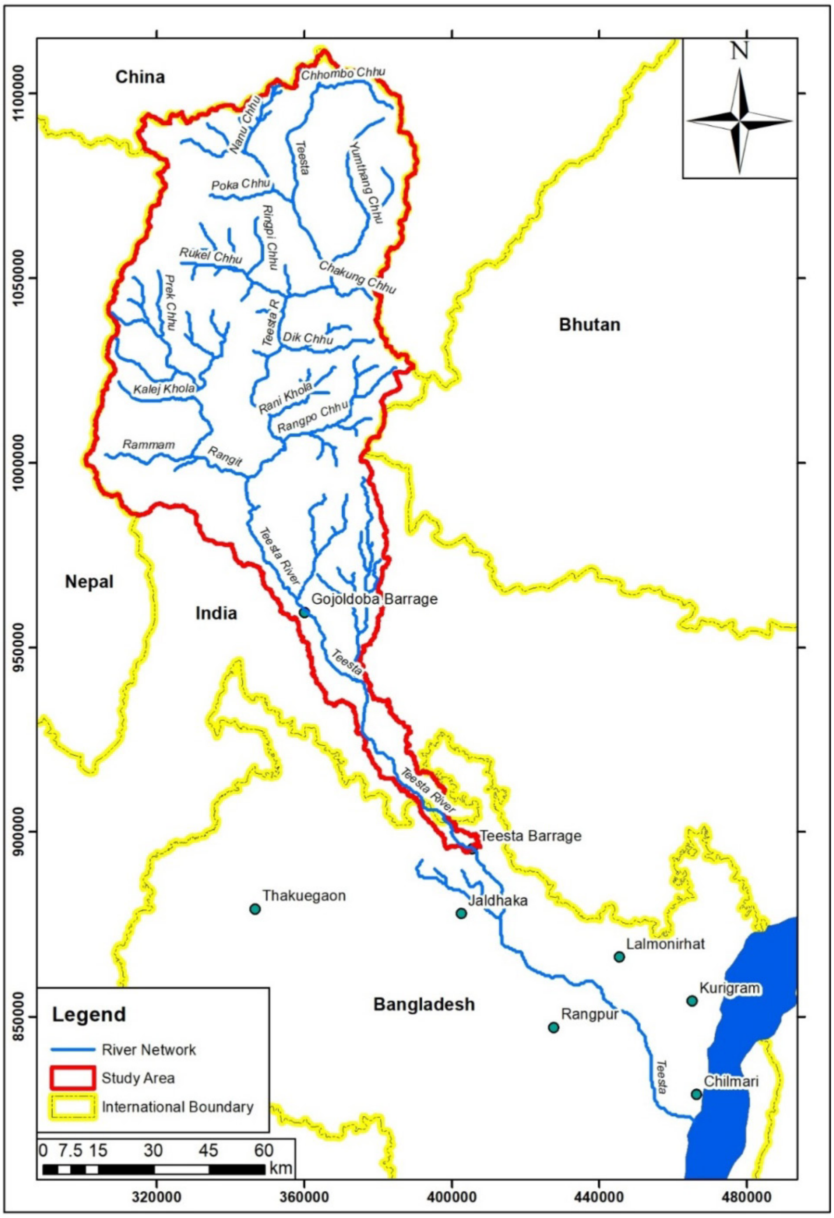

Figure 1. River Network in the Teesta Basin

The trans-boundary basin of the Teesta River encompasses 12,159 square kilometers, of which 10,155 are in India and 2,004 are in Bangladesh. Approximately 8,051 square kilometers of the river basin lie in hilly parts of Sikkim (6,930 square kilometers) and West Bengal (1,121 square kilometers). Approximately 4,108 square kilometers of the basin lie in the plains of West Bengal (2,104 square kilometers) and Bangladesh (2,004 square kilometers) [1].

The Teesta River has an average annual runoff of 60 billion cubic meters (BCM) (90% of the river's flow occurs during the monsoon or wet season i.e. between June and September [6]. The importance of the flow and seasonal variation of this river is felt during the lean season (October to April/May) when the average flow is about 500 million cubic meters (MCM) per month [6]. The maximum discharge of the Teesta river at Kaunia station is 8,500 cumec with the minimum flow is 5.50 cumec [7]. The water level at Dalia station varies from 52.97 mPWD to 48mPWD [7]. Mean daily maximum temperature in the sub-basin varies from about 26.8°C in September to 20.7°C in the month of January [4]. Mean daily Relative Humidity varies from 63.8 percent to 88.7 percent over the basin [4]. The mean daily Relative Humidity is 68.3 percent in January, 66.2 percent in April, 88.7 in July and 68.0 in October [4]. The mean monthly wind speed varies from as low as 43.2 km/day from July to September to high of 98.4 km/day in the month of April [4].

3. Methodology

Assessment of climate change impact on the flow of any river basin using hydrological model involves several steps. Numerous amount of preprocessing and post-processing is one of the major difficulties faced by the researchers. In the present work initially several types of data such as, Digital Elevation Model, land use pattern, soil distribution, climate data and flow time series were collected to setup a semi-distributed model using SWAT. Steps followed in the present research can be described as following:

Step 1-Data Collection: This include DEM, land use pattern, soil distribution, climate data and flow time series

Step 2-Model Setup: Model setup which includes watershed delineation, weather data setup, HRU definition and selection of calculation methods.

Step 3-Model Development: Sensitivity analysis of the calibration parameters, calibration using the selected parameters, validation of the model and evaluation of the performance

Step 4-Scenario Selection: Selection of scenarios for climate change and upstream development impact assessment.

Step 5- Impact Assessment: Run the model with high resolution projected data and analyzed the impact of climate change as well as input the upstream development scenario to simulate its impact on the flow of Teesta river Basin.

3.1. Data Collection

Spatially distributed physiographical (e.g. topographical, soil, and landuse) and meteorological data (e.g. temperature and precipitation) are required to run hydrological model. For the purpose of this study, six different types of data were collected. They are presented in Table 1.

