International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.3 Issue No.9, pp : 1170-1174 1 Sep 2014

Climate Change Impact on Haor flooding in Bangladesh using Three Global Circulation Models

Asadusjjaman Suman[1], Farnaz Akther[2], Biswa Bhattacharya[3]
[1, 2] Faculty of ESTeM, University of Canberra, ACT-2601, Australia
[3] Hydroinformatics System, UNESCO-IHE Institute for Water Education, Delft, The Netherlands
Corresponding Email: Asadusjjaman.Suman@canberra.edu.au

Abstract: ***The study presents the possibilities of climate change and their potential impacts on the flooding regime at Haor area of Bangladesh. The possible changes in the magnitude of flood were assessed using a hydrological and 1-D hydrodynamic model. Climate change scenarios were constructed from the results of three General Circulation Models (GCMs)- ECham5, CSIRO-Mk3.5 and MIROC3.2 (medres) with the B1 and A2 IPCC scenarios for 2050 and 2090. Different GCMs predict an increase in precipitation in the Haor area. The study also reveals an increase in peak discharge in the major rivers at the Haor area. The pre-monsoon flood peak discharge and water level are predicted to increase significantly compared to the monsoon peak and water level. A flood index was developed for 2050 with the predicted hydrograph. It is predicted that the flood severity would increase most of the rivers in the deeply flooded area of Haor. Further study considering the entire Haor area of Bangladesh is necessary to further investigate the flooding characteristics and the impact of climate change.***

Keywords: Haor area, Flood index, Climate change, ECHam5, CSIRO-Mk3.5, MIROC3.2 (medres), Bangladesh

I. Introduction

It is predicted that the frequency, depth and extent of flooding has increased in recent years due to climate change in Bangladesh. This research paper has presented climate changes impact on flooding at Haor area in Bangladesh. This area is located at north-eastern part of Bangladesh.

Normally Haors are almost round shaped tectonically depressed and marshy lands. Originally the word "Haor" is derived from the Sanskrit word "Sagor" which means sea. There are about 411 Haors in the Haor region of Bangladesh encompassing an area about 8,000 km^2 (BWDB, 2011). Haors can be divided into three categories depending on the geographical location and flooding characteristics of the area (CEGIS, 2011): i) Foothill and near hills Haor; ii) Floodplain area Haor; and iii) Deeply flooded Haor. In the deeply flooded Haors, flood depth and extent is higher in comparison to the foothill and floodplain Haors. According to the third assessment report of Intergovernmental Panel on Climate Change (IPCC) South Asia is the most vulnerable region of the world to climate change impacts (McCarthy et al., 2001). Bangladesh's high vulnerability to climate change is due to a number of hydro-geological and socio-economic factors that include: (a) its geographical location in South Asia; (b) its flat deltaic topography with very low elevation; (c) its extreme climatic variability that is governed by monsoon and which results in acute water distribution over space and time; (d) its high population density and poverty incidence; and (e) the majority of its population being dependent on agricultural crops, which are highly influenced by climate variability and change (Ahmed, 2006). Despite the recent strides towards achieving sustainable development, Bangladesh's potential to sustain its development is faced with significant challenges posed by climate change (Ahmed and Haque, 2002). A recent study of Asian Development Bank (ADB) reported that Asia and the Pacific have six of the world's 10 countries that are most vulnerable to climate change. Bangladesh tops this list, followed by India (2nd), Nepal (4th), the Philippines (6th), Afghanistan (8th) and Myanmar (10th) (ADB, 2012). It is predicted that climate change in these countries will worsen existing vulnerabilities, exposing millions to flooding and posing threat of displacement. It is therefore of utmost importance to understand its implication on flood in Bangladesh.

Climate change and variability may impact Haor areas more frequently. During pre-monsoon and monsoon, increase in the precipitation is anticipated and subsequently increase in the volume of surface runoff may aggravate the flooding condition in the area. Due to climate change induced inundation, a large portion of the area could face major challenges in terms of displaced populations and their loss of income (CEGIS, 2011). Agriculture and human health may affect, while ecologically important this areas may suffer from extreme flow and other effects.

II. Material and Methodology

General Circulation Models (GCMs) use columns of atmosphere covering about 200 by 300 km at ground level. So they do not simulate the weather on the ground at a particular place very accurately. To get back we have to use downscaling. The mean deviation from the baseline for each atmospheric column (pixel) is re-evaluated to take into account the ground terrain and the characteristics of the expected weather.

