DEVELOPMENT OF AN INTEGRATED WATER RESOURCES MANAGEMENT PLAN FOR THE SANGU RIVER BASIN UNDER CLIMATE CHANGE

Hasan Md Khairul*
MEE21726

Supervisors: Prof. Mohamed Rasmy**
Prof. KOIKE Toshio ***
Prof. SUGAHARA Masaru ****

ABSTRACT

The Sangu river basin contributes to national economy significantly, however, exposures to water-related hazards frequently. It is expected that water-related disasters will be increased in manifold in the future due to accelerated water cycle by global warming, rapid basin development, and lack of evident-based information for policy making that will hamper the sustainable development of the region. Accordingly, this study investigated an end-to-end approach (i.e. scientific, engineering and economic analyses) to develop an Integrated Water Resources Management (IWRM) plan and to increase the confidence level in decision-making under climate change in the basin. This study scientifically selected five Global Climate models (GCMs) to include the model climate sensitivity and statistically bias-corrected their outputs to reduce biases from coarse resolutions. The analysis of the GCMs indicated that monsoon rainfall will increase in the future. The extreme rainfall events and drought will be more severe and frequent in the future. The Water and Energy Budget based Rainfall-Runoff-Inundation (WEB-RRI) model was used to simulate hydrological responses of the basin under changing climate. The model outputs indicated that annual daily maximum discharge, mean monthly discharge during monsoon and high flow will increase in the future, whereas annual daily minimum discharge and low flow will decrease. These results indicate more frequent and intensified floods and droughts in the future. To mitigate these identified water-related disasters and to maximize the water usage under climate change, several countermeasures has been investigated in this study. The proposal of river capacity enhancement can reduce the future floods and the dam can increase the agricultural productivity. Finally, Pressure and Release (PAR) model was used to develop disaster risk reduction policies in this basin.

Keywords: climate change, GCMs, RCP8.5, WEB-RRI model, flood and drought

INTRODUCTION

Bangladesh is one of the most climate vulnerable countries (ranked 7th) in the world. To prevent new and reduce existing risk, The Government of Bangladesh recognizes the 7 key targets of Sendai Framework for Disaster Risk Reduction (SFDRR) and formulated a comprehensive development plan, the Bangladesh Delta Plan (BDP-2100), focusing on economic growth, environmental conservation, and enhanced climate resilience. The Sangu River Basin is located in the Chittagong Hill Tracts (CHTs) which is one of the seven "hotspots" defined in

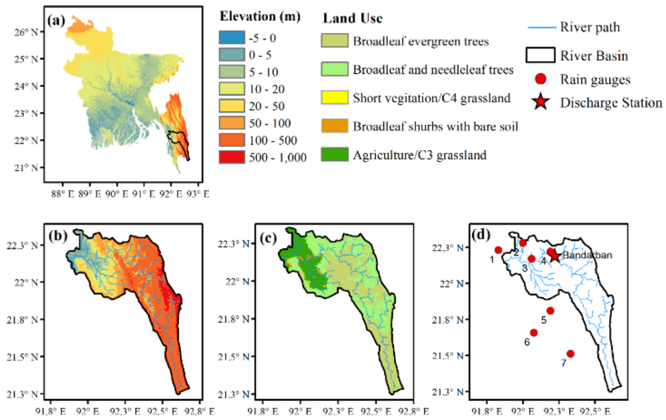

Figure 1. (a) Topographical map of Bangladesh, (b) topography of Sangu river basin (c) land use (d) raingauge and discharge station

* Sub-divisional Engineer, Bangladesh Water Development Board, Bangladesh
** Adjunct Professor GRIPS/ Senior Researcher, ICHARM
*** Director of ICHARM/ Adjunct Professor GRIPS
**** Professor GRIPS

BDP-2100 and most vulnerable to many natural hazards such as storm surge, tropical cyclone, flash flood, landslides etc. Furthermore, the area is economically important because it contributes 12% to the national GDP and more than 60% of the country's total revenue. The past disasters have extensively damaged property, assets and human life in the basin. About 1,800,000 and 50,000 people were affected in 2015 and 2019 flood, respectively. In addition to the flood hazard, CHTs is low to medium drought prone area in Bangladesh and the river flow during dry season is decreasing which causes severe problems of water availability for domestic use and irrigation as there is no storage facilities within the basin. In addition, there are no previous study that investigated the climate change (CC) impacts strategically indicating the absence of evident-based information and its poor preparedness in responding to the challenges of climate change and Disaster Risk Reduction (DRR) activities. Therefore, this study aims to provide evidence-based information obtained from climate change impact assessment and to propose the mitigation measures and policy implications in the basin.