The DEM was collected from Shuttle Radar Topography Mission (SRTM), which has a resolution of 90m x 90m. River network data, which helps the model identify the natural streams in the area was downloaded from USGS Hydroshades. "Soil map of the world" prepared by a joint project of UNSECO and FAO was used to provide the soil data of the model. The Land use data was downloaded from U.S Geological Survey (USGS) Land Cover Institute (LCI) website. The Land Use map has a resolution of 90m x 90m.

The precipitation data for the model was acquired from the Tropical Rainfall Measuring Mission (TRMM). The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the Japan Aerospace Exploration (JAXA) Agency to study rainfall for weather and climate research. The TRMM satellite ended collecting data on April 15, 2015. Launched in late November 1997, with a design lifetime of 3 years, the TRMM satellite produced over 17 years of valuable scientific data. TRMM carried 5 instruments: a 3-sensor rainfall suite (PR, TMI, VIRS) and 2 related instruments (LIS and CERES). TRMM delivered a unique 17-year dataset of global tropical rainfall and lightning. The TRMM daily precipitation data comes at a gridded format at an interval of 0.25 degrees and the collected data ranges from 1998-2013. Other climatic datasets such as daily mean temperature, relative humidity and wind speed data was downloaded from NASA POWER project, which has a spatial distance of 1 degree and ranges from 1997-2013.

Table 1. Details of the collected data

Data Type	Source	Station Name	Time Period	Remarks
DEM	Shuttle Radar Topography Mission (SRTM)	-	-	DEM with resolution of 90m
River Network	USGS Hydrosheds	-	-	-
Land Use	The USGS Land Cover Institute (LCI)	-	-	-
Soil data	FAO/UNESCO Soil Map of the World	-	-	The FAO soil types were manually included in the SWAT database, so they can be recognized by the program.
Climatic Data	NASA Prediction of Worldwide Energy Resource (POWER) and Tropical Rainfall Measuring Mission (TRMM)	-	1998-2013	Precipitation data was taken from the TRMM archive which provides the data from 1998-2013. Other climatic parameters such as Temperature, Wind Speed and Relative Humidity was retrieved from NASA POWER project.
Discharge Data	Bangladesh Water Development Board (BWDB)	Dalia (u/s of Teesta Barrage)	1985-2013	Discharge data of Dalia point was collected from BWDB

The discharge data of Dalia point, upstream of Teesta Barrage which is situated in Nilphamari district near the Bangladesh-India border has been collected from Bangladesh Water Development Board (BWDB) for the period of 1985-2013.

3.2. Model Setup

The physically based semi-distributed hydrological model Soil and Water Assessment Tool (SWAT) of Arnold and Allen [8] selected for study. The model uses spatially distributed physiographical, meteorological and streamflow data to calculate water balance components at daily time steps. All the computations are performed at HRU level [9]. HRU is the smallest spatial discretization level created from unique combination of land use, soil type and slope. The hydrological cycle as simulated by SWAT is based on the water balance equation which is given below:

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right) \quad (1)$$

Where SWt is the final soil water content, SW_0 is the initial soil water on day i, t is the time in days, R_{day} is the amount of precipitation on day i, Q_{surf} is the amount of surface runoff on the day i, E_a is the amount of evapotranspiration on day i, w_{seep} is the amount of water entering the vadose zone from the soil profile on day i and Q_{gw} is the amount of flow on the day i (All units except the time are presented as mm of water).

The watershed of the Teesta River basin delineated using the Arc-SWAT tool had an area of 9,993 sq. km and it was divided into 43 sub-basins. Based on land cover, soil type and slope of the watershed, the sub-basins were further subdivided into 360 HRUs (Average area 27.76 sq. km).

Once the discretization into HRU level was completed, weather datasets such as daily precipitation, mean daily temperature, wind speed and relative humidity was applied for the base model (1995-2013). The first three years of the simulation (1995-1998) served as the warm-up period of the model and model outputs beginning from 1999 was considered for the base model. The potential evapotranspiration (PET) estimates was calculated using Penman/Monteith method while for rainfall distribution, the skewed normal distribution was used. The variable storage method developed by Williams (1969) [10] was selected as the channel routing method.

3.3. Model Development

Calibration is generally done with the latest available data series. As a result the final eight years of available data series that is from 2006-2013 has been used for calibration. After finalizing the parameters the model was simulated for the entire time frame and the first seven years of the simulation from 1999-2005 was chosen as the validation period for the model. The calibration and validation plots of the model at Dalia point is shown in Figure 2. The performance of the model in both calibration and validation stage were evaluated using various Goodness-of-Fit statistics: the Nash–Sutcliffe Efficiency value (NSE), the coefficient of determination (R^2), percent bias (PBIAS) and the ratio of the root mean square error between the simulated and observed values to the standard deviation of the observations (RSR). The NSE, R^2, PBIAS and RSR for the calibration & validation periods are 0.91 & 0.80, 0.93 & 0.85, 12.48 & 17.82 and 0.30 & 0.44, respectively. These statistics demonstrated that, the developed SWAT model for the Teesta River basin generally performed well in both calibration and validation stages, which established the basis for conducting climate change studies based on the simulations of the SWAT, assuming the basin's physical conditions remain basically unchanged.