Under the present study to generate future precipitation for different scenario MarkSim online software was used. MarkSim is a third-order Markov rainfall generator (Jones and Thornton, 2000, Jones et al., 2002) that has been developed over 20 years. It downscales GCM weather data by a stochastic process.

MarkSim interface is integrated with Google Earth. There it is possible to select the area of interest of weather data. Moreover it is also possible to put the value of latitude and longitude to navigate the location. Under the present study the Haor area of Bangladesh was selected. To generate different precipitation file: GCM model, IPCC scenario, year of simulation and number of replications were selected in the MarkSim interface. In the present study future weather file was generated with B1 & A2 scenario for 2050 and 2090 using CSIRO-Mk3.5 (Gordon, Rotstayn, & McGregor, 2002), ECHam5(Roeckner *et al.*, 2003) and MIROC3.2 (Hasumi & Emori, 2004) GCM models.

The number of replications was used 5 and values were averaged from the replication. The climate data generated from the MarkSim software was validated in respect to ground data. Then upstream boundary data for 2050 was generated using the future precipitation by a rainfall-runoff model. Finally the 1-D model was run with changing boundaries to see the future impact of flood characteristics. In the present study, 1-D model was run with the A2 scenario for 2050.

III. Results and Tables

From MarkSim different runs rainfall for the years 2050 and 2090 were found for scenarios B1 and A2. The output from MarkSim was in WTG files. These WTG files were opened and processed in Excel. Future rainfall was analysed in the context of rainfall of 2004. According to rainfall for 2050 and scenario A2, the 1-D model was run to generate future hydrograph and water level.

Precipitation

Bangladesh has a tropical monsoon climate. It is hot and humid from May to September while cool and dry from November to February. Rainfall occurs during the pre-monsoon from April to May and in the monsoon from June to September. Rainfall at the Haor area of Bangladesh is quite higher in comparison of other parts of the country. Figure 1 shows temporal distribution of rainfall at the Haor area of Bangladesh during 2004. Average annual rainfall of the country is approximately 2,200 mm. More than 80% of the annual rainfall occurs from May to September and July to August are the months of heavy rainfall (Farquharson *et al.*, 2007).

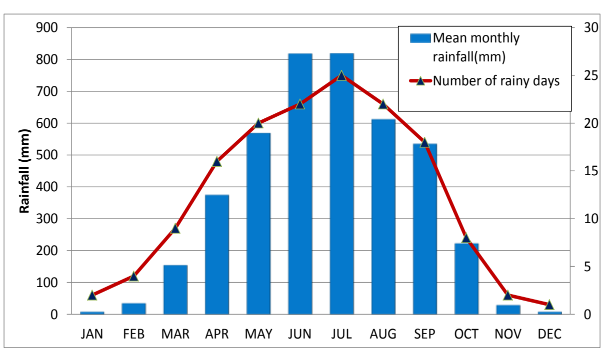


Figure 1: Yearly rainfall pattern at the Haor area of Bangladesh

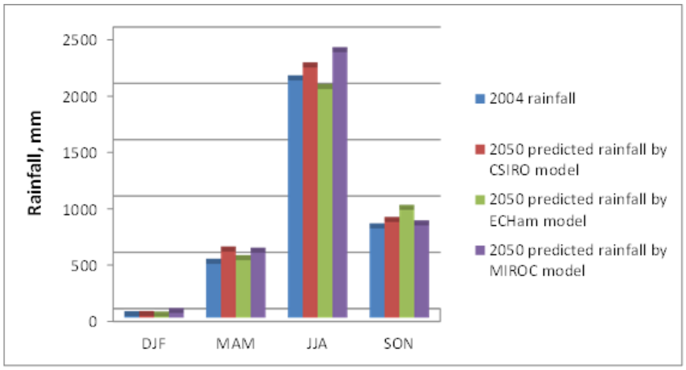
Most of the GCMs are in general agreement about increases in precipitation over the region of South Asia (Mirza, 2001). In the present study an increase of precipitation in both B1 and A2 scenario for 2050 and 2090 with all three GCM models has been observed. The National Adaptation Programme for Action (NAPA) for Bangladesh has been the latest attempt to develop a climate change scenario for the country. NAPA Core Team (GOB, 2005) has found mean rainfall increase by 6% and 10% by 2050 and 2100 respectively.

