DEVELOPMENT OF INTEGRATED WATER RESOURCES MANAGEMENT PLANS OF SITTAUNG RIVER BASIN UNDER CHANGING CLIMATE

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ABSTRACT

Sittaung River Basin (SRB) is one of the water-related hazards affected basins in Myanmar. To prevent and reduce socio-economic losses, both structural and non-structural countermeasures need to be considered in this basin. The overall objective of the research is to improve flood and drought analysis system in Myanmar using advanced spatial technologies, to understand on the past and future climate and to examine the effectiveness of existing and proposed countermeasures. In this study, past hydro-meteorological data analyzes by the Standardized Precipitation Index (SPI) method was used to understand the significant changes of hydro-meteorological condition of the area. The outputs of six models selected from the Coupled Model Inter-comparison Project Phase 5 (CIMP5) were used to identify signals of climate change. The Water and Energy based Rainfall-Runoff-Inundation (WEB-RRI) Model was used to estimate flood inundations and discharges, to analyze the effectiveness of existing countermeasures, and to propose new mitigation measures for future development works. This research finding indicated that by managing the water level of the reservoir, the flood can be mitigated during the rainy season, as well as the drought during the summer season. The proposed countermeasures can contribute to reduce the peak-inundation depth and thus reduce the agricultural damages.

Keywords; Sittaung River Basin (SRB), CIMP5, WEB-RRI model, Flood Mitigation

INTRODUCTION

The Sittaung River Basin (SRB) is the 4th largest river in Myanmar and is located in the east-central zone, originating in Mandalay Region on the edge of the Shan Plateau and flowing south before it runs out into the Gulf of Martaban of the Andaman Sea. The catchment area of the Sittaung River is 34950 km^2 and it runs 450 km from upstream to the outlet. Every year, a monsoon rainfall event triggers a flood disaster. A state of emergency declared in the five regions; Bago, Taungoo, Phyu, Madauk and Shwegyin where devastated disasters often happen. Once a flood occurs, the agricultural fields are inundated, the major network of motor roads and railways passes through this region are blocked by flooding. Not only severe flooding but also drought is a major problem at some places. During the dry period, the amount of reservoir storage water decreases associated with climate change.

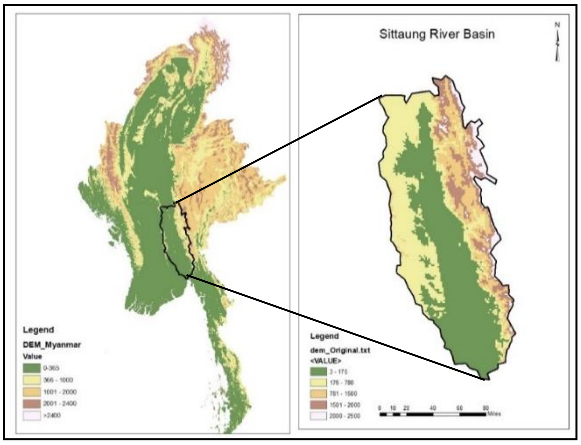

Figure 1 Topography of Myanmar and Location of Study Area

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The region often faces the shortage of water supply for hydropower generation, the farmland and drinking water. Although local people encounter huge losses almost every year, there are lack of systematic activities to prevent and mitigate of these damages. There are very few records for floods and no historical records for droughts and dam operations exist in this basin. An optimization-based approach for a multi-reservoir system operation is needed to mitigate flood damage and support stable water supply. Therefore, an integrated research is necessary to analyze climate change scenarios and seek lasting solutions for the flood and drought induced problems.

