DEVELOPING AN INTEGRATED WATER RESOURCES MANAGEMENT PLAN FOR CHINDWIN RIVER BASIN UNDER CHANGING CLIMATE

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ABSTRACT

Agriculture is the mainstay of the economy in Myanmar, and the Chindwin River Basin (CRB) plays a vital role in both agricultural production and food exportation. However, inadequate water resource management policies together with water-related disasters that are exacerbated by climate change (i.e., floods and droughts) are major threats to the country's economy. This research has been carried out to address scientific, engineering, and policy challenges by utilizing advanced models and technologies to obtain evidence-based information to implement an Integrated Water Resources Management (IWRM) plan for this basin. The results indicate that rainfall in the basin is set to increase during the wet season and decrease in the dry season as a result of the future climate. The number of extreme rainfall events and intensities are also expected to increase in the future. To address the impact of climate change, a Water and Energy Budget of Rainfall-Runoff Inundation model (WEB-RRI) was developed for this basin, and its performance in simulating low flow, high flood peak, and inundation extents was verified. The model-simulated output for the future climate showed that monthly mean flow, extreme peak flow, and inundation extents will increase, whereas low flow will be slightly reduced. These results indicate more frequent and intensified floods in the future. To mitigate these identified water-related disasters under a changing climate and to introduce IWRM practices, several implementation strategies were examined for policy recommendation and proposed for use by decision makers.

Keywords: Chindwin River Basin (CRB), IWRM, Flood, Drought, GCMs, Rainfall

1.0 INTRODUCTION

Myanmar was known as the Rice Bowl of Asia in the early 20th century due to its abundant water source and fertile soil. Until now, the agriculture sector has served as the backbone of the economy (34% of GDP) (NAPA, 2016). Local people rely on the four major rivers that flow through the basin for irrigation, transportation, and domestic use. The amount of water per capita in Myanmar is higher than that in all surrounding countries. To reclaim its former title as Asia's Rice Bowl, the Government of Myanmar has implemented several measures, such as extending the agricultural area, producing crops with high yields, and the initiation of both large- and medium-scale water resource development projects. The Chindwin River Basin (CRB), which is the third largest basin in Myanmar, plays a vital role both in terms of agriculture production and the exportation of food. The basin is generally covered by mountainous forest, except for the far south, which is a vast plain. There are distinct differences in the amount of precipitation over the basin because of the effects of the southwest monsoon and the topography, which results in abundant rainfall (approximately 4,000 mm/y) upstream and low precipitation (approximately 750 mm/y) downstream. Severe floods hit at least one region in the basin every year because of the high intensity of rainfall that occurs during the monsoon (Latt & Wittenberg, 2015). The frequent floods that result from this intense rainfall destroy agricultural land, ruining the livelihoods of residents in the area almost every year (the maximum water level reached levels that are considered dangerous in 2002, 2008, 2011, and 2015). Flooding is generally the highest in July and August; floods that occur during these months constitute 72% of the total. However, droughts also occur in the downstream areas, which endure low amounts of rainfall and high temperatures. Severe droughts were recorded downstream during the periods 1997–1998, 2001–2005, 2008–2009, and 2012–2014, which is located in the central dry zone of Myanmar. Therefore, the main issues affecting the basin are severe floods and droughts.

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Myanmar is considered as one of the most vulnerable countries to the impacts of climate change in the world. The Global Climate Risk Index 2020 listed the countries and territories that were most affected during the period 1999 to 2018, in which Myanmar ranked the highest (Eckstein, et al., 2019). Currently, the water-related disasters that are exacerbated by climate change directly affect the properties, human lives, food security and economy of the basin. No research considering the impacts of climate change impact that can be used to implement an Integrated Water Resources Management (IWRM) approach in this area has as yet been carried out, indicating its poor preparedness in responding to the challenges of global warming. To understand the hydro-meteorological characteristics and the behavior of climate responses, it is therefore necessary to establish a comprehensive and end-to-end research framework that address scientific, engineering, and policy challenges by utilizing advanced models and technologies to obtain evidence-based information for implementing an Integrated Water Resources Management (IWRM) plan for the basin.