This study overcomes the scientific, engineering, and technological challenges by utilizing advanced models and technologies to obtain evidence-based information for implementing an IWRM plan in the basin. Basin-scale CC impact assessments require handling big datasets from several GCMs and to reduce the uncertainty due to coarse resolution of GCMs. In this study, Data Integration and Analysis System (DIAS) system was utilized to scientifically select five GCMs models with better regional and local performances and to statically correct the biases of GCMs to address model climate sensitivity. In addition, the selection of physically based water and energy budget based hydrological model (i.e. seamless model) is important to incorporate various hydrological components (peak and low estimations, inundation, soil moisture, evapotranspiration) under different global warming projections. In this study WEB-RRI model was utilized to simulate the hydrological responses in the basin due to its physical formulation for dominant hydrological components and its suitability for flood- and drought-related risk assessments under water cycle variability and climate change scenarios.

THEORY AND METHODOLOGY

As shown in the Figure 2, this study has five major components 1) GCMs selection and bias correction, 2) Meteorological impact assessment, 3) Hydrological modeling, 4) Hydrological impact assessment and 5) Proposal of countermeasures, and disaster risk reduction and policy implicaton.

1) GCM Selection and Bias correction: For GCM selection, mean monthly statistical indices spatial correlation (Scorr) and root mean square error (RMSE) are used to calculate each GCM's score. Using the grand score five GCMs have been selected i.e. ACCESS1.0, CESM1(CAM5), CMCC-CMS, MPI-ESM-LR and MPI-ESM-MR. Three steps of the statistical bias correction function by using the time series historical rainfall data has been applied to correct the biases of the GCMs rainfall. The extreme-rainfall correction, normal-rainfall correction and no-rain days correction are employed by utilizing Generalized Pareto Distribution, gamma distribution and statistical ranking order, respectively.

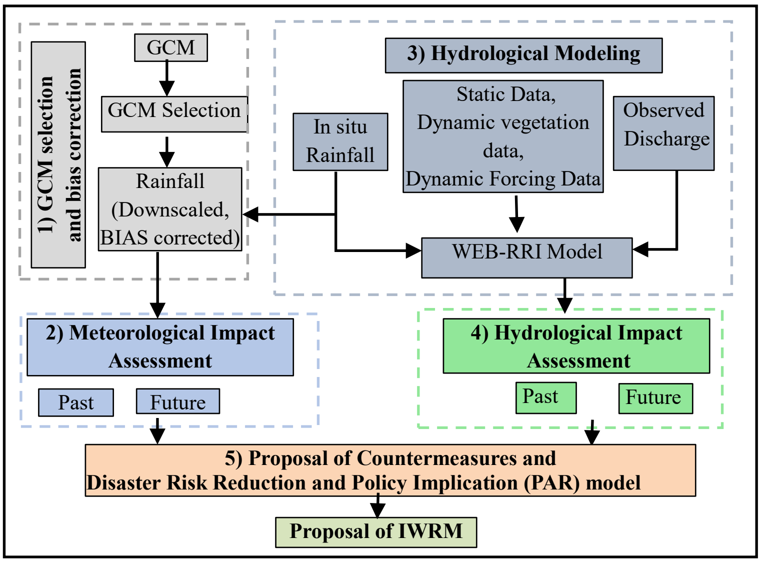

Figure 2. Methodology

2) Meteorological Impact assessment: The meteorological impact has been assessed by using CMIP5-DIAS for three time series: past (1980-2005), near-future (2025-2050) and far-future (2075-2100). Annual, seasonal and extreme events have been analyzed by using the bias corrected data. These evidence-based information has been used to assess the meteorological impact in the basin.