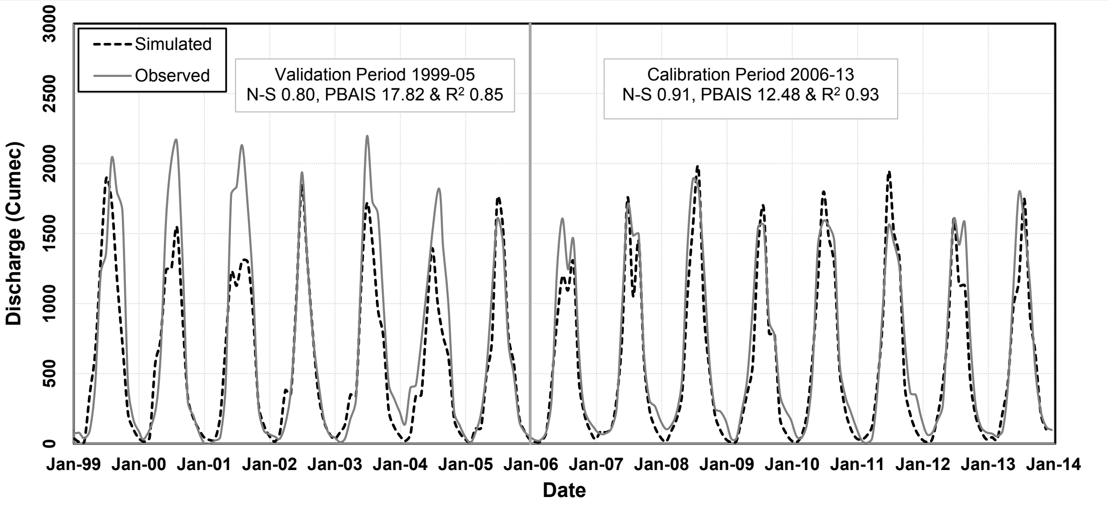

Figure 2. Monthly observed and simulated flows at Dalia point for calibration and validation of the model

Table 2. Statistical performance of the developed Teesta river basin model

Period		Observed Mean (m^3/s)	Simulated Mean (m^3/s)	Model Performance Parameter			
				N-S	PBAIS	RSR	r^2
Calibration	2006-2013	634.46	549.48	0.91	12.48	0.30	0.93
Validation	1999-2005	684.64	576.52	0.80	17.82	0.44	0.85

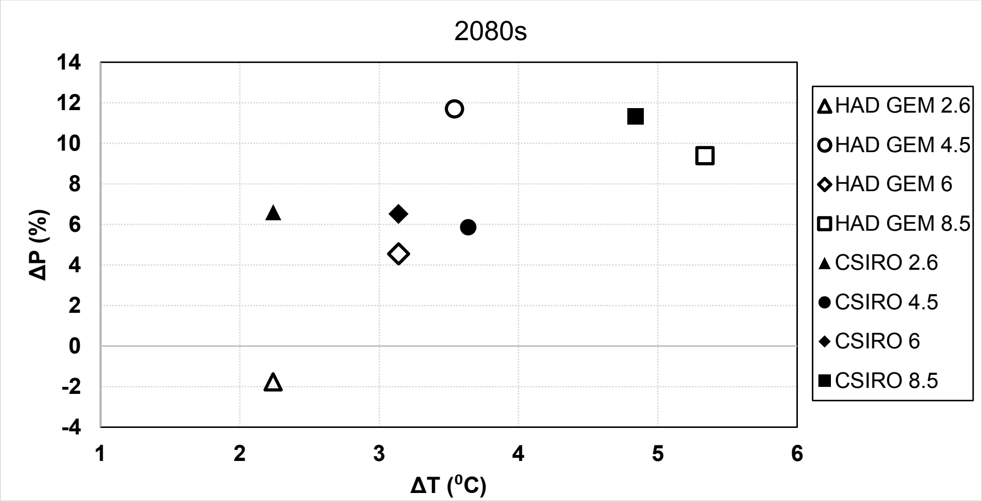

Figure 3. ΔTmax vs ΔP Plot for the 2080s

Table 3. Selected Scenarios

Scenario	Model	RCP	Δ Value
Wettest	HAD GEM 2 ES	4.5	ΔP = 11.71%
Driest	HAD GEM 2 ES	2.6	ΔP = -1.76%
Warmest	HAD GEM 2 ES	8.5	ΔT = 5.34°C
Coolest	CSIRO MK 3.6.0	2.6	ΔT = 2.24°C

3.4. Scenario Selection

For the CMIP5 twenty eight different institutions have sixty one different GCM models, with each GCM model providing completely different output from the other one. Working with all those sixty one models becomes quite challenging. Thus selecting proper scenarios becomes very important. For the purpose of this study all the RCP scenarios (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) for two different GCMs were chosen. The GCMs are HADGEM 2ES and CSIRO MK 3.6.0. The acquired downscaled GCM data has been analyzed at different point of the Teesta Basin to find the wettest, driest, coolest and warmest model scenarios for each of the RCPs. The precipitation data have been analyzed at eighty eight (88) different points and the temperature data have been analyzed at sixty three (63) different points. From the analyzed downscaled GCM data, Figure 3 has been produced which shows ΔTmax vs ΔP Plot for 2080s.

From the analyzed data four climate change scenarios were chosen: “Warmest” (projecting the highest temperature increase by 2080s), “Coolest” (projecting the lowest temperature increase by 2080s), “Driest” (projecting the lowest precipitation increase or highest precipitation decrease by 2080s), and “Wettest” (projecting the highest precipitation increase or lowest precipitation decrease by 2080s). The selected scenarios are shown in Table 2.

3.5. Impact Assessment

Statistically downscaled GCM data downloaded from CGIAR to be used as the input for the climate change scenarios. The downscaled data had a 0.5 degree resolution. The outputs of these option model were compared with the base model of the climate normal period to find out the changes due to climate change in the Teesta River Basin.

4. Result

After simulating the model for the base condition and the option scenarios, the water balance for the option model was compared with base model to find the changes in water balance due to climate change scenarios. Along with that, changes to the flow at Dalia point, upstream of Teesta Barrage due to different climate change scenarios were also compared.

4.1. Water Balance of base model

The water balance of the Teesta Basin for base model condition is shown in Table 4. It can be seen that July is the wettest month (520.94 mm) and December is the driest month (4.31 mm) in the Teesta Basin. Around 39% of precipitation gets converted into surface runoff, while the share of sub surface flow and shallow ground water flow remains at 17% and 23% of precipitation respectively. 24% of precipitation turned to evaporation. Around half of the stream flow comes from the surface runoff (49%). The water balance of the Teesta River Basin has been presented graphically in Figure 4, which can better illustrate the temporal changes of each parameter of the water balance.

