CLIMATE CHANGE IMPACTS ON WATER AVAILABILITY IN THE MEGHNA BASIN

Bhuiya Md. Tamim Al Hossain[1*], Tanvir Ahmed[2], Most. Nazneen Aktar[3], Malik Fida Abdullah Khan[4], A K M Saiful Islam[5], Munshi Md. Shafwat Yazdan[6], Farhana Noor[7], Ahmmed Zulfiqar Rahaman[8]

[1]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail: cetamim@gmail.com
[2]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail: tahmed.wre@gmail.com
[3]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail:nazneen.aktar@yahoo.com
[4]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, email: mkhan@cegisbd.com
[5]Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh, e-mail: akmsaifulislam@iwfm.buet.ac.bd
[6]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail: yazdan06buet@gmail.com
[7]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail: 07farhana@gmail.com
[8]Center for Environmental and Geographic Information Services (CEGIS), Dhaka-1212, Bangladesh, e-mail: saikat07_wrebuet@yahoo.com

ABSTRACT

The Meghna River is one of the most important rivers in Bangladesh and the largest fanning out to the Bay of Bengal. Climate change impacts in Bangladesh are showing various impacts in the Meghna river basin. In recent years, a number of studies have assessed the impact of climate change on water resources in Bangladesh. However, none of the studies attempted to assess the basin level water resources availability incorporating climate change scenarios. In this context, an approach has been developed in this paper to establish a basin scale hydrological model for the Meghna basin to predict the impact of climate change on national and sub-national water resources availability on three time slices up to 2100. A semi-distributed hydrological model SWAT has been utilized. Temperature and precipitation data from 9 GCMs and two SRES scenarios (A1B and A2) are used along with various input data (e.g., DEM, land use/cover, soil type, discharge). Besides, assessment of statistical confidence of the results from different GCM is done utilising the non-parametric Mann-Whitney U test. The monthly changes in discharge for different scenarios are compared with base at Bhairab Bazar. The results indicate that the flow reduces for most of the time until 2050.

Keywords: *Climate change, hydrologic modelling, water availability, Meghna basin*

1. INTRODUCTION

The Meghna River is one of the most important rivers in Bangladesh and the largest fanning out to the Bay of Bengal. The Meghna Basin comprises of an area of about 75,500 km^2 out of which around 68% area lies within India. The Meghna is formed inside Bangladesh by the joining of different rivers originating from the hilly regions of eastern India. The Barak River is a major river of north-eastern India and it is the source of the Surma-Meghna Kushiyara River System in Bangladesh. The principal tributaries of the Barak in India are the Jirl, the Dhaleshwari, the Singla, the Longai, the Sonai and the Katakhal. The Barak River flows westward through Manipur, Mizoram and Assam states of India. Reaching the border with Bangladesh at Amalshid in Sylhet district, Barak splits to form the rivers Surma and Kushiyara. The Meghna is an important river in South Asia, and is one of the three major rivers that flow into the Ganges delta. The river meets Padma River in Chandpur District. Figure 1 shows the catchment area and tributaries of the Meghna river basin.

Climate change is an unfolding physical phenomenon with very drastic and adverse environmental, economic, social, even cultural consequences, particularly for Bangladesh. The country is going to be one of the worst victims of climate change in the world. Warming of the climate system is now an established fact. It is now evident from observations that, among other things, global average air and ocean temperatures are rising, widespread melting of snow and ice is occurring, and global sea level is rising. Climate change impacts in Bangladesh are showing various impacts in the Meghna river basin also. In recent years, a number of studies have assessed the impact of climate change on water resources in Bangladesh. However, none of the studies attempted to assess the basin level water resources availability incorporating climate change scenarios. In this context, an approach has been developed in this paper to establish a basin scale hydrological model for the Meghna basin to predict the impact of climate change on national and sub-national water resources availability on three time slices up to 2100.