3) Hydrological modeling: Rasmy et. al. developed Water and Energy Budget-based Rainfall-Runoff-Inundation (WEB-RRI) model (Rasmy *et al.*, 2019). The model provides trustworthy responses to climate change scenarios because it accepts more inputs (such as radiation, temperature, humidity, wind speed, and leaf area index) than just precipitation.

4) Hydrological Impact assessment: Simulated WEB-RRI model has been used for the hydrological impact assessment. Annual daily maximum and minimum discharge, monthly discharge and flow duration curve has been used for the assessment of hydrological impact in the basin. The hydrological response of the basin under changing climate has been assessed from these information.

5) Proposal of countermeasures, and policy implementation: Countermeasures has been proposed by utilizing the evidence-based information obtained from this study for the sustainable development of the Sangu river basin. In addition to that disaster risk of the basin has been assessed by using PAR model and risk reduction policies has been suggested from the result obtained in this study.

DATA

Rainfall and discharge data were collected from the Bangladesh Water Development Board. The static and dynamic data for the hydrological modelling has been obtained from open source and JRA-55.

RESULTS AND DISCUSSION

1. Climate change impact assessment

1.1. Effect of climate change on annual rainfall: The effect of climate change on the mean annual rainfall is shown in Figure 3. The mean annual rainfall project an increasing trend from 2% to 13% in near-future. In far-future, the mean annual rainfall project an increasing trend from 11% to 52%. However, MPI-ESM-LR projects a decreasing (7%) trend in far-future. The misrepresentation of topography due to very coarse resolution of GCMs, model physics, etc. could be the reason of projecting less rainfall in far-future by MPI-ESM-LR, which needs further investigation.

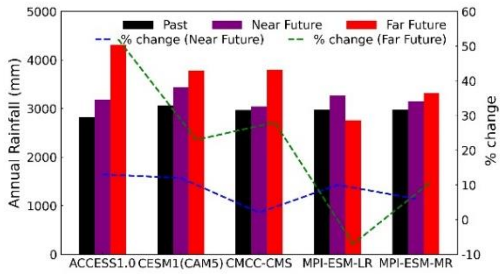

Figure 3. Basin average annual rainfall

1.2. Effect of climate change on seasonal rainfall: Bangladesh has four climatic season i.e. pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November), and winter (December-February). The monsoon rainfall project an increasing trend 8% to 21% in near-future and 22% to 48% in far-future. However, similar to the annual rainfall MPI-ESM-LR projects a decreasing (5%) trend in far-future. Only two or three models project an increasing trend for both near-future and far-future during other three seasons. Therefore, the projected trend of the other three seasons has a higher uncertainty.

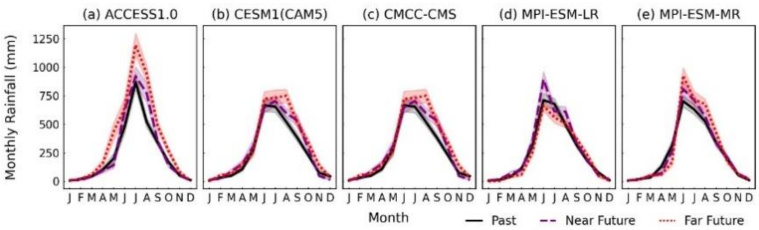

Figure 4. Comparison of monthly rainfall

1.3. Effect of climate change on extreme rainfall and drought: R100m (annual count of days when rainfall greater than 100 mm) project an increasing trend for all selected GCMs in both near-future and far-future [Figure 5.a]. Though MPI-ESM-LR projects a decreasing trend of annual rainfall and monsoon rainfall in far-future, the model also projects an increasing trend for R100mm. The mean of

CDD (consecutive dry days) of four GCMs project increasing trend for both near-future and far-future among the five selected GCMs, [Figure 5.b]. Though MPI-ESM-LR and MPI-ESM-MR project a decreasing trend of mean CDD for near-future and far-future respectively, the decreasing trend is very marginal (within 1% for both models). CMCC-CMS projects the highest increasing trend for both near-future and far-future