The IPCC Data Distribution Centre has experimented seven climate model using SRES emissions scenarios (A1FI, A2, B1 and B2). Data are averaged over the entire South Asian region and found that rainfall increases in all cases during the summer, ranging from 5-7% in the 2020s, and 10-13% in 2050 and 15-26% in the 2080 (Ruosteenoja *et al.*, 2003). Under present study, in the B1 scenario the least precipitation increase was found by the ECHam5 GCM model with a value of 2.76% and the highest precipitation increase was found by the MIROC3.2 (medres) model with a value of 9.99% for 2050**.** On the other hand, in the A2 scenario the least precipitation increase was found by the ECHam5 GCM model with a value of 3.46% and the highest precipitation increase was found by the MIROC3.2 (medres) model with a value of 11.96% for the 2050. Table 1 depicts the precipitation increase in two different scenarios with three different GCM models for 2050 and 2090.

Table 1: Percentage of precipitation increase in the B1 and A2 scenarios with different GCM models

GCM model	% of precipitation increase in Scenario **(B1)**		% of precipitation increase in Scenario **(A2)**	
	2050	**2090**	**2050**	**2090**
CSIRO-Mk3.5	5.31	6.60	8.35	16.42
ECHam5	2.76	11.75	3.46	17.82
MIROC3.2 (medres)	9.99	15.77	11.96	19.28

Lal and Aggarwal (2001) simulated daily rainfall in the CCSR/NIES A-O GCM corresponding to the year 2050. The analysis suggests an intensification of the monsoon rainfall over the Indian subcontinent and an enhancement in the summer monsoon precipitation variability in each of the four SRES marker emission scenarios. They also examined the frequency distribution of daily monsoon rainfall over India and suggested that the intensity of extreme rainfall events is likely to be higher in future, a consequence of increased convective activity during the summer. In the present study it has also found the seasonal variation of precipitation for 2050. Figure 2 shows predicted pre-monsoon and post-monsoon rainfall will increase in 2050 with all GCM model simulation. However during the monsoon predicted precipitation will decrease in the ECHam model.



DJF=December, January, February; MAM=March, April, May; JJA=June, July, August and SON=September, October, November

Figure 2: Rainfall pattern of 2004 and simulated rainfall pattern of 2050 with different GCM models and the A2 scenario

In the present study it has found that the percentage increase of pre-monsoon rainfall will higher among other seasons. Figure 3 illustrates the seasonal variability in predicted rainfall. CSIRO-Mk3.5 and MIROC3.2 both have predicted pre-monsoon rainfall will increase significantly in comparison to monsoon and post monsoon rainfall. However, ECHam5 model predicts post-monsoon rainfall will higher in comparison to other two seasons. Mukherjee *et al.*, (2001) have found the suitability of MIROC3.2 (medres) model in the prediction of future scenario in Bangladesh**.** As CSIRO-MK3.5 has agreed well with MIROC3.2 (medres), so, it can be concluded that in future pre-monsoon rainfall will increase in comparison to other seasons at Haor area.

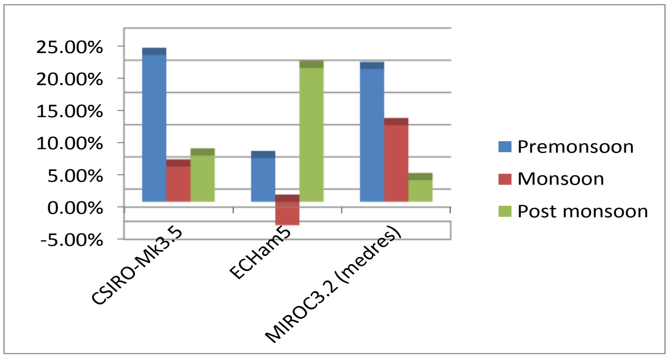


Figure 3: Precipitation changes with different GCM models and the A2 scenario for 2050

Flood peak and water level

Flood peak and water level has been studied with all three GCMs models and the A2 scenario for 2050. Precipitation data for 2050 was generated by different GCM models. Upstream boundaries, discharges were generated using the future precipitation and hydrological model (developed by Institute for Water Modelling, Bangladesh). Downstream boundary, water level was considered same as 2004. The location of downstream boundary is about 250 km upstream from the Bay of Bengal and considered a negligible effect of sea level rise in this location. It was found that precipitation is expected to increase in all the scenarios and all the GCM models, so it is expected to increase the flood peak and water level in all the rivers in the Haor area of Bangladesh. The following section describes the likely changes in flood peak and water level a major river in study area.

