Investigating the Impact of Climate Change on Flooding in the Sittaung River Basin, Myanmar

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ABSTRACT

Flooding is a serious problem in the Sittaung River Basin (SRB) in Myanmar. The floods have displaced and killed millions of people, caused damage to infrastructure, and eroded the country's economic base which is already in precarious conditions due to the civil war, the country experienced during last two decades. Therefore, this study aims to investigate the impacts of climate change on flooding in the basin. Rainfall Runoff Inundation (RRI) Model was used to analyze the past flood events which were 2012-2015 flood events. For the future climate prediction, five models outputs from Coupled Model Inter-comparison Project Phase5 (CMIP5) were selected based on their performance scores, and the selected models data were bias corrected for current (1990-2005) and future (2046-2061) under the RCP8.5 emission scenario. The results of the assessment showed an increase in extreme flood discharges under future climate conditions. The RRI model was used to propose structural mitigation measures such as multi-purpose dams for future flood risk reduction and mitigation measures. The inundation analysis indicated that the new proposed dams and embankment will contribute to a reduction of flood discharge of future flood inundation in the basin under 50 year return period. According to the different scenarios, the embankment construction, combined with dam construction projects can give the best solution for reducing future flood inundated area.

Keywords: *RRI Model, Frequency Analysis, Flood Inundation Map, CMIP5, Countermeasures*

INTRODUCTION

Sittaung is the 4th largest River basin in Myanmar which is important for agricultural production and food exportations accounting for 40 percent of the country`s gross domestic product (GDP), as well as acting as the center for the transport network system connecting the seven regions and seven states of the country. The basin is located in a low lying area of the attitude 50 m.a.s.l **Figure 1.** This physical location makes the basin prone to flood disasters annually. The frequency and intensity of flooding in the basin is increasing in the face of climate change such that during the monsoon season, about two third of flood plain areas are usually inundated by severe floods due to the torrential rainfalls. This makes the River unable to carry out excess discharge of water, hence causing floods around the river bank. Considering the frequency and intensity of the floods coupled with increasing of population growth and

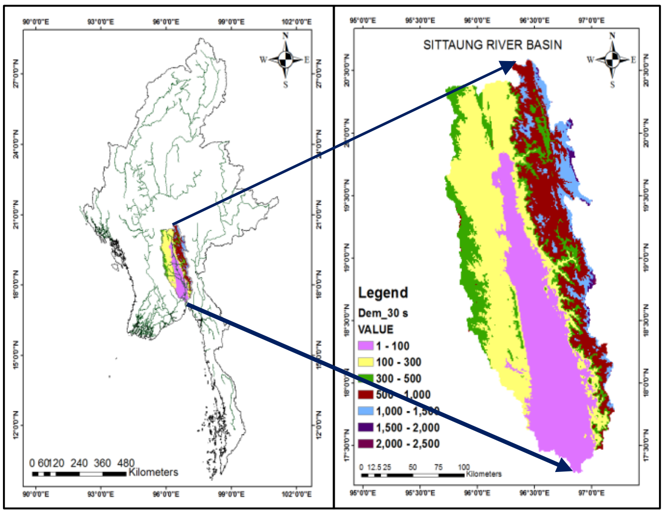

Figure 1: Location of Sittaung River Basin, Myanmar

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unsustainable land uses, the impacts of the floods are increasing such that more people are affected by the floods and more damage and losses are recorded on each flood event. Therefore, this study aims at developing flood inundation maps that will be used to inform decision making by all policy makers by having a clear understanding of the behavior and impacts of floods on the local people and the economic assets. The study would like to further propose the construction of new structural flood countermeasures e.g. dams and embankments that will help in reducing the extent of inundation area in the basin, in so doing protecting people's lives, crop fields and the infrastructure.