4.2. Changes in Water Balance

Figure 5 shows changes in precipitation with respect to base condition for different climate change scenarios. All the graphs generally shows similar kind of trend, decreasing rainfall in the dry season and increasing rainfall for the monsoon season. For the wettest scenario, the precipitation increases by 48% in the month of June comparing to the base condition but still predicts 30% less precipitation for the month of March. The driest scenarios predicts a 43% decrease of rainfall in February but still predicts 14% higher precipitation in the month of September. The similar trend can be more or less observed for the Warmest and Coolest scenarios. So analyzing the changes of precipitation due to climate change scenarios, it can be said that, the lean season will get more drier and the monsoon season will get more wetter due to climate change.

The changes in Surface runoff has also been prepared for different climate change conditions which is shown in Figure 6. Except the coolest scenario, where the surface runoff has increase all throughout the year, the general trend for the changes in surface runoff, is that is has increased in the monsoon season and decreased in the lean season. It can be seen that the surface runoff has decreased by 70% for the driest condition in the month of February. Even for that dry lean season, the monsoon flows may increase by as much as 15% creating a more unbalanced condition in the future. As for the wettest scenario, in which the surface runoff increases by nearly 80% in the month of July while the lean season sees as much as 45% decrease in surface runoff in the month of February and March. So, from the analyzed surface runoff data it can be said that lesser water would be available in the dry season due to the effect of climate change.

The similar plots have been prepared for percolation as well which is shown in Figure 7. Omitting the graph of the coolest scenario, all the scenarios show a general trend, the percolation drops drastically in the lean season. While for the driest and the warmest scenario, the percolation sees only a marginal increase in the monsoon months. The coolest climate change scenario shows a complete different trend for percolation comparing to the other scenarios. It shows an increase in percolation in the dry season while the rate of percolation drops slightly in the peak monsoon season, increasing again in the post monsoon season.

Figure 8 shows changes in ground water flow in to the stream (Base Flow) with respect to base condition for different climate change scenarios. A distinct pattern can be seen from the figure. The base flow has increased substantially in the dry season for all the scenarios. Nearly 200% increase in base flow can be seen in the Figure for the warmest scenario while 40% increase in base flow occurs in the driest scenario in the dry season. This peak in base flow in the months of February and March is followed by a sharp decline in the month of April, May and June before reaching a steady state from July onwards. The base flow for the climate change scenarios starts to increase again after the month October. This sharp increase followed by a sharp decline in base flow in the dry season indicated that there is a water scarcity in those months and base flow increase tries to compensate for the lack of surface runoff.

The changes in Evapotranspiration has also been prepared for different climate change conditions which is shown in Figure 9. It can be seen from the Figure that the overall evapotranspiration has increased for the Teesta river basin due to Climate Change scenarios. The highest increase in evapotranspiration occurs in the warmest scenario which is due to the highest increase in temperature in this scenario. The evapotranspiration has increased by nearly 50% in the month of January but overall shows increase of about 15% for the warmest scenario. However the lowest increase in evapotranspiration occurs during the driest scenario which can be explained as the lack of water supply into the system. The evapotranspiration has increased by around 8% from the base condition even during the coolest scenario.

Figure 10 has been prepared to show the changes in water yield due to Climate change scenarios. Only the coolest scenario shows a continuous increase in water yield all throughout the year. The other scenarios shows a decrease in water yield in the dry season and an increase in water yield in the monsoon. The highest increase of water yield in the monsoon can be observed in the wettest scenario when the water yield increases by 52%. That means huge increase of water volume into the system during the monsoon which may cause flooding. However in the dry seasons, around a 25% percent decrease in water yield can be observed for wettest, driest as well as warmest scenarios. For the driest scenario, the water yield for February, March, April and May are considerably lower than the base condition. This implies that water scarcity may be observed during these months.

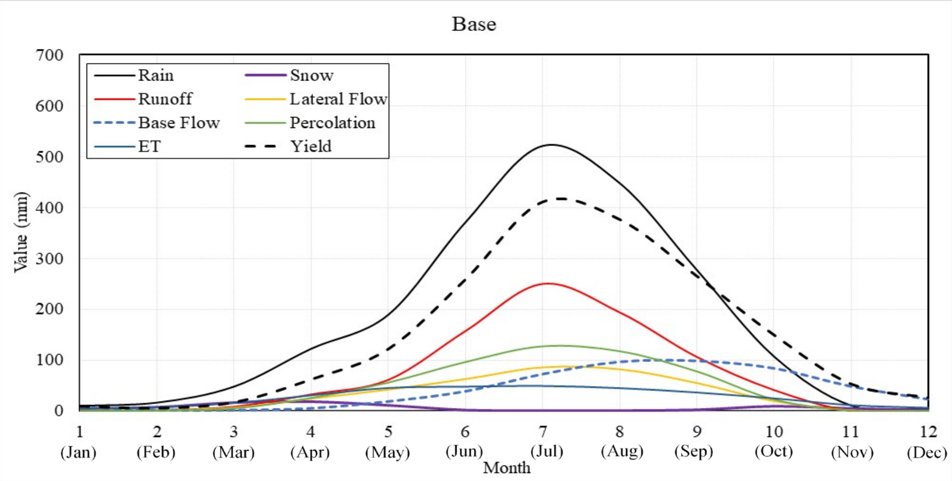

Figure 4. Water Balance of the Teesta Basin for Base Condition (1995-2013)

Table 4. Water Balance of the Teesta Basin for Base Condition (1995-2013)