The Data Integration and Analysis System (DIAS) system developed by the University of Tokyo was used in this study to overcome the scientific and engineering challenges in mitigating these issues. The use of this system provides a unique opportunity to handle big data from several GCMs and select several models with better regional performance that can be downscaled to the scale of a single basin. The Water and Energy Budget of Rainfall-Runoff Inundation model (WEB-RRI) was used to estimate the hydrological responses occurring in the basin. The WEB-RRI model was developed to address the issues surrounding the development of an IWRM system (floods and droughts) under changing climate conditions (Rasmy, et al., 2019). The model uses physical formulas to describe the soil-vegetation-atmosphere interaction, soil moisture dynamics, and hydrological processes, thereby improving the accuracy of flood and drought related estimations and risk assessments and producing reliable responses to the variability in the water cycle and climate change scenarios to obtain IWRM practices that can be used for sustainable development under a changing climate. The evidence-based information obtained from scientific and engineering approaches will be used to develop and implement proposals including IWRM plans for use by policy makers.

2.0 METHODOLOGY

The overall methodology is developed with the aim of achieving sustainable development based on the Integrated Water Resources Management Plan (Figure 1). The study emphasizes the occurrences of floods and droughts and the efficient and effective use of dams in mitigating the effects of climate change. The four areas covered by this methodology are: 1) assessment of rainfall under past climates, 2) assessment of rainfall under future climates, 3) hydrological modeling, and 4) climate change impact assessments of flooding, droughts, and dam operation.

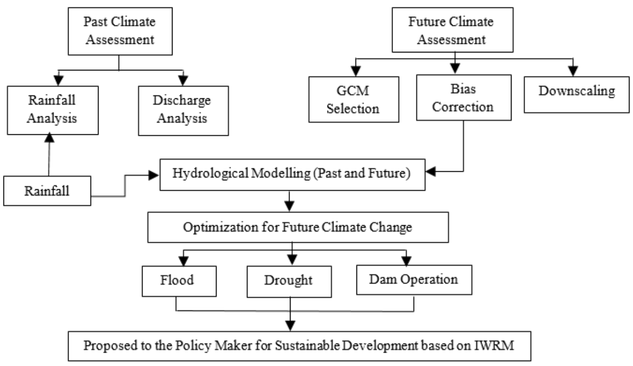

Figure 1. Research Methodology

(1) The assessment of rainfall under past climates: Long-term patterns of observed rainfall and river flow were analyzed in this section, considering rainfall and discharge data from 1980 to 2018. The hydro-meteorological data were examined for climate signals.

(2) The assessment of rainfall under future climates: The future climate was analyzed using the Coupled Model Inter-comparison Project Phase (CMIP 5) data for the periods 1981 to 2000 and 2040 to 2059 using the climate change projection tool of DIAS. GCM models were selected for the area of interest using performance indices based on their capability of simulating the regional climate. The observed rainfall data for the past climate from (1981 -2000) was used for bias-correction and downscaling the future (2040 – 2059) climate projection (Koike, 2014).

(3) Hydrological Modeling (WEB-RRI): The WEB-RRI model was employed to study the hydrological responses of the basin to climatic conditions both in the present and in the future. WEB-RRI is an advanced version of the RRI model, and is more applicable for IWRM practices under changing climate conditions. Data concerning topography, MODIS LAI and FPAR satellite data, Japanese 55-year reanalysis forcing data, soil, land use, vegetation data, and observed rainfall data were collated and prepared for input into the model. The WEB-RRI model is capable of estimating low flow, flood onset timing, and peak flood discharge and inundation extents (Rasmy, et al., 2019).

(4) Climate change impact assessments of flooding, droughts, and dam operations: To reduce the inundation that occurs as a result of flooding in this basin, effective structural measures are required to mitigate against floods, with flood control managements. Based on the results of model outputs, the optimization of dam operation while considering climate change will be investigated for the effective management of water-related disasters, the utilization of water for agriculture, and hydropower production.

3.0 STUDY AREA AND DATA

The CRB is located in the north-western part of Myanmar in the Sagaing Region, which covers an area of 115,300 km^2. Part of the basin extends across the border into India (Fig. 2). One of the most significant tributaries is Myittha river, which intersects the right bank of the Chindwin River. The climate varies from tropical to subtropical over different regions. The region is hot and dry from March to April, wet from May to October, and cold and dry from November to February. The annual average rainfall in the basin varies considerably, from 750 mm downstream to 4000 mm upstream.