Surma River:

The Surma is a major river in the Haor area of Bangladesh. It is a slow response River (Suman and Bhattacharya, 2014). During the 2004, its pre-monsoon and monsoon peak discharge were 3700 m^3/sec and 5550 m^3/sec respectively. Figure 4 shows a comparison among hydrograph for 2004 and simulated hydrograph for 2050 and the A2 scenario in the Surma River. Table 2 shows discharge changes in 2050 and A2 scenario in the same river. It shows that the pre-monsoon flood peak is expected to increase by 21.62% to 71.62% by the different GCM models for 2050 and the A2 scenario in the Surma River. The MIROC3.2 (medres) simulation result has shown a large increase in discharge, one of the reason may due to higher resolutions (2.8 *2.8 degrees) has used in this model. Whereas resolution has used in the ECham5 and CSIRO-Mk3.5 models are 1.9 * 1.9 degrees (Jones *et al.*, 2009). In addition, some uncertainty is associated in climate model (Bony *et al.*, 2005). However, in general it is predicted that pre-monsoon and average discharge will increase in the Surma River in 2050. Same scenario has predicted all other rivers at the Haor area of Bangladesh.

Table 2: Discharge changes in 2050 and A2 scenario in the Surma River

Item	ECham5	CSIRO-Mk3.5	MIROC3.2 (medres)
Pre-monsoon peak discharge	21.62%	35.14%	71.62%
Monsoon peak discharge	-1.82%	- 4.55%	5.45%
Average discharge	12.65%	12.98%	27.19%

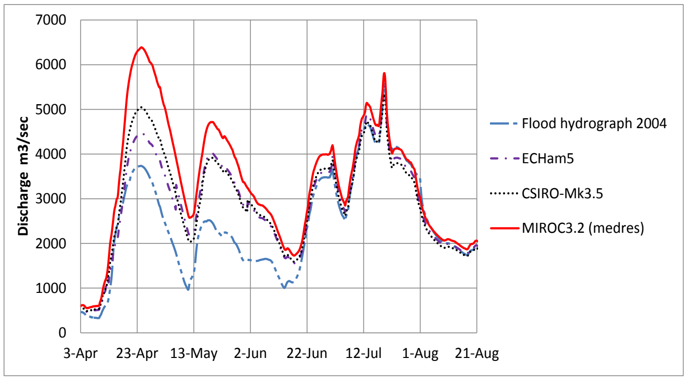


Figure 4: Comparison of the flood hydrograph for 2004 and a simulated hydrograph with different GCM models for 2050 and A2 scenario in the Surma River

Development of Flood Index

The flood severity is not the same in all rivers of the Haor region. If flooded, emergency response requirements largely depend on the severity of flooding. The area does not have flood risk maps or comparable tools for flood management. Accordingly, the development of a flood index to express the flood severity was contemplated. A procedure for characterizing flood severity by defining an index for each river based on characteristics of the shape of the flood hydrograph was developed according to Suman and Bhattacharya, 2014 and Bhaskar *et al.*, 2000. Characteristics of the flood hydrograph such as the rising curve gradient (*K*), flood magnitude ratio (*M*) and time to peak (*TP*) were used in computing the index. Table 3 shows different parameters of flood hydrograph to calculate the predicted flood index for 2050.
Raising curve gradient was calculated using simple exponential equation. Flood magnitude ratio was calculated by peak discharge and average annual flow. Time to peak was calculated by time lag between initial discharge and peak discharge. All values are normalised between 0 to 1. In normalization of time to peak, lower value is considered as severe flood.
Predicted flood index was compared with flood index for 2004. Flood index for 2004 is adopted from Suman and Bhattacharya, 2014. It has found flood severity will be increased most of the rivers in Haor area of Bangladesh. Figure 5 shows the comparison of flood index between 2004 and predicted 2050.
Rivers at the Haor area are classified into two major categories. Quick Response Rivers: higher raising curve gradient & flood magnitude ratio with low time to peak and high flood indexed rivers. Slow Response Rivers: low raising curve gradient & flood magnitude ratio with higher time to peak and low flood indexed rivers (Suman and Bhattacharya, 2014). An important observation can be made from Figure 5, flood index would increase considerably in most of the quick response rivers. However the flood index would be the same or increase slightly in the slow response rivers. From figure 5, it can be concluded there is a possibility that flood severity most of the rivers in the deeply flooded Haor area of Bangladesh will increase due to climate change.