Month	Water Balance Parameter (mm)							
	Rain	Snow	Surface Runoff	Lateral Flow	Base Flow	Percolation	ET	Yield
Jan	10.15	4.53	0.58	0.77	6.41	0.27	5	9.87
Feb	16.54	7.5	1.77	1.37	1.29	0.79	7.22	5.95
March	48.05	16.72	8.49	6.73	1.17	5.32	15.73	17.55
April	122.43	18.4	32.71	24.43	4.95	25.70	30.83	62.54
May	189.32	11.26	61.26	42.14	18.46	55.99	45.43	122.16
June	370.82	1.92	157.19	62.85	38.63	96.35	47.87	258.69
July	520.94	0.85	249.77	85.76	72.61	127.09	49.32	410.4
Aug	447.51	0.91	193.69	82.05	96.93	117.49	45.01	375.85
Sep	276.9	2.33	106.24	55	98.85	77.71	36.45	264.9
Oct	107.08	9.33	41.16	19.62	84.13	22.71	24.95	149.63
Nov	10.74	4.91	0.38	1.44	48.29	0.95	11.57	53.43
Dec	4.31	2.11	0.23	0.53	22.81	0.35	6.25	26.31
Sum	2124.79	80.77	853.47	382.69	494.53	530.73	325.63	1757.28