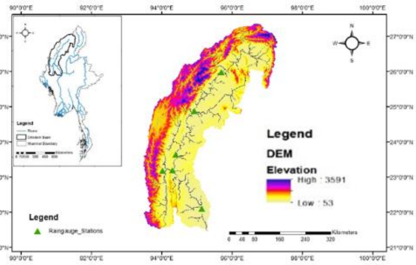

Figure 2. Study Area and Data

Six datasets collected at rain-gauge stations were used for bias correction of the GCMs models and hydrological modeling. Topographic data such as that provided by the digital elevation model (DEM), flow direction (DIR), and flow accumulation (ACC) from the U. S. Geological Survey's Hydrological data (USGS) were downloaded for this area. The 2 km resolution DEM data and maps are based on Shuttle Elevation Derivations at multiple scales (HydroSHEDS). Land use data were extracted from USGS at a resolution of 1 km. The soil distribution data were obtained from the FAO. The soil datasets include essential parameters such as the saturated hydraulic conductivity, the saturated soil moisture content, residual soil moisture content, and ground water. The Leaf Area Index (LAI) and the Fraction of Photo Absorbed Photosynthetically Active Radiation Data (FPAR) were obtained using 8 days MODIS composites from NASA's Earth Observation Data and Information System to produce vegetation phenology for model input. JRA-55 re-analysis data were obtained from the Japan Meteorological Agency (JMA). GCMs for CMIP-5 experimental data archived at DIAS were used in this research**.**

4.0 RESULT AND DISCUSSION

4.1 Investigation of past and future rainfall for assessing the probable impacts of climate change

Data concerning the annual rainfall that occurred in the basin from 1980 to 2018 was used for past rainfall analysis. According to the long-term rainfall data, the wet spells (where rain fell continuously for more than 5 days) and dry spells (where no rain fell for more than 10 days) events are plotted in the Figure 3. The results show a clear downward trend in dry spells and an upward trend in wet spells. Therefore, the number of dry days

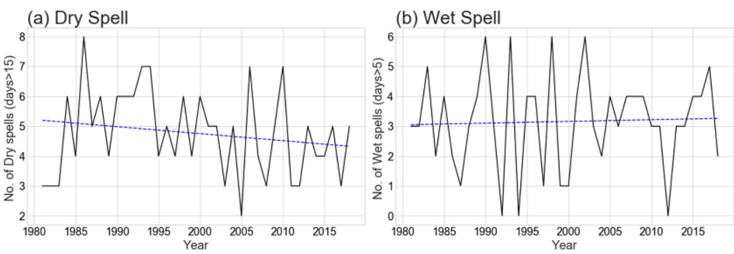

Figure 3. Dry and wet spell analysis at the basin

decreased while the number of the wet days increased over the period studied. GCM climate models for the past 20 years (1981-2000) and 20 years into the future (2040-2059) were examined to carry out the future hydro-meteorological analysis. Based on the analysis of 39 years of rainfall data, no significant changes were observed in the mean precipitation or extreme rainfall events over the period 1981-2018

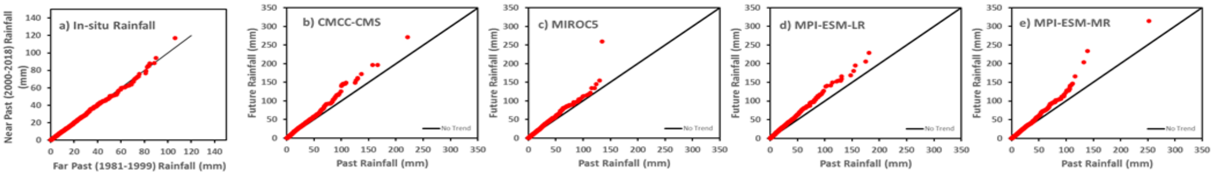

Figure 4. Trend Analysis for the daily past and future climate rainfall events

(Figure. 4a). After bias correcting for the rainfall produced by selected models, all GCM models clearly indicate that the amount of rainfall will tend to increase in the future. In particular, the basin will receive more intensified and frequent extreme rainfall events in the future as compared to the past (Figure 4b-e).

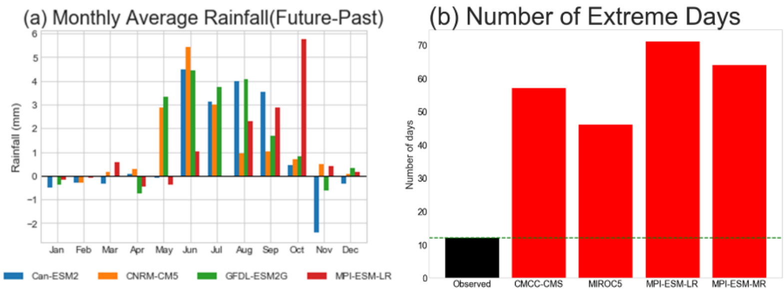

Figure 5. (a) Future-Past Monthly Rainfall, and (b) No. of Extreme Rain Days compared with the Observed and Four Models (rainfall exceeding 75 mm/day)

Figure 5(a) indicates that all GCM models projected a significant increase in the amount of rainfall occurring during the wet season and moderate decrease in the amount of rainfall during the drier months (e.g. Jan. and Feb.). This indicates that there may be dry days in the future. Therefore, drought mitigation measures need to be considered as part of the climate change impact assessment. Figure 5(b) indicates that there is expected to be a fourfold increase in the number of extreme rainfall events in which more than 75mm of precipitation occurs per day in the future than there was in the past climate.