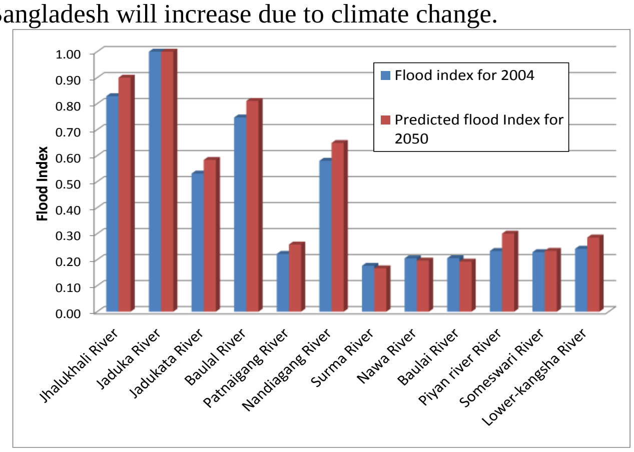


Figure 5: Comparison flood index of 2004 and 2050

Table 3: Summary of flood indices of different rivers in the Haor region.

River Name	Initial dischargeQ0 (m3/sec)	Predicted peak discharge Qt (m3/sec)	Average annual discharge (m3/sec)	Normalized K	Normalized M	Normalized TP	Predicted flood Index for 2050
Lower-kangsha River	30	250	20	0.16	0.41	0.29	**0.29**
Someswari River	500	7850	548	0.10	0.47	0.13	**0.23**
Piyan river River	10	110	6	0.11	0.61	0.18	**0.30**
Baulai River	900	6150	1000	0.12	0.20	0.25	**0.19**
Nawa River	400	5975	1200	0.18	0.16	0.25	**0.20**
Surma River	1000	6400	1240	0.11	0.17	0.22	**0.17**
Nandiagang River	100	2025	88	0.52	0.76	0.67	**0.65**
Patnaigang River	75	720	52	0.12	0.46	0.20	**0.26**
Baulal River	50	1050	54	0.79	0.64	1.00	**0.81**
Jadukata River	35	580	32	0.48	0.60	0.67	**0.58**
Jaduka River	100	4750	157	1.00	1.00	1.00	**1.00**
Jhalukhali River	175	5025	200	0.87	0.83	1.00	**0.90**

iv. Conclusion

The study reports on climate change and its impact on flood characteristics in the deeply flooded Haor area in Bangladesh. The possible changes in the magnitude of flood were assessed using a hydrological model and 1-D hydrodynamic model. Climate change scenarios were constructed from the results of three GCM models- ECham5, CSIRO-Mk3.5 and MIROC3.2 (medres) with the B1 & A2 IPCC scenarios for 2050 and 2090.

Different models also predict an increase in precipitation by 2.76% to 9.99% and by 3.46% to 11.96% in 2050 according to scenarios B1 and A2. Besides this an increase in precipitation by 6.60% to 15.77% and by 16.42% to 19.28% is expected in 2090 according to scenarios B1 and A2. In addition different GCM models predict an increase the pre-monsoon precipitation by 6.77% to 22.78% in 2050 according to the A2 scenario. However, the prediction for monsoon precipitation is -3.64% to +11.89% with the same scenario in 2050.

The study reveals an increase in peak discharge and average discharge in the major rivers in the Haor area of Bangladesh. The pre-monsoon flood peak discharge and water level is predicted to increase considerably in comparison to the monsoon peak and water level. The model predicts that increases in peak discharge are higher in quick response rivers in comparison to slow response rivers in that area. So flood risk is likely to increase in quick response river basins in future.

An integrated flood index was developed with the predicted hydrograph for 2050. The flood index indicates the relative overall severity of flood in the different rivers. It is predicted that the severity would be increase considerably at the quick response rivers in the deeply flooded area.

Acknowledgement

We acknowledge the financial support of the project MorphoFloodHaor funded by DGIS and UNESCO-IHE Programmatic Cooperation (DUPC). The research was done in collaboration with Institute of Water Modelling (IWM, Bangladesh), Center for Environmental and Geographic Information Services (CEGIS, Bangladesh) and Institute of Water and Flood Management, Bangladesh University of Engineering and Technology (BUET).