METHODOLOGY

The overall objectives are to analyze the changes in precipitation and floods and water scarcity in the past, to develop the countermeasures considering future climate change impact based on the flood and drought impact assessment and to integrate the efficient water allocation method by modifying the dam operation. Schematic diagram of the study approach is shown in **Figure 2**. Past data analysis for extremely flood and drought were carried by the Standardized Precipitation Index (SPI) method. For identifying the past alternating wet and dry periods, the SPI method is primarily useful in the study of non-stationary associations using time-series data to provide the decomposition of precipitation time series. To improve the estimation of water and energy budget processes and initial soil storages, Rasmy et al.(2019) developed a Water and Energy based Rainfall-Runoff-Inundation (WEB-RRI) model by coupling the Simple Biosphere Model-2 (SiB2) (Wang et al. 2009) with the Rainfall-Runoff Inundation (RRI) model (Sayama et al. 2010). The WEB-RRI model was calibrated and validated by using the observed hydrograph at Taungoo and Madauk discharge measuring stations in 2011 and 2012, respectively. The selected six models of the Coupled Model Inter-comparison Project Phase 5 (CIMP5) under the Representative Concentration Pathways (RCP-8.5) scenario were used to investigate future climatology. To correct the biases in GCM precipitation, the daily precipitation data observed at six rain gauge stations were used for developing bias-corrected GCMrainfall data sets for 20 years in the past (1981 -2000) andfor the future (2041 -2060) climate. The combination of the hydrological and climatological models illustrates excellent performances in simulations of the low flow, the timing of flood onset, flood peak discharges, and inundation extents and capabilities for identifying effectiveness of the existing countermeasures and proposing new mitigation measures for future development works. This research will focus on how to generate reliable and accountable information for supporting policy decision making related to integrated water resource management of the Sittaung River Basin (SRB) in the future.

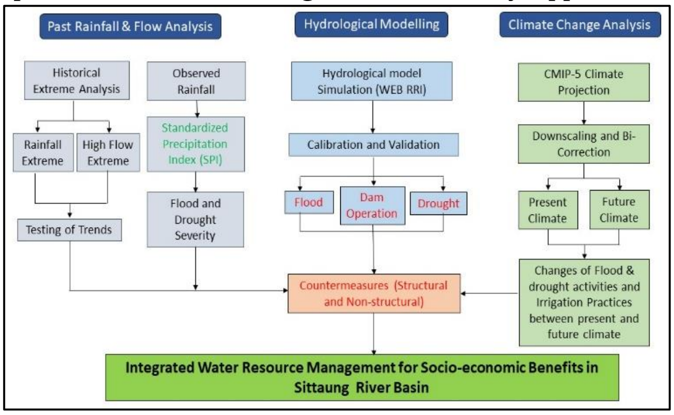


Figure 2 Schematic diagram of the study approach

DATA

Daily rainfall data were collected at six stations of the Department of Meteorology and Hydrology (DMH) and 22 stations from Irrigation and water utilization management Department (IWUMD). The seventeen dams released discharge data (maintained by IWUMD) were used for model validations, and the two observed discharge stations (maintained by DMH) were used to validate the model. The location of the dams and hydro-meteorological stations are shown in **Figure 3**. Topographic data such as digital elevation models (DEM), flow direction (DIR) and flow accumulation (ACC) were collected from the U.S Geological Survey's Hydrological data (USGS) of 15 arc-sec (450m) based on Shuttle Elevation Derivatives at multiple scales (Hydro- SHEDS). Leaf Area Index (LAI) and Fraction of Absorbed Photosynthetically Active Radiation Data (FPAR) were obtained from NASA Earth Observation Data and Information System. Meteorological forcing inputs data such as Japanese 55-year Reanalysis Data (JRA55 Data) were obtained from the Japan Meteorological Agency (JMA).

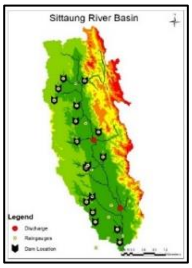


Figure 3 Dams and Hydro-meteorological Stations

RESULTS AND DISCUSSION

The SPI values in a 3-months timescales were calculated using the six rain gauge data and plotted in Figures 4 to demonstrate wet and dry climate seasonality. In SRB, the SPI analysis values show that although floods are more severe than droughts, the duration of some drought events were longer and devastating in recent years. Droughts occurred in 1983, 1990, and 2010 as the SPI in those years indicates severe dryness.