2. METHODOLOGY

The study follows a multi step methodology. This is described in the following paragraphs. The steps are:

i. Selecting emission scenario
ii. Selecting GCMs
iii. Data collection and preparation
iv. Hydrological model development
v. Calibration and validation
vi. Estimation of flows and changes in future time slices

2.1 Selecting emission scenario

Emission scenarios are derived from population, economic and technology scenarios, which also shape vulnerability and hence impacts of climate change. Emission scenarios drive scenarios of climate change, which in turn drive impacts research. In order to have a common and global set of climate change scenarios, the IPCC in 1990 published the first set of emission scenarios, known as SA90. Thereafter, it published IS92 and SRES scenarios. According to Nakicenovic (2000), there are four base scenarios in the SRES: A1, A2, B1 and B2. The A scenarios place more emphasis on economic growth, the B scenarios on environmental protection; the 1 scenarios assume more globalization, the 2 scenarios more regionalization. The A1 scenario has three variants: A1B, A1FI, and A1T. According to the IPCC AR4, there are mainly three emission scenarios such as high A2, medium A1B and low B1. These emission scenarios describe three different possibilities e.g., a global curbing of emissions over the next century (B1), a mid-21st century levelling-off of emissions (A1B), and a continual increasing rate of emissions over the 21st century (A2) (Nakicenovic 2000). Due to these patterns, during 2050 A1B shows higher temperature and precipitation estimates than A2, while during 2100 the situation is completely opposite. Based on these characteristics of different emission scenarios, A2 and A1B scenarios have been selected for the present study. A2 has been selected as an extreme scenario and A1B has been selected as a balanced scenario.

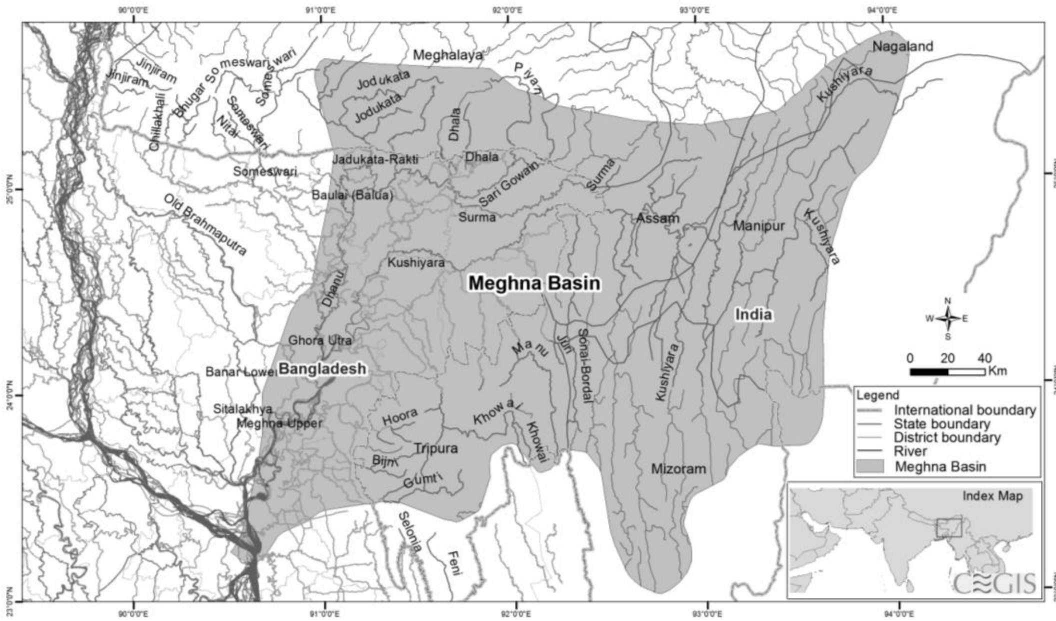

Figure 1: River system of the Meghna Basin

2.2 Selecting GCMs

Climate data for the future is an important part for water availability assessment for future. For this purpose, projected data set on climate change from different IPCC approved GCMs are required. So, for the present study, nine GCMs were selected which have better representation of climate system in areas near Bangladesh (Mukherjee et al, 2011). These GCMs are: CGCM3.1 (T47), CSIRO-Mk3.0, GFDL-CM2.0 and CM2.1, INM-CM3.0, MIROC3.2 (medres), ECHAM5, CCSM3 and UKMO-HadCM3. Temperature and precipitation data from these 9 GCMs for two emissions scenarios (A1B and A2) are used to characterize the range of potential climate changes for the GBM basins and Bangladesh. Additionally, PRECIS RCM data (for A1B and A2 scenarios) have been used for the model solely for areas covering Bangladesh. For the simulation with PRECIS data, the GCM data of UKMO-HadCM3 has been used for areas outside Bangladesh.