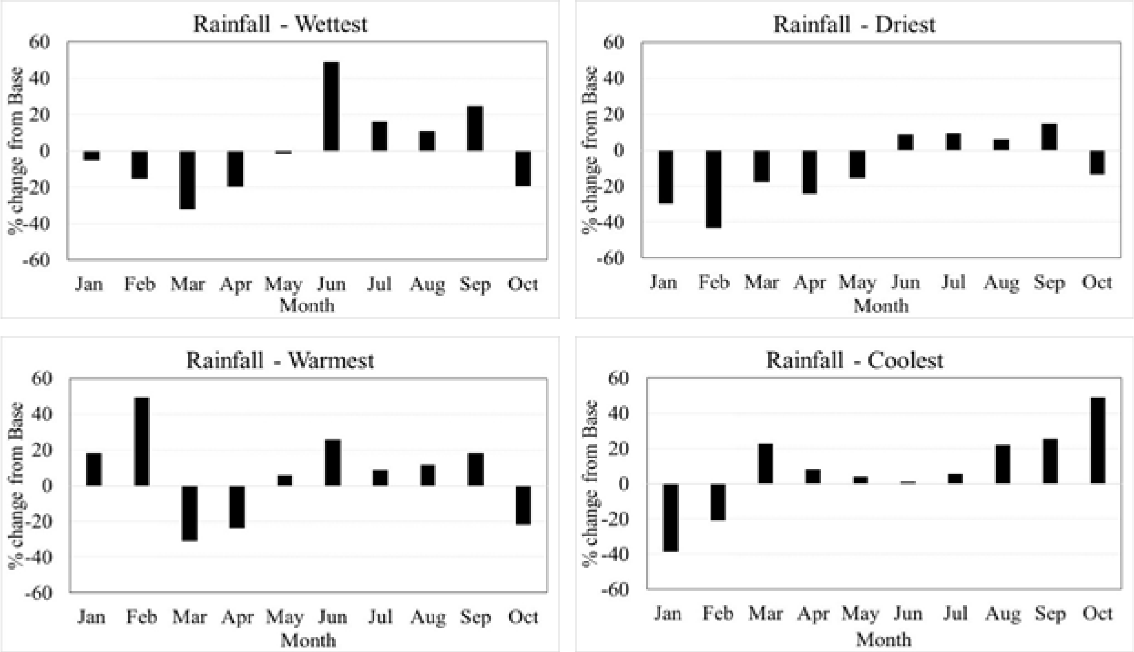

Figure 5. % Changes in Rainfall for different Climate Change Scenarios

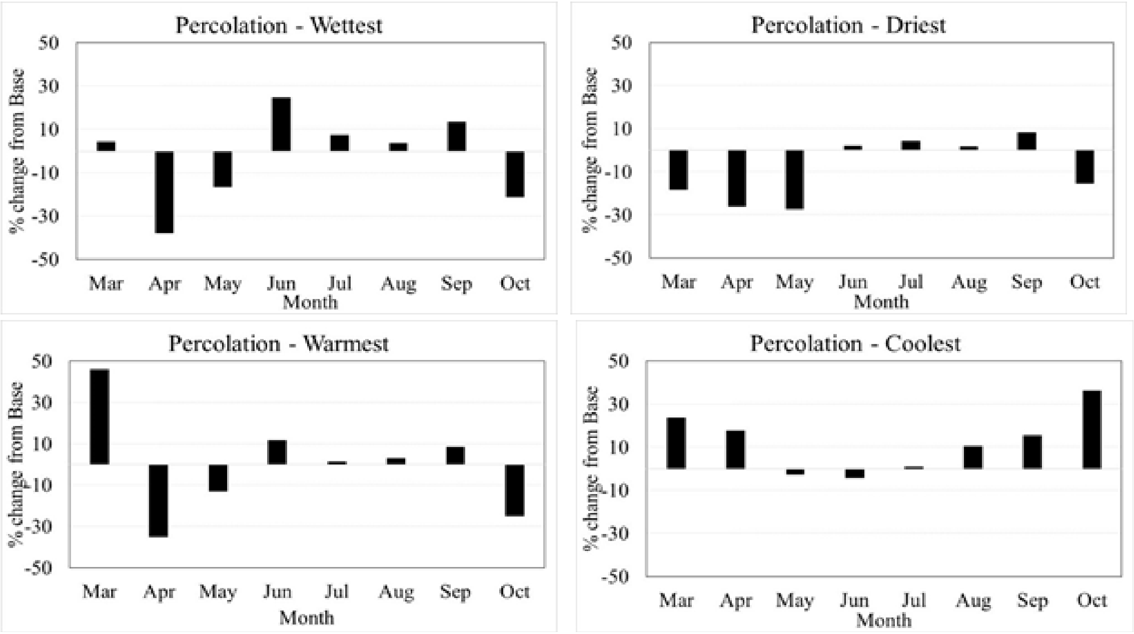

Figure 6. % Changes in Surface Runoff for different Climate Change Scenarios

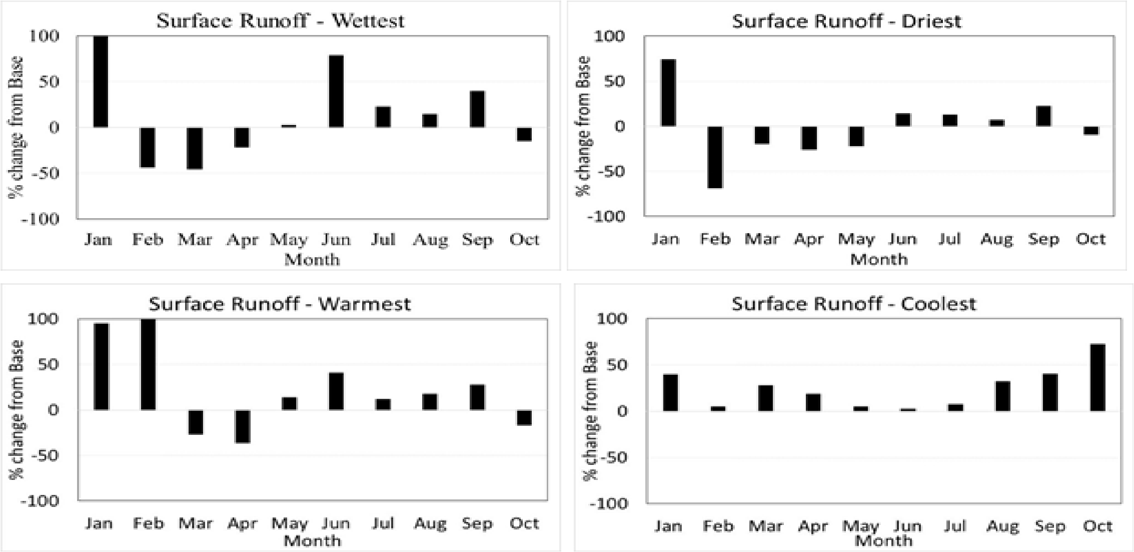

Figure 7. % Changes in Percolation for different Climate Change Scenarios

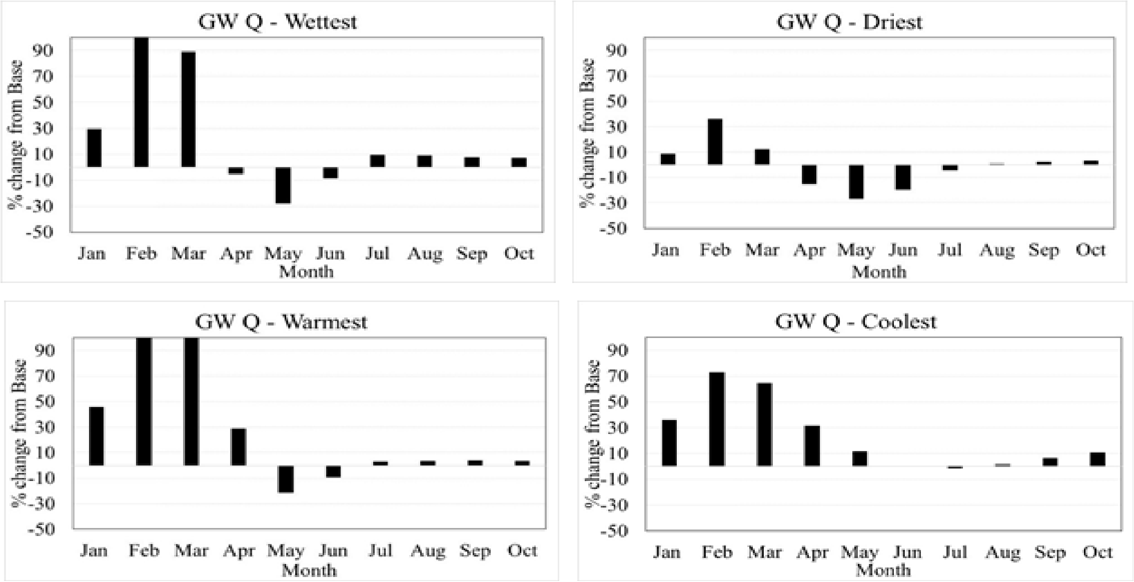

Figure 8. % Changes in Ground Water Flow for different Climate Change Scenarios

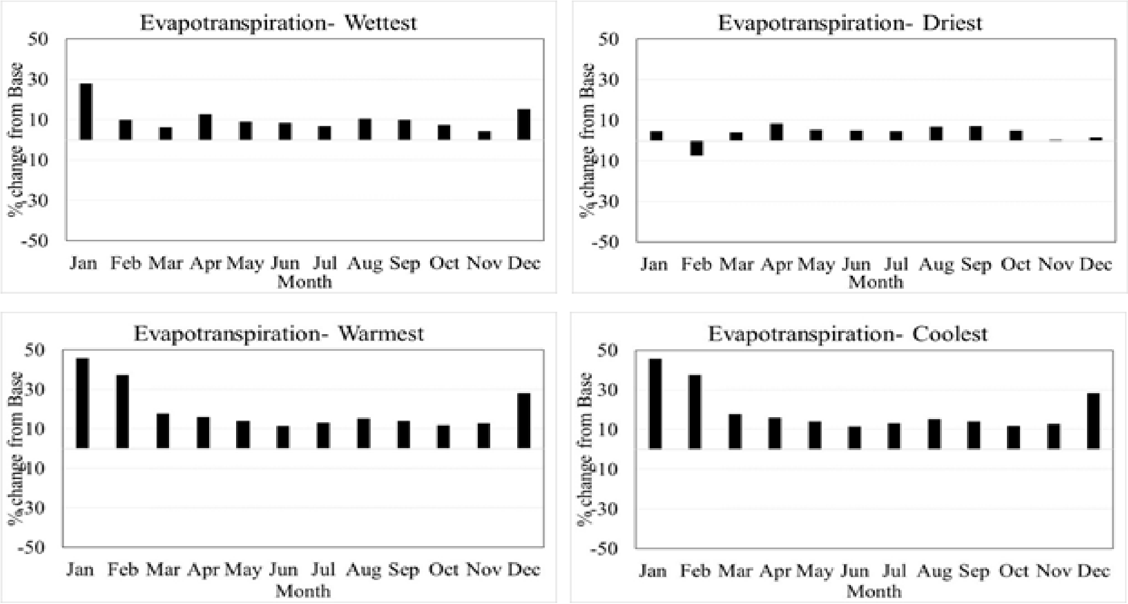

Figure 9. % Changes in Evapotranspiration for different Climate Change Scenarios

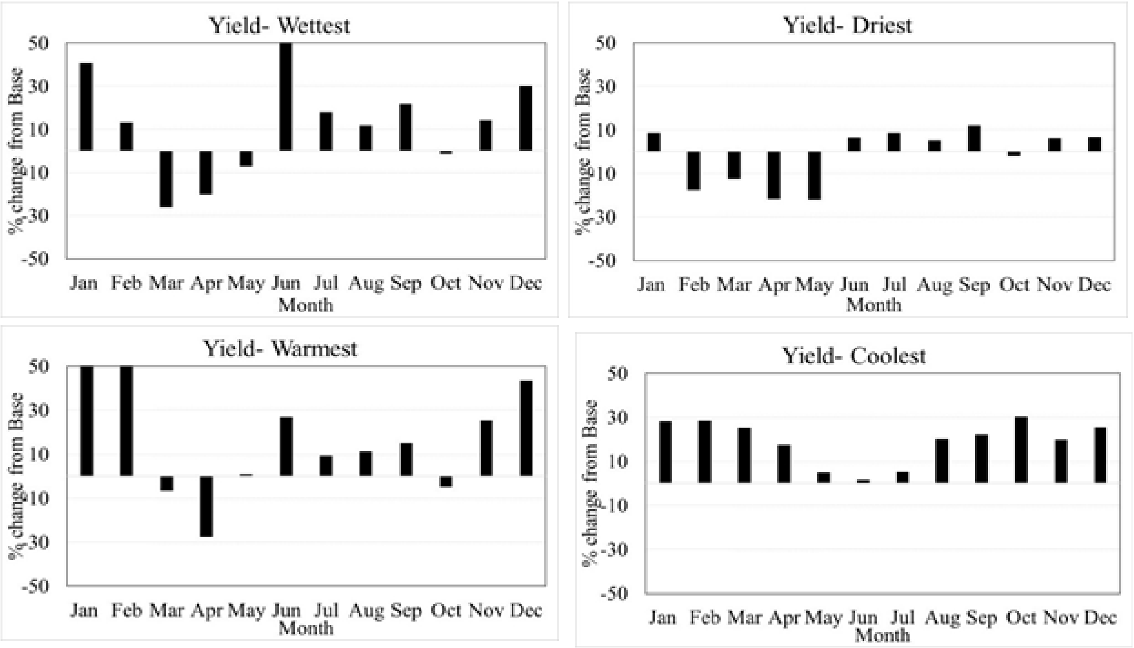

Figure 10. % Changes in Water Yield for different Climate Change Scenarios

Table 5. Mean Monthly Flow at Dalia due to different Climate Change Scenarios

Month	Base	Coolest	Warmest	Wettest	Driest
Jan	37.51	49.03	58.96	54.72	41.62
Feb	24.17	32.11	60.91	29.42	20.61
Mar	66.66	84.07	67.33	51.96	58.47
Apr	250.60	295.86	185.62	198.64	194.40
May	475.98	497.96	475.61	436.01	364.97
Jun	1025.22	1037.11	1302.46	1582.08	1086.55
Jul	1575.40	1652.13	1720.20	1862.40	1712.20
Aug	1442.69	1742.40	1606.67	1620.27	1522.13
Sep	1046.33	1287.01	1211.61	1281.18	1177.17
Oct	571.31	752.28	540.12	561.86	558.22
Nov	210.45	254.96	271.47	244.05	226.15
Dec	100.40	126.97	146.35	131.77	108.07