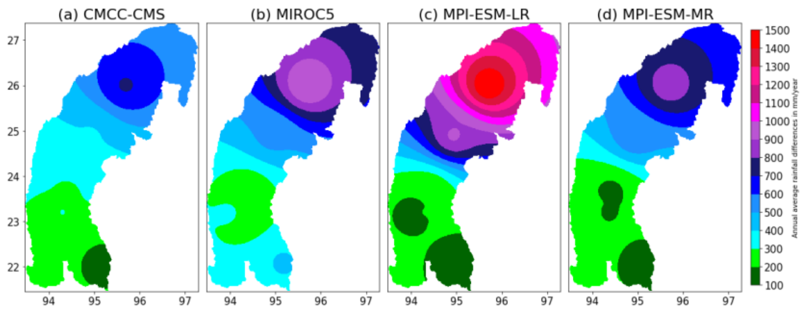

Figure 6.Annual Average Rainfall in mm/year

Figure 6 indicates all the four models projected more high intensity rainfall in the area upstream than that the downstream. MPI-ESM-LR projected that there will be an increase of nearly 1500mm more rain annually upstream, while CMCC-CMS projected an increase of approximately 750 mm in this part of the basin in the future. Almost all models projected an annual increase of 100-400 mm. These results indicate that in the future, the climate of this basin will change to include higher amounts of rainfall of increased intensity that will favor frequent flooding with wider areas of inundation than that seen in the past.

4.2 Development of the WEB-RRI model and validation of the model using ground and satellite data

The WEB-RRI model was used to simulate the past climate of Chindwin Basin and projected the future hydrological responses that are expected to result from climate change. The model was tuned by adjusting the parameters in order to simulate the hydrological responses of the past. The period 1990 to 1991 was selected for calibration (Figure 7a), and validation was carried out using data from the period

1992 to 1993 (Figure 7b). The model was found to be well calibrated during both low-flow and high-peak simulations, and both calibration and validation performed well, with Nash coefficients of 0.776 and 0.687, respectively.

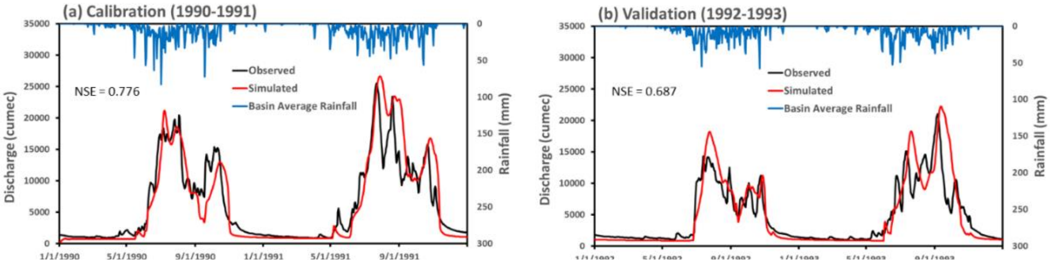

Figure 7. Calibration and Validation with Discharge at Monywa Station

The extent of inundation simulated using the WEB-RRI model was compared with the satellite-derived inundation map downloaded from the Myanmar Information Management Unit (MIMU). The model was found to be capable of simulating the actual area flooded when compared with satellite imagery collected during the 2015 flood that occurred in Kale City (Figure 8). The left of the figure shows the results of the model simulation and the right side shows the satellite image map. The flooding simulated by the model in 2015 is notably similar to the satellite imagery. It can therefore be assumed that the WEB-RRI model can be used to simulate future hydrological responses and inundation extents that occur in the basin.

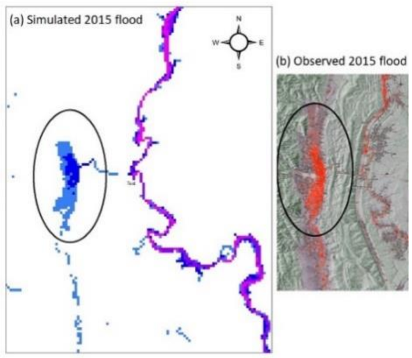

Figure 8. Simulated and observed flood inundation extents in 2015

4.3 Investigation of past and future discharge for climate change impact assessment

Fig. 9 indicates that the two selected models projected increases in the monthly discharge from May to November. The CMCC-CMS model projected that the low flow will decrease slightly; however, the MPI-ESM-LR model projected no changes in the low-flow conditions. The maximum inundation depth simulated by both models is shown in Figure 10. MPI-ESM-LR produced a higher depth for the inundation and differences in the area covered, whereas the CMCC-CMS model showed only a moderate depth of inundation and differences in the area covered by flooding only in terms of the past climate. Both models produced an increase in the depth of inundations occurring both downstream and in Kale city.