2.3 Data collection and preparation

For the hydrological model development several data layers are required. These are: weather/ climate data, topography data, land use and soil data and discharge data for calibration.

2.3.1 Weather/ climate data

The weather data for the Meghna basin has been collected from NASA POWER website (http://power.larc.nasa.gov). From this source daily weather data (precipitation, minimum and maximum temperature) has been collected for 1981 to 2012. The data has a spatial resolution of 1°. At the same time, weather data of BMD stations for the same period has been collected also.

The GCM data for three future time slices centering on 2030, 2050 and 2080 were collected as monthly average. The used data sets are downscaled from the CMIP3 multi-model dataset (Meehl et al., 2007) using the bias-correction/ spatial downscaling method (Wood et al., 2004) to a 0.5 degree grid, based on the 1950-1999 gridded observations of Adam and Lettenmaier (2003) (Maurer et al., 2009). These dataset is available at www.engr.scu.edu/~emaurer/global_data/.

2.3.2 Topography data

The topography data includes the Digital Elevation Model (DEM) data and has been collected for the Meghna basin area from the Shuttle Radar Topography Mission (SRTM). The DEM resolution is 90m. Besides for the area inside Bangladesh, the national DEM of Bangladesh has been used from the national water resources database (NWRD).

2.3.3 Land use and soil data

Model development incorporates input data from land use/cover data and soil type data. Land use data for Meghna basins has been collected from USGS - Global Land Cover 2000 database which has a spatial resolution of 1 km. The soil type data was collected from the Food and Agricultural Organization database. The spatial resolution is 10 km with soil properties for two layers 0-30 cm and 30-100 cm depth. Besides these, land use and soil data for areas inside Bangladesh are collected from NWRD and the Soil Resource Development Institute (SRDI).

2.3.4 Discharge data

For model calibration and validation, discharge data is essential. The discharge locations for the model calibration have been selected based on the availability of data. The discharge data has been collected from NWRD database for the stations in Bangladesh.

2.4 Hydrological model development

In order to assess the water availability for different climate change scenarios a semi-distributed hydrological model named Soil and Water Assessment Tool (SWAT) has been utilized. The SWAT model (Arnold et al., 1998, Arnold et al., 2009) is a physically-based, continuous simulation model developed for watershed assessment of short- and long-term hydrology and water quality. It is a widely used catchment-scale model that can predict the impact of land management practices and climate change over time on water, sediment and agriculture (Santhi et al., 2001). The model development has been completed in five sequential steps, namely, watershed delineation, weather data definition, editing SWAT inputs, calibration and validation and simulation. For the present study two model setup was done, the coarse-scale Meghna basin model (covering the whole basin) and fine-scale North-east, north-central and south-east region model (covering the North-east, north-central and south-east hydrological regions of Bangladesh). The NE-NC-SE region model is feeded by the outputs from the coarse model. The watershed delineation is accomplished using the automatic watershed delineation tool of SWAT 2012 employing a resampled 900 m DEM for Meghna basin and resampled 200 m DEM for NE-NC-SE region. After watershed delineation, the Meghna basin has been divided into 74 watersheds while the finer model is divided into 315 watersheds.

During the model development, the distribution of rainfall has been done by the skewed normal probability distribution function. SWAT uses Manning‘s equation to define the rate and velocity of flow while routing through channel network has been done using the variable storage routing method. For estimating runoff, the SCS curve number method (variable CN: Moisture condition II) has been used. The Hargreaves method has been used to calculate potential evapotranspiration (PET). Existing irrigation practices as per crop water demand and irrigation sources has also used in the SWAT model setup. The spatial distribution of the surface water and groundwater irrigation activities has been collected from Global Map of Irrigation Areas (Siebert et al., 2013).

2.5 Calibration and validation

The developed models has been calibrated and validated against daily and monthly stream flow data for the period of 1981 to 1990 and 1991 to 2000 respectively. To facilitate the evaluation of model quality, visual comparison has been normally done between observed and simulated hydrographs; also, some statistical analyses have been applied, such as Nash-Sutcliffe Efficiency (NSE), Coefficient of determination (R^2), Mean Relative bias (PBAIS) and ratio of the root mean square error to the standard deviation of measured data (RSR). For the model calibration, SWAT-CUP has been used.

2.6 Estimation of flows and changes in future time slices

Stream flow has been generated from the developed model (both for present condition as well as the future) at different crucial points in some major rivers which are basically the outflow of different sub-catchments. The models have been run to generate monthly results for different time slices e.g., base period, 2030, 2050 and 2080.