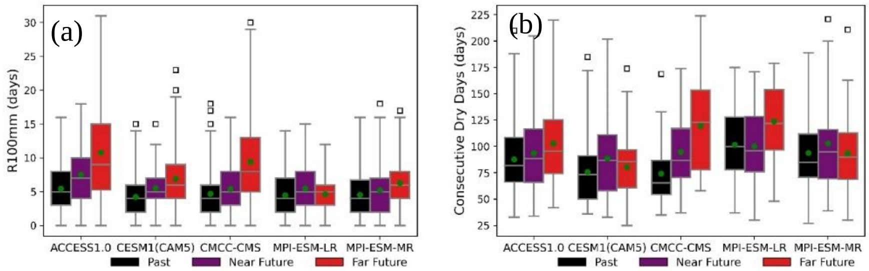

Figure 5. comparison of (a) R100mm (b) CDD

1.4. Discharge calibration and validation: The model was calibrated for the year 1992-1993. The calibrated model could produce both base and peak discharge with NSE equal to 0.83 [Figure 6a]. The same parameters were used to validate the daily discharge at the same location from the year 1997 to 2005. The NSE for validation is 0.71 [Figure 6b].

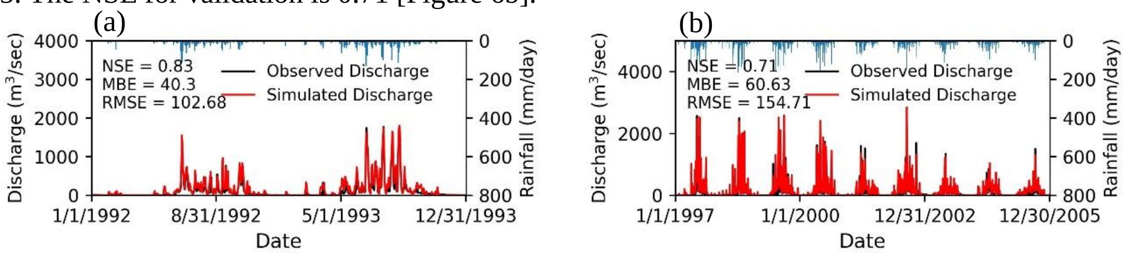

Figure 6. Model (a) calibration and (b) validation

1.5. Effect of climate change on annual daily maximum and minimum discharge: Figure 7(a) demonstrates that the projected mean annual daily maximum discharge for all selected GCMs are tend to increase in the near-future by 1%-38%. On the other hand, the mean annual daily maximum discharge in the far-future projects an increasing trend for four GCMs by 24%-44% but a decreasing trend (11%) for MPI-ESM-LR. Figure 7(b) demonstrates that the mean annual daily minimum discharge for all selected GCMs are tend to decrease in the near-future by 4%-18% and in the far-future by 6%-31%. Therefore, more flood will occur in the future during monsoon, whereas there will be scarcity of water during dry period.

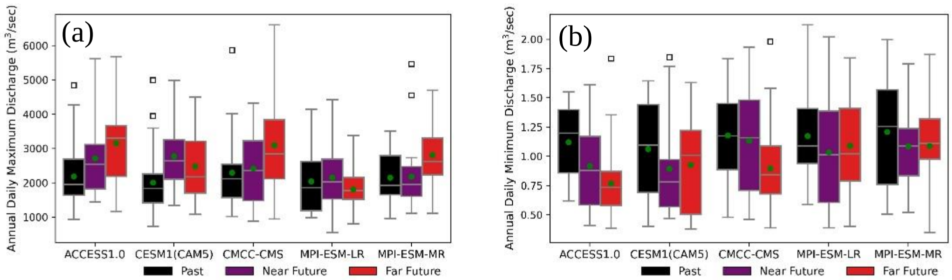

Figure 7. comparison of (a) Annual daily maximum discharge (b) annual daily minimum discharge

1.6. Effect of climate change impact on seasonal flow: The monsoon flow project an increasing trend 4% to 20% in near-future and 17% to 59% in far-future. However, similar to the monsoon rainfall MPI-ESM-LR

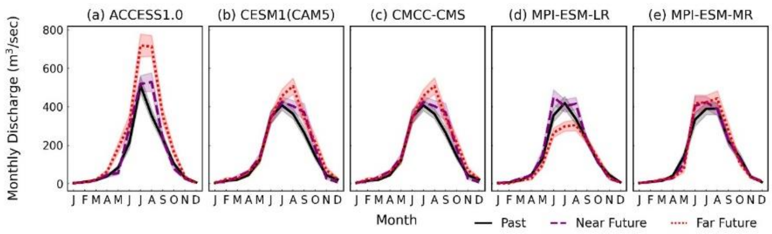

Figure 8. comparison of monthly flow

projects a decreasing (18%) trend in far-future. Four models shows decreasing trend by 3%-56% during winter in the far-future and 6%-35% during post-monsoon in near-future. Other seasonal flow has a higher degree of uncertainty.