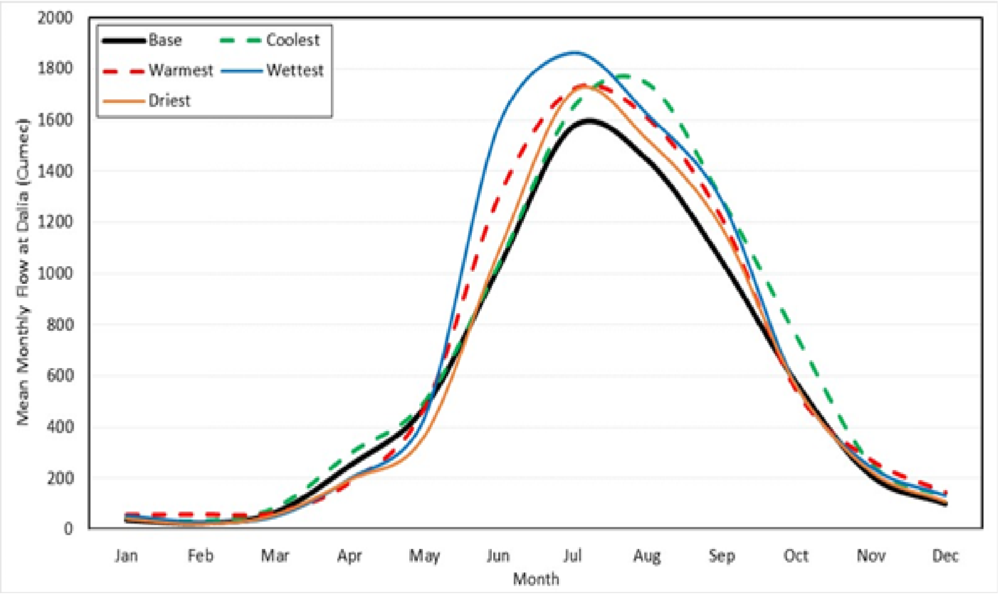

Figure 11. Mean Monthly Flow at Dalia due to different Climate Change Scenarios

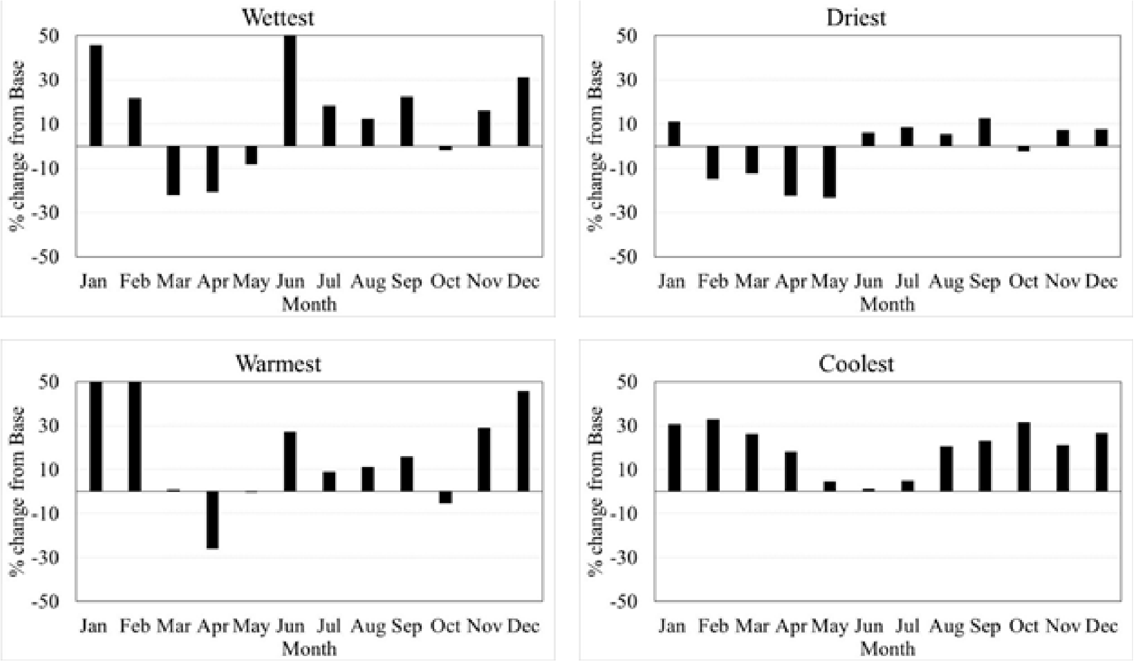

Figure 12. % Change in Mean Monthly Flow at Dalia due to different Climate Change Scenarios

4.3. Flow at Dalia Point, Upstream of Teesta Barrage

The flow at Dalia Point due to different Climate Change scenarios is shown in Table 5. The data set has been presented graphically in Figure 11. From the figure it can be seen that the flow at Dalia point will increase in the monsoon season for all the scenarios. For the wettest scenario, the mean monthly flow in the month of June increases by more than 50%. The peak flow also increases by 18%. But the wettest scenario also sees more than 20% reduction in flow in the month of March and April. The lowest lean season flow occurs in the driest scenario where the lean season mean monthly flow drops to 20 cumec. The driest scenario sees 15% reduction in flow in February, 13% in March and close to 25% in the months of April and May. Hence in the driest scenario the water availability during the lean season will substantially decrease. The warmest scenario more or less follows the same pattern as the wettest and the driest scenarios, reduction in flow during the lean season while the flow increases in the monsoon. The worst case scenario is in the month of April for the warmest scenario when the mean monthly discharge decreases by more than 25%. The coolest scenario shows a different kind of trend comparing to the other scenarios. The flow at Dalia point shows an increasing trend throughout the year for the coolest scenario.

But from the general trend, it can be said that due to climate change the Dalia point will experience a more severe shortage of water during the lean season even without the future upstream control structures. Percent Change in Mean Monthly Flow at Dalia due to different Climate Change Scenarios is shown in Figure 12.

5. Conclusion

Potential change in the water balance due to climate change and upstream development in the Teesta River Basin has been assessed using SWAT hydrological model. The climate change scenarios were based on the projection of couple of GCM models (HAD GEM2 ES and CSIRO MK 3.6.0) for all the RCP scenarios of IPCC AR-5, during the 2050s and 2080s.

The downscaled GCM model data of temperature and precipitation for all the RCPs were analyzed at different points in and around the Teesta to find the driest, wettest, warmest and coolest scenario of the Teesta basin in 2080s, which were found to be HAD GEM2 ES RCP 2.6, HAD GEM2 ES RCP 4.5, HAD GEM2 ES RCP 8.5 and CSIRO MK 3.6.0 RCP 2.6 respectively. For the wettest scenario the precipitation had increased by 11.71% while it decreased by 1.76% for the driest scenario. The increase in temperature for the coolest and the warmest scenario is found to be 2.24°C and 5.34°C. These scenarios were used as the input data for SWAT model to assess the changes in water balance due to climate change.

And before inputting the climate change scenarios, the hydrological model was calibrated and validated between the periods of 1998 to 2013. The 1998-2013 model result served as the base model output to be compared against climate change model results. Comparing the water balance of the climate change model with the base model, it was clearly evident that the monsoon season will become more wetter and the dry season become more drier due to climate change for all the climate change scenarios. The monsoon may see as much as 80% increase in surface runoff (wettest scenario) while the dry season might see a 70% decrease in surface runoff (driest scenario). The base flow is expected to decrease in the month of April, May and June while increase in temperature means the evapotranspiration is expected to increase all throughout the year. The outputs of water yield shows it might increase by more than 50% in the monsoon season and reduce by 30% for the dry seasons.

The flow comparison at the Dalia point for different climate change scenarios shows similar kind of trend to that of the water balance comparison. While for the wettest scenario the mean monthly flow may increase by more than 50%, for the driest scenario the mean monthly flow in the lean season may decrease by around 20%. The general trend emerging from the flow analysis is that the Dalia point will experience a more severe shortage of water during the lean season even without the upstream development.

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