During SWAT modelling for the different downscaled GCM and RCM outputs, it has been found that there is a large range of variation in model results for the same time slice. So, an attempt was made to assess the confidence of the results. In order to do this, non-parametric Mann-Whitney U test (Haan, 2002; Maurer, 2007) has been employed to assess the probability that the changes in future projections are statistically significant. The analysis has been carried out following the approach of Maurer (2007). In this method, all GCM/RCM fed results of SWAT for the same emission scenario and time slice are assembled together in an ensemble and it was compared with base period for equality of means. These results are also presented with the results of future changes in flow patterns.

3. RESULTS

In this study, base period has been taken from 1981 to 2012. Basin-wise water availability of the base scenario has been analyzed based on SWAT results. The detail results are presented in the following sections.

3.1 Calibration and validation of the model

The SWAT model has been calibrated at Bhairab Bazar for the Meghna basin. The model has been calibrated during 1981 to 1990 and validated during 1991 to 2000 against monthly discharge data.

Figure 2 presents the visual comparison of simulated flow and observed flow of Bhairab Bazar station. The simulated results under-predicted the high flows in 1988 and in other years also. In the context of low flow, the observed and simulated flow matched each other very well. In validation period the simulation is also relatively well.

The model performance has been evaluated by analyzing the statistical measures after SWAT simulation. The statistical measures of the Meghna basin for the calibration and validation periods are shown in Table 1. From the table it can be seen that, NSE shows very good performance rating for calibration period and good during validation period. PBIAS shows good performance for calibration and satisfactory during validation period. RSR shows very good performance during calibration and satisfactory performance in validation. R^2 shows satisfactory results for both calibration and validation time period.

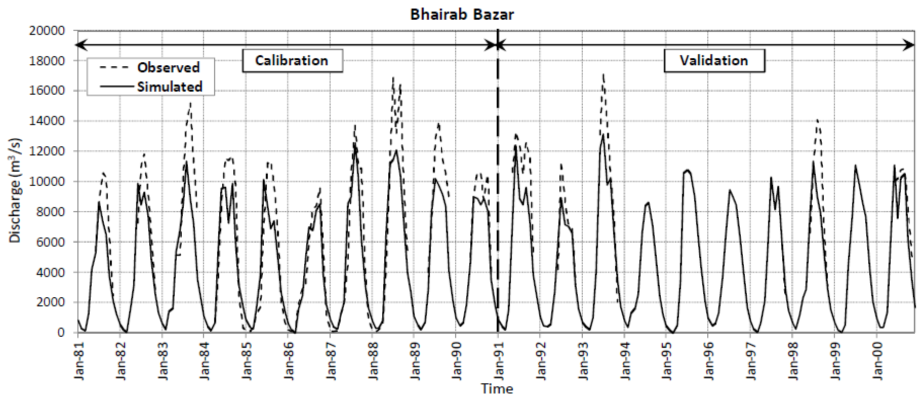

Figure 2: Calibration and Validation of SWAT model at Bhairab Bazar

Table 1: Model performance statistics for calibration and validation period of the Meghna basin

Station	**Calibration (1981-1990)**				**Validation (1991-2000)**			
	NSE	**PBIAS**	**RSR**	**R2**	**NSE**	**PBIAS**	**RSR**	**R2**
Bhairab Bazar	0.77	14.38	0.48	0.83	0.63	15.38	0.61	0.78

The basin-wise water availability of the base scenario has been analyzed based on SWAT results. The average annual flow generated from the Meghna basin is 170,100 Mm^3. The flows are mainly concentrated in the monsoon period (June to October) and the maximum monthly flow is 31,109 Mm^3. For the Meghna basin, the peak flow occurs during August. The annual average water balance analysis of the meghna basin for the base period is presented in Table 2. The water balance in SWAT considers precipitation and snow melt as inflow while evapotranspiration and percolation as loss and surface runoff and lateral flow as the outflow. The annual average water balance for the meghna basin shows a very good match.