References

i.*ADB (2012). Asian Development Bank report on "Addressing Climate Change and Migration in Asia and the Pacific, released on March 13, 2012.*

ii.*Ahmed AU (2006). Bangladesh Climate Change Impacts and Vulnerability, A synthesis. Climate Change Cell, Department of Environment, Component 4b, Comprehensive Disaster Management Programme, Paribesh Bhabhan, Agargaon, Dhaka-1207, Bangladesh*

iii.*Ahmed AU and Haque N(2002) Climate Change and Sustainable Development. Paper presented at the Dhaka Meet on Sustainable Development, March 14-18, 2002. Incorporated in Q.K. Ahmad and A.U. Ahmed (eds.), Citizens' Perspectives on Sustainable Development, Bangladesh Unnayan Parishad (BUP).*

iv.*Bony S, Dufresne JL (2005) Marine boundary layer clouds at the heart of tropical cloud feedback uncertainties in climate models. Geophysical research letters, vol. 32, L20806, doi:10.1029/2005GL023851, 2005*

v.*Bhaskar NR, French MN, Kyiamah GK (2000) Characterization of flash floods in Eastern Kentucky, Journal of Hydrologic Engineering, vol. 5, No. 3 June 2000.*

vi.*BWDB (2011) Bangladesh Water development Board website, http://www.bwdb.gov.bd/index.php?option=com_content&view=article&id=105&Itemid=95, accessed on January 15, 2012*

vii.*CEGIS (2011) Master Plan of Haor area, Ministry of Water Resources, Bangladesh Haor and Wetland Development Board, Government of the People's Republic of Bangladesh, Dhaka, Published December 2011.*

viii.*Farquharson F, Fung F, Chowdhury JU, Hasan A, Horsburgh K and Lowe J(2007)Final report on Impact of climate and sea level Change in part of the Indian Sub-Continent (CLASIC), DFID, UK*

ix.*Gordon, H., Rotstayn, L., & McGregor, J. (2002). The CSIRO Mk3 climate system model. CSIRO, Atmospheric Research, Australia.*

x.*GOB (2005). National Adaptation Programme of Action (NAPA), Final report: November 2005, Ministry of Environment and Forest, Government of the People's Republic of Bangladesh (GOB), Dhaka, 48 p.*

xi.*Hasumi, H., & Emori, S. (2004). K-1 coupled gcm (miroc) description, National Institute for Environmental Studies (NIES); Frontier Research Center for Global Change (FRCGC), Tokyo, Japan. Center for Climate System Research, University of Tokyo.*

xii.*Jones PG, Thornton PK, Diaz W and Wilkens PW (2002) MarkSim: A computer tool that generates simulated weather data for crop modeling and risk assessment. CD-ROM Series, CIAT, Cali, Colombia, 88 pp.*

xiii.*Jones PG, Thornton PK and Heinke J (2009) Generating characteristic daily weather data using downscaled climate model data from the IPCC Fourth Assessment. https://hc.box.net/shared/f2gk053td8*

xiv.*Jones PG and Thornton PK (2000) MarkSim: Software to generate daily weather data for Latin America and Africa. Agronomy Journal 93, 445-453.*

xv.*Lal M and Aggarwal D (2001). Climate change and its impacts on India. Asia Pacific Journal on Environment and Development 7 (1), 1–41.*

xvi.*McCarthy JJ, Canziani OF, Leary NA, Dokken DJ and White KS (2001) Climate Change 2001: Impacts, Adaptation. and Vulnerability, Inter-Governmental Panel on Climate Change (IPCC), Work Group II Input to the Third Assessment Report, Cambridge University Press, Cambridge.*

xvii.*Mirza MMQ (2001) Global warming and changes in the probability of occurrence of floods in Bangladesh and implications, Global Environmental Change 12 (2002) 127–138*

xviii.*Mukherjee N, Khan MFA, Hossain BMTA, Islam AKMS, Atrar MN and Rahman S (2001) A hybrid approach for climate change scenario generation for Bangladesh using GCM model results, 3rd International Conference on Water & Flood Management (ICWFM-2011), Dhaka, Bangladesh*

xix.*Roeckner, E., Bäuml, G., Bonaventura, R., Brokopf, M., Kornblueh, M., & Al., E. (2003). The Atmospheric General Circulation Model ECHAM5, Report No: 349, The Maxplanck Institute for Meteorology, Hamburg, Germany.*

xx.*Ruosteenoja K, Carter TR, Jylhä K and Tuomenvirta H (2003) Future climate in world regions: an intera comparison of model-based projections for the new IPCC emissions scenarios. The Finnish Environment 644, Finnish Environment Institute, 83pp.*

xxi.*Suman and Bhattacharya (2014) Flood characterisation of the Haor region of Bangladesh using flood index. In Revision. Hydrology Research. IWA Publishing, London SW1H 0QS, UK*