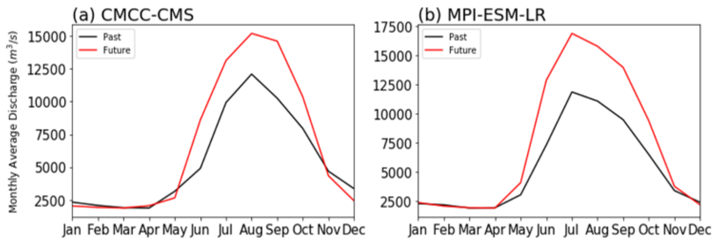

Figure 9. Monthly Average Discharge

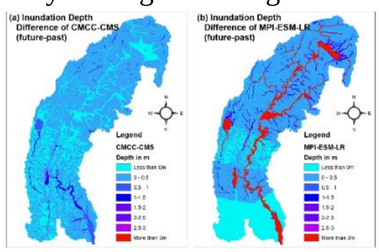

Figure 10. Inundation depth difference from future and past

4.4 Investigation of dam operations

The Myittha Dam, which is used to produce hydropower, is located on the Myittha river tributary that joins the Chindwin river. Based on data gathered from observation, the dam received 94% of the annual inflow during the wet season (May to

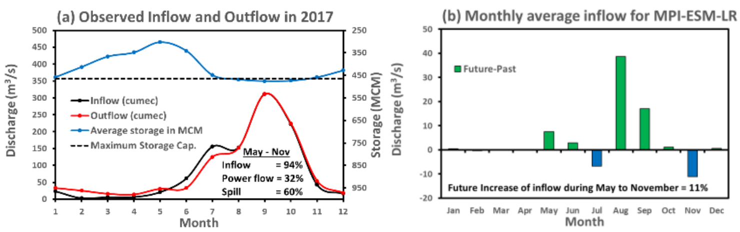

Figure 11(a). Observed inflow and outflow in 2017, and (b). monthly average inflow for MPI_ESM_LR

November) of 2017, of which only 32% was utilized in the production of hydropower, and 60% of the total annual yield is allowed to spill without any usage, as shown in Figure 11(a). According to the MPI-ESM-LR projections shown in Figure 11(b), an 11% increase in future inflow could be observed during the wet period, with a decrease in the inflow during July and November.

4.5 Proposed counter measures for policy making

The above observation is particularly alarming as the quantity of unused water produced during this period will increase and the damage downstream that results from dam release (spill) is therefore set to increase significantly in the future. Therefore, it is necessary to implement both soft and hard countermeasures against floods in order to minimize damage and increase the efficiency of the water usage. To minimize downstream damage and flooding, this study proposes the construction of flood levees and flood control structures along the river. Further, this study proposes an increase in the storage capacity either by increasing the volume of the present Myittha Dam or by adding more dams along the course of the river, which would only be carried out following a detailed investigation in terms of utilizing the surplus water falling in the wet season to supplement the lack during the dry season.

5.0 CONCLUSION AND RECOMMENDATION

Inadequate water resources management plans and the impact of climate change is expected to lead to frequent water-related disasters and significantly affect the agricultural economy of Myanmar basin in the future. This research implemented recent advancements in science and technology (i.e., DIAS system and WEB-RRI modeling) in order to obtain evidence-based information that can be used in the sustainable development of the water resources in this area. Analysis of past rainfall indicated that the number of wet days is currently increasing while the number of dry days is decreasing under the present climate. Future rainfall analysis was applied to bias-corrected rainfall from selected GCM models. The outputs of all GCM models indicated an increase in the number of extreme rainfall events and precipitation trends in the future as a result of climate change. The WEB-RRI model successfully simulated flood and drought-related variables for the basin with good model performance indices. In particular, the discharge simulated by the model correlates well with the observed discharge at both low and high flow. Analysis of the discharge expected in the future indicated that extreme flood events will result in wider inundation. Effective new countermeasures were proposed for flood and drought monitoring under a changing climate. Policies should be made using IWRM in order to minimize vulnerability and reduce the risk of disasters that are caused by climate changes in the future.

6.0 ACKNOWLEDGEMENTS

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