1.7. Effect of climate change impact on high and low flow: Figure 9 (a-e) show high flows (probability of exceedance ≤ 10%) project an increasing trend for all selected GCMs for both near-future and far-future except MPI-ESM-LR in far-future. The similar trend has been found for annual daily maximum discharge. The figure 9 (f-j) depict that all selected GCMs project decreasing trend for both near-future and far-future. The similar trend has been found for annual daily minimum discharge. Therefore, both flood and drought will be more intense in the future.

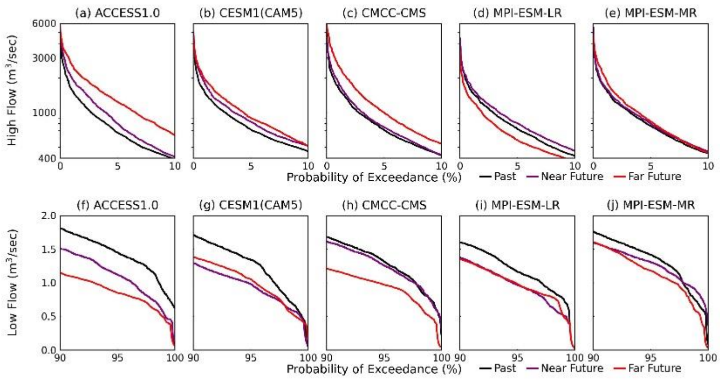

Figure 9. comparison of (a-e) high flows, (f-j) low flows

2. Countermeasures and policy implication

2.1 Countermeasures against flood: To select the suitable countermeasures, first we selected two options (i) construction of dam (Dam-1: 25 MCM, Dam-2: 20 MCM and Dam-3: 20 MCM) (ii) re-excavation ($33X10^6$ m^3) of the downstream of the river. Flood event 2017 has been considered to select the appropriate option which can effectively control the flood. The flood event 2017 is equivalent to return period 20. The Figure 10 compares the inundation extent without countermeasures and with countermeasures. Without countermeasures the inundation extent is 208 km^2. With option-1 the inundation extent is 199 km^2 and with option-2 the inundation extent is only 85 km^2. Therefore, dam can reduce the flood event of 2017 only 4%, whereas re-excavation of the downstream of the river can reduce the flood up to 59%. Dam is an effect option to control the both flood and drought, the shape of the basin are the rationales of poor performance of dam to control the flood. The downstream area of the basin is wide. Hence, rainfall in the downstream area is sufficient to make inundation in the downstream area. Therefore, increasing the river capacity by re-excavating is an effective option for the flood control in the basin.

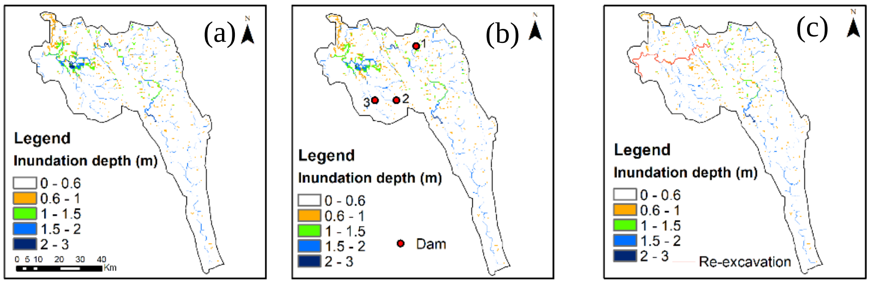

Figure 10. Comparison of inundation (a)without countermeasures, (b) with dam (c) with Re-excavation

The design return period in the Sangu river basin is 50 years. Frequency analysis of observed and near-future rainfall from selected GCMs has been performed and due to the rainfall variation two cases has been considered i.e. case-1 CESM1(CAM5) only and case-2 average of other four GCMs. Analysis result show that re-excavation can reduce inundation by 29% and 44% for return period 50 years for case-1 and case-2, respectively. Therefore, enhancing the river capacity is capable of improving the future flood.