Table 2: Water Balance in the Meghna basin during Base period

Basin	**Precipitation (mm)**	**Snow melt (mm)**	**Evapotranspi-ration (mm)**	**Percolation (mm)**	**Surface runoff (mm)**	**Lateral flow (mm)**
Meghna	207,422	-	67,226	97,186	40,865	2,177

The calibrated and validated models has been utilised to simulate six sets of climate change scenarios (A1B and A2 scenario for 2030, 2050 and 2080). The SWAT model has been run for the future considering a monthly change in temperature and precipitation with respect to base period. Table 3 and Figure 3 shows the results of monthly average discharge during base period and also the changes in future scenarios at Bhairab Bazar. The results indicate that the flow reduces for most of the time until 2050. It was also found that there were large variations among different GCM/RCM data. It is found that flow increases during April and May months of 2030 and 2050, while for 2080, there is increase during February, March and monsoon. Maximum reductions in flow volumes are found for March in 2030 and 2050 while for 2080, there is highest decrease in June. The results of Mann-Whitney U test shows that the statistical significance of the future changes are mostly around 50% while for some months the significance is very small (10%) or negligible.

Table 3: Monthly flow volume change of climate scenarios with respect to base scenario for the Meghna basin at Bhairab Bazar

Month	Discharge (Mm^3)	Percentage change of monthly flow					
		A1B_2030	A2_2030	A1B_2050	A2_2050	A1B_2080	A2_2080
January	2,266	-2.58	-5.76	-5.57	2.84	0.68	8.48
February	820	1.41	-1.52	-0.68	0.41	15.74	16.14
March	946	-15.20	-21.82	-24.08	-24.06	51.41	53.49
April	3,852	17.62	-3.18	1.78	18.68	-17.26	18.44
May	11,891	34.05	-12.50	18.34	5.16	-17.54	27.99
June	30,015	-11.63	-22.33	-13.26	-3.62	-18.82	6.94
July	30,821	-4.36	-13.93	-14.61	-3.30	6.09	9.89
August	31,109	-14.32	-16.33	-8.63	-14.97	-10.67	0.69
September	23,878	-2.89	-7.34	1.93	8.00	4.85	25.68
October	20,146	-3.41	-19.13	-5.62	-15.07	-6.32	1.33
November	9,402	-1.33	-3.47	-3.10	1.92	-1.41	15.89
December	4,955	-4.26	-3.63	-5.01	1.22	-3.04	10.53