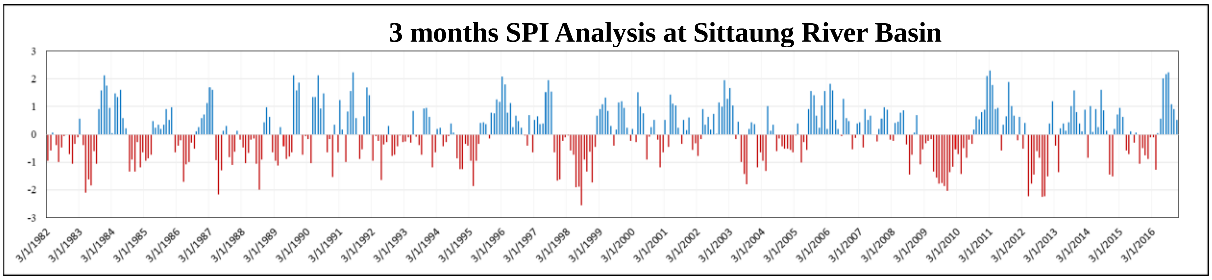


Figure 4 (3) Months SPI for wet and dry periods of Sittaung River Basin

The WEB-RRI model was set up for model calibration during 2012 flood events. The model sensitivity study was conducted to find the model calibrated parameter values. This simulation results showed the reasonable results for the model calibration at Taungoo and Madauk as shown in **Figure 5**.

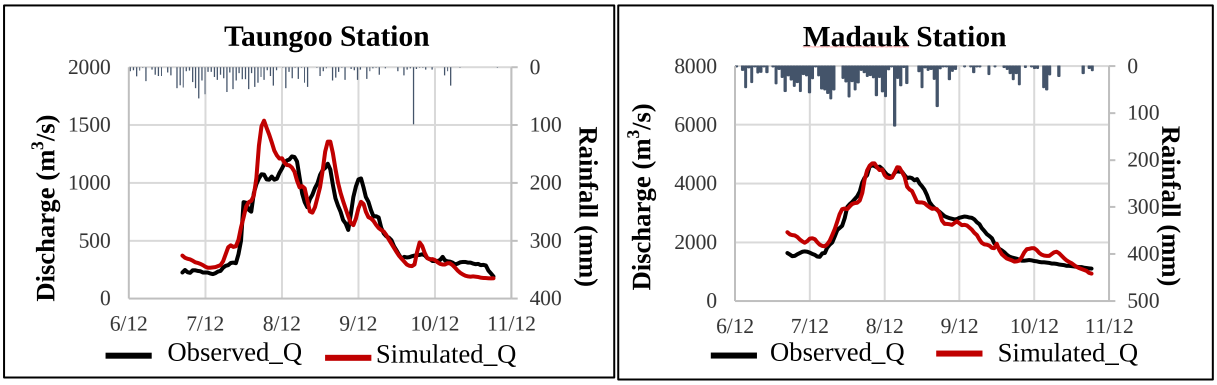


Figure 5 Simulated and Observed Discharge of Sittaung River Basin for 2012 Flood Event

Figure 6 demonstrates the observed and simulated discharge of the SRB at these two stations. At Taungoo station, the model outputs are similar to the observed values at the high flow and low flow condition of the year 2011 and 2012. Although there is a gap between the simulated and observed discharge at the Madauk station before and after the monsoon periods due to the effect of the dams' release and storage, the result during flood events is nearly similar to observed discharge. Even though many existing facilities such as reservoirs were established, new countermeasures are needed for flood mitigation because those facilities were not designed for flood management. Currently, three sluice gates and one retarding basin are proposed as shown in **Figure 7.**