2.2 Proposal of dams: There are scarcity of water during dry season and many available cultivated areas remain unused. Climate change analysis result shows that the scarcity of water will be more in the future and more land will be unused during dry period. Therefore, three dams [Figure 10.b] has been proposed in the basin. As the rainfall and discharge are increasing during monsoon, water can be stored during monsoon and can be used during dry period. The economic analysis shows that proposal of dam increases the revenue from the rabi rice by doubled [Figure 11]. Therefore, dam is an effective option to increase the water availability during dry period and to increase the economic benefit.

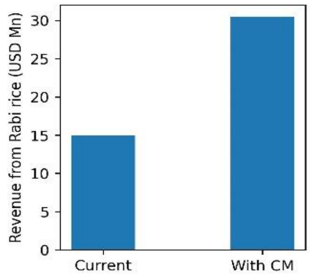

Figure 11. Economic Benefit of dam

2.3 Disaster risk assessment and policy implication: A well-planned policy can reduce the risk of disasters. Therefore, vulnerability assessment was carried out in this study using PAR model and the relevant policies has been suggested based on the findings of this research. The increase of extreme rainfall and floods will cause increase in disasters. Therefore, this study proposes to increase the river capacity by re-excavating the downstream of the river. As rainfall and discharge increase during the monsoon, and water scarcity increases during the dry season, this study recommends dams to store water during the monsoon and use it during the dry season to increase economic benefit.

CONCLUSION AND RECOMMENDATION

This research utilizes modern scientific and technological advances (such as the DIAS system and WEB-RRI modeling) to obtain evidence-based information and to implement IWRM in the study area. Analysis results indicate that future rainfall will increase in the basin. The extreme rainfall and drought will be more frequent and intense in the future. The WEB-RRI hydrological model performed well in simulating basin hydrological responses. The simulated hydrological model showed that future annual daily maximum discharge and high flow will increase, whereas annual daily minimum discharge and low flow will decrease in the future. These findings indicate that flood risk will increase during monsoon as well as water scarcity during dry period will increase. The evidence based information of this research showed that increasing the river capacity by re-excavating the downstream of the river can reduce the flood risk and dam can increase the agricultural productivity during dry period. Finally, this study summarized the key policy recommendations based on the research findings to strengthen climate change mitigation strategies in the IWRM plan. This study provide complete evidence based solution to future climate change issues and hence the suggested policy recommendation should be applied in the Sangu river basin to mitigate flood risk and water scarcity and to maximize the economic benefit.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank Prof. Mohamed Rasmy, Senior Researcher ICHARM and Professor at GRIPS, for his direction and guidance throughout this study, as well as his constant encouragement. I consider myself privileged to be able to work under his supervision. My sincere appreciation is due to Prof. KOIKE Toshio, Executive Director, ICHARM, and Professor, GRIPS, for his valuable comments, review and suggestions.

REFERENCES

Koike, T., Koudelova, P., Jaranilla-Sanchez, P. A., Bhatti, A. M., Nyunt, C. T., & Tamagawa, K. (2015). River management system development in Asia based on Data Integration and Analysis System (DIAS) under GEOSS. *Science China Earth Sciences*, 58(1), pp.76–95.

Nyunt, C. T., Koike, T. and Yamamoto, A. (2016) ‘Statistical bias correction for climate change impact on the basin scale precipitation in Sri Lanka, Philippines, Japan and Tunisia’, *Hydrology and Earth System Sciences Discussions*, pp. 1–32. doi: 10.5194/hess-2016-14.

Rasmy, M., Sayama, T. and Koike, T. (2019) ‘Development of water and energy Budget-based Rainfall-Runoff-Inundation model (WEB-RRI) and its verification in the Kalu and Mundeni River Basins, Sri Lanka’, *Journal of Hydrology*, 579, pp. 124163. doi: https://doi.org/10.1016/j.jhydrol.2019.124163.