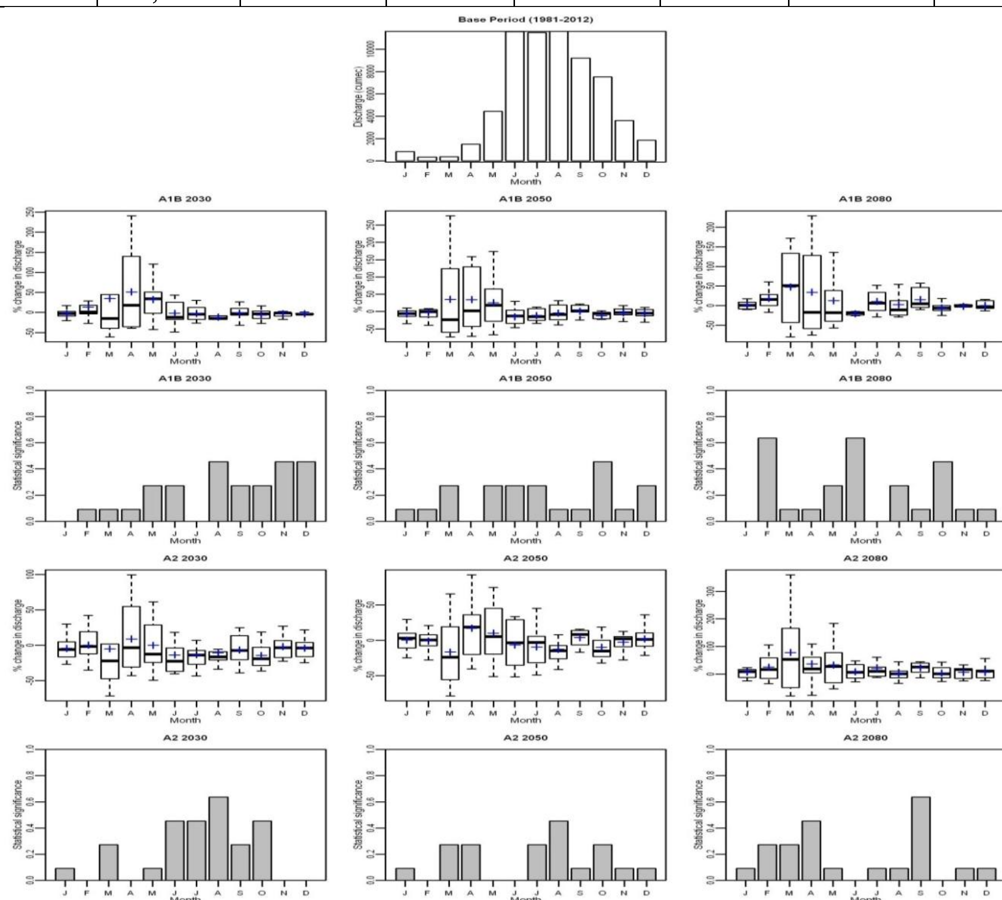

Figure 3: Monthly flow in Meghna River at Bhairab Bazar

4. CONCLUSIONS

The average annual flow volumes of different time slices shows that, annual flow volume decreases 4% by 2030, 6% by 2050 and 6% by 2080 for A1B scenario. For A2 scenario, the changes are 14% decrease (2030), 4% decrease (2050) and 11% increase (2080). These results present a overall holistic view of the whole basin and can be used in any future study as reference.

ACKNOWLEDGEMENTS

The authors express their deepest gratitude and thanks to CEGIS and PKSF for supporting and financing this research initiative. The authors are also grateful to the different organisations/ agencies that supported the study with data support. In this regard, special thanks goes to global downscaled CMIP3 dataset source (www.engr.scu.edu/~emaurer/global_data/), Met Office UK and IWFM, BUET for the PRECIS model results for Bangladesh, NASA POWER, SRTM, USGS-global land cover 2000, FAO soil database and FAO global map of irrigation areas.

REFERENCES

Adam, J. C. and Lettenmaier, D. P. (2003). "Adjustment of global gridded precipitation for systematic bias", J. Geophys. Res., 108, 1–14.

Arnold, J.G., Neitsch, S.L., Kiniry, J.R., and Williams, J.R. (2009). "Soil and Water Assessment Tool – Theoretical Documentation", Version 2009, Texas, USA.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., and Williams, J.R. (1998). "Large area hydrologic modelling and assessment: Part I. Model development". J. American Water Res. Assoc. 34(1): 73-89.

Haan, C. T. (2002). "Statistical Methods in Hydrology", second edition. Iowa State Press, pp. 496.

IPCC, (2007). "Climate Change 2007: The Physical Science Basis. Contribution Of Working Group I To The Fourth Assessment Report Of The Intergovernmental Panel On Climate Change". Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Maurer, E.P., Adam, J.C. and Wood, A.W. (2009). "Climate Model based consensus on the hydrologic impacts of climate change to the Rio Lempa basin of Central America", Hydrology and Earth System Sciences 13, 183-194.

Maurer, E.P., (2007). "Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California under two emissions scenarios", Clim. Change, pp. 82, 309–325.

Meehl, G. A., Covey, C., Delworth, T., Latif, M., McAvaney, B., Mitchell, J. F. B., R. Stouffer, J. and Taylor, K. E. (2007). "The WCRP CMIP3 multi-model dataset: A new era in climate change research", Bulletin of the American Meteorological Society, 88, 1383-1394.

Mukherjee, N., Khan, M.F.A., Hossain, B.M.T., Islam, A.K.M.S., Aktar, M.N., and Rahman, S. (2011). "A hybrid approach for climate change scenario generation for Bangladesh using GCM model results", Third International Conference on Water & Flood Management, Institute of Water and Flood Management (IWFM), BUET, Dhaka.

Nakicenovic N, Alcamo J, Davis G, de Vries D, Fenhann J, et al. (2000). "Special Report on Emissions Scenarios". The Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., Srinivasan, R. and Hauck, L.M. (2001). "Validation of the SWAT model on a large river basin with point and non point sources". J. American Water Resources Assoc. 37(5): 1169-1188.

Siebert, S., Henrich, V., Frenken, K., and Burke, J. (2013). "Global Map of Irrigation Areas version 5". Rheinische Friedrich-Wilhelms-University, Bonn, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: www.fao.org/nr/water/aquastat/irrigationmap/index10.stm

Wood, A.W., Leung, L.R., Sridhar, V., and Lettenmaier, D.P. (2004). "Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs", Climatic Change, 62, 189–216.