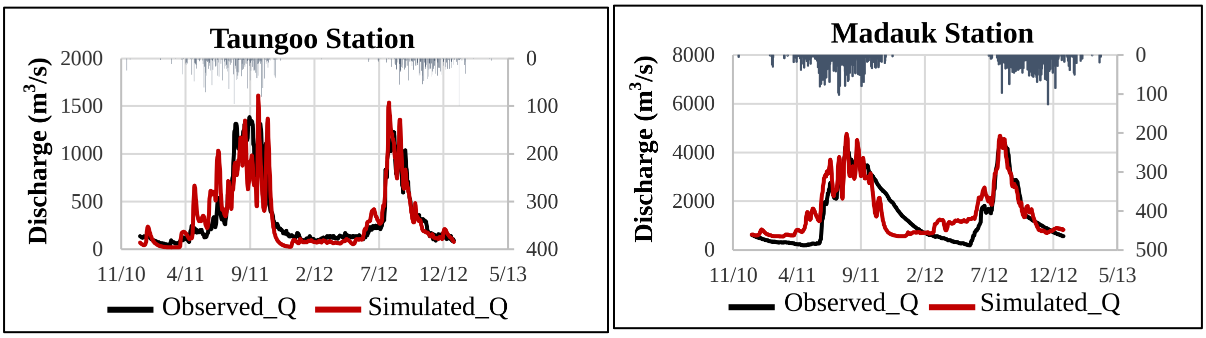


Figure 6 WEB-RRI Model Validation and Observed Discharge for 2011 and 2012

When the flood water enters, each sluice gate stores the water up to its designated level. The excess flood water overflows the sluice gate and flows down to the next one. At third one, the floodwater is transferred to the Ngabataing Lake that will act like a retarding basin. If we assume that discharge more than a threshold value of 2000 m^3/s can be diverted to the retarding basin, a total of 68 MCM of water can be stored to reduce the flood peak.

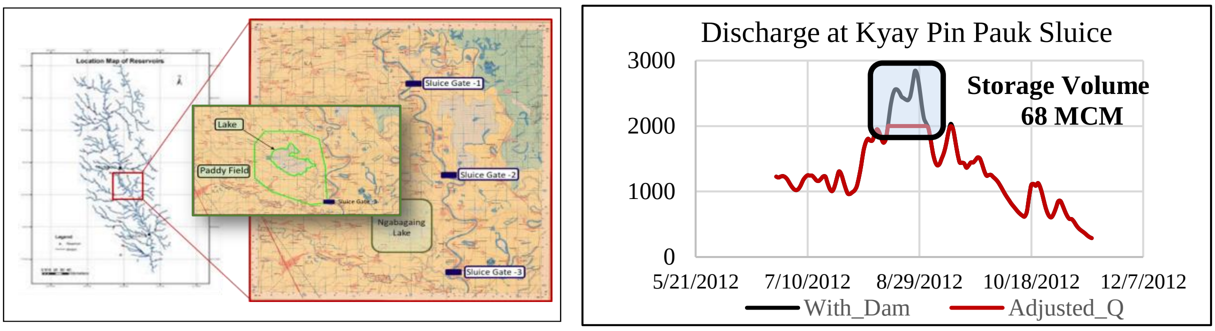
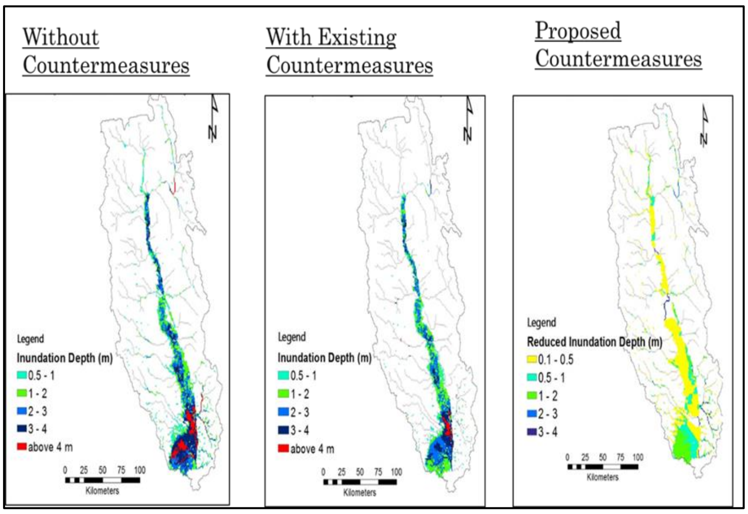
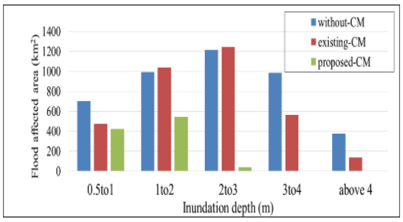


Figure 7 **New Countermeasures for Flood Mitigation and Operation Capacity of Retarding Basin**

Figure 8 illustrated the flood affected area and inundation depth in three cases, including without dams, with effective dam operations and with proposed countermeasures. Based on the simulated results, the total inundated area is reduced 20% and 40% by the existing countermeasures and the proposed





	Without countermeasure	Existing countermeasure	Proposed countermeasure
Total flood affected area	4055 km²	3240 km²	2460 km²
Reduced area		815 km²	1595 km²
Reduced area %		20 %	40 %

Figure 8 **Inundation depth and area maps of different countermeasures**

countermeasures, respectively. The paddy damaged area and value are estimated by analyzing the inundation depth with a stage of monsoon paddy and the production cost. Typical rice production cost to monsoon paddy is approximately USD 373. **Table.1** shows the expected maximum area of the paddy

***Table 1.* Expected max paddy damage area and value**

Without countermeasure		Existing countermeasure		Proposed countermeasure	
Area (ha)	Value (US$ Million)	Area (ha)	Value (US$ Million)	Area (ha)	value (US$ Million)
82553	28.48	65961	22.75	32472	11.2
Reduced damage value			5.72		17.3

damages and their values for different types of countermeasures. On the other hand, the past and future climates were studied by using GCM of RCP8.5 Scenarios of the future climate, Six GCMs were selected and all the models showed that monthly precipitation would increase in the wet season and three models showed that monthly precipitation would decrease in the dry period compared with the present climate. All six models show large increase rates of the daily extreme rainfall, 21% by ACCESS model, 33% by CMCC_CESM model, 29% by CMCC_CMS model, 4.78% by CMCC_CM5 model, 22.58% by MPI_ ESM_LR model and 42% by MPI_ ESM_MR model from the year 2040 to 2060 over the SRB (See as in **Figure 9**).

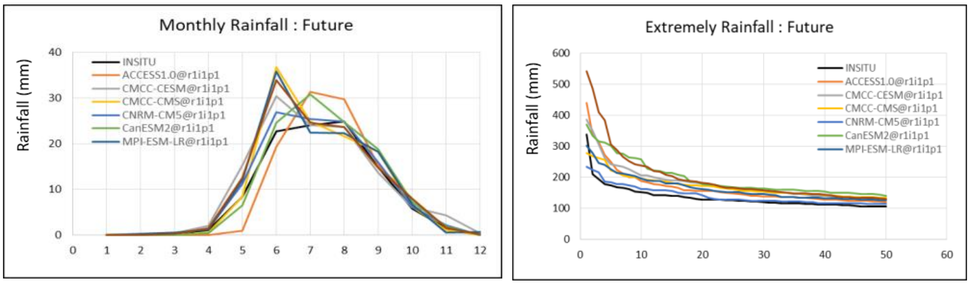


Figure 9 Monthly average and Probability of extreme precipitation under the present and future climates

Figure 10 shows probability distribution of precipitation and inflow at the downstream of SRB. All the models showed that extreme precipitation would increase in the future climate and that will subsequently lead to more inundation. However, three models showed that deficit rainfall would occur in the dry season in the future and meteorological drought also would occur in the dry period. According to the result of the WEB-RRI model simulation using the GCMs past and future data, inflow will increase in the future, that will lead to increase of inundation extents during flooding time. However, inflow will decrease in the dry season and that will lead to the hydrological drought condition.

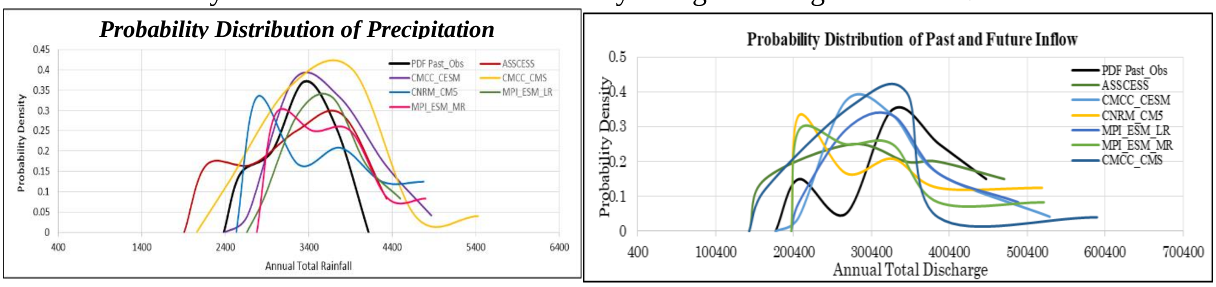


Figure 10 Probability Distribution of Precipitation and Inflow under Past and Future Climate

Keeping GCM model scenarios, the hydrological assessment of dams should be addressed as a prioritized project. Paung Laung Dam is selected to check the storage capacity and similar methodology to cope with other dams. **Figure 11** shows the gap between past (1980-2005) and future (2040-2065) averaged inflows of the six GCM data. According to the figure, the inflow will decrease in summer and then increase in the rainy season (July to December). During the rainy season, there is an ample amount of water which may create flood and ultimately could reach the sea without any usage. Therefore the surplus water has to be stored to use for upcoming dry season (January to June). Hence the storage capacity of reservoir has to be increased to minimize the effect of drought during the dry season such as shortage of water for irrigation, hydropower and drinking water for the local people. Therefore, optimizing the water allocation management in the dam to improve the water storage capacity during the flood time is prime task in Paung Laung Dam. Subsequently the stored water will be made available for use in dry or summer season. Apart from the climate change, the population of this area under the dam is in increasing trend. Due to the demographic increase, the future water demand will also increase. In that sense, irrigation, hydropower, drinking water, sanitation and industrial water usages will increase. Hence, the optimization of water usages is essential for decision makers of the SRB and this research will support them for timely decision making.

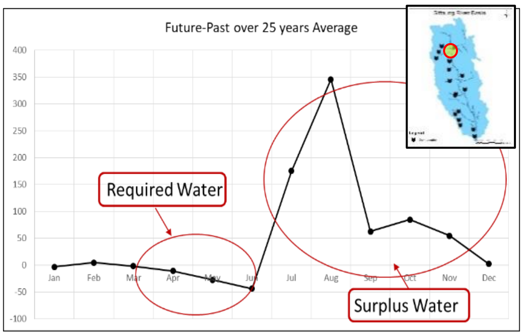


Figure 11. **Future – Past over 25 years Average Inflow at Paung Laung Dam**

CONCLUSION AND RECOMMENDATION

According to the SPI analysis, in most of the years, severe floods were recorded in the Sittaung River Basin. But some drought events were prominent and they lasted for long period of time in recent years. For the future climate assessments, the GCM rainfall data bias-corrected by using the in-situ data and indicated an increasing trend in the wet season and a decreasing trend in the dry period in the SRB. Therefore, the increasing precipitation will result in increasing water levels, and discharges during the wet season and vice versa in the dry season. In this study, WEB-RRI modeled hydrographs showed acceptable performance in simulating flooding events, and the modeled discharge hydrographs correlated well with the observed discharge hydrographs. This study also examined the effectiveness of countermeasures for scenario flood events to minimize severe inundation damages by extreme rainfall events derived from the climate scenarios. To reduce the flood inundation area and inundation depth, the proposed cascade flood gate operations and diverting a peak discharges to a retention basin can reduce the flood damages during the rainy season, significantly. As the SRB also plays an important role for the national agriculture production and hydropower generation, the projected water demand and seasonal water availability in dams for the future should be considered based on the present demand to improve the dam operation system. This outputs of this research, which based on natural science and advanced method of technology can support policy and decision making to optimize the future water resources of the basin in an integrated approach.

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