METHODOLOGY

This study aims (1) to analyze hydrological responses of the past flood events, (2) to investigate the change in precipitation and river flows under the future climate condition and (3) to propose the development of the countermeasures. To analyze the flood inundation of Sittaung River Basin, the research will use observed discharge and observed rainfall data that will be used as an input to Rainfall Runoff Inundation (RRI) model (Sayama, et. al 2015) to identify the flood prone areas, flood duration and depth. For the model calibration, the 2012 flood event was simulated by using the observed rainfall data and model validation was done for the 2013 - 2015 flood events. In addition, flood inundation analysis by moderate-resolution imaging spectroradiometer MODIS remote sensing image was considered to validate the RRI inundation maps for the 2013, 2014 and 2015. Satellite-based data were applied to calculate floodwater indices such as NDVI, LSWI, MLSWI and water bodies. To assess the effects of the climate change, five models from outputs Coupled Model Inter-comparison Project Phase5 (CMIP5) were selected based on their performance scores, and the selected models data were bias corrected for current (1990-2005) and future (2046-2061) under the RCP8.5 emission scenario. The results of the assessment showed an increase in extreme flood discharges under future climate. Then new additional countermeasures were proposed to the river system where it was possible and compare the inundation scenarios results by the effect of new countermeasures and then selected the most appropriate project for flood mitigation in the near future.

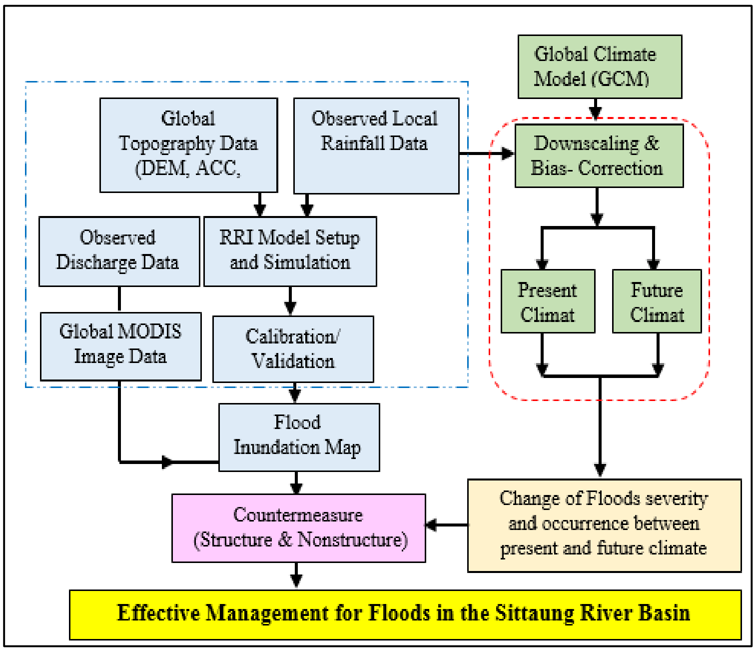

Figure 2. Flow chart of methodology

The following countermeasures are conducted to the river system as scenarios:

Scenario-1: Construction of 3 m height embankment along the bank of river in the downstream area.

Scenario-2: Construction of dams near the Taungoo station in the upstream area.

Scenario-3: Construction of 3 m height embankment and dams in the upstream area and downstream area where more inundated.

DATA

Daily precipitation, river water level, river discharge and hydropower dam data were collected from the Department of Meteorology and Hydrology and department of irrigation, Myanmar. The GIS data such as the 30 seconds resolution data of Digital Elevation Model (DEM), Flow accumulation (ACC) and Flow direction (DIR) were obtained from HydroSHEDS dataset. The MODIS Terra Level-3 8-day composite surface reflectance products (MOD09A1) was used to validate the RRI model result. For the climate change simulation, the daily precipitation data set covered the year from 1990 to 2005 (16 years) was applied for the current climate condition. Future climate condition from 2046 to 2061 (16 years) was estimated by substituting the target data sets in the APHRODITE reference data set. The gridded rain gauges dataset in Asia, APHRODITE, was used as a reference observation for the SRB, Myanmar.

RESULTS AND DISSCUSSION

The RRI model was calibrated and validated by using historical flood events rainfall and water discharge. Model calibration was done by using observed and simulated discharge data 2012 flood event. For the model validation, the 2013-2015 flood events were used and the model showed very good performance. **Figure 3** Shows the model calibration and validation results of comparative hydrograph for 2012 flood event and 2013-2015 flood events at Madauk station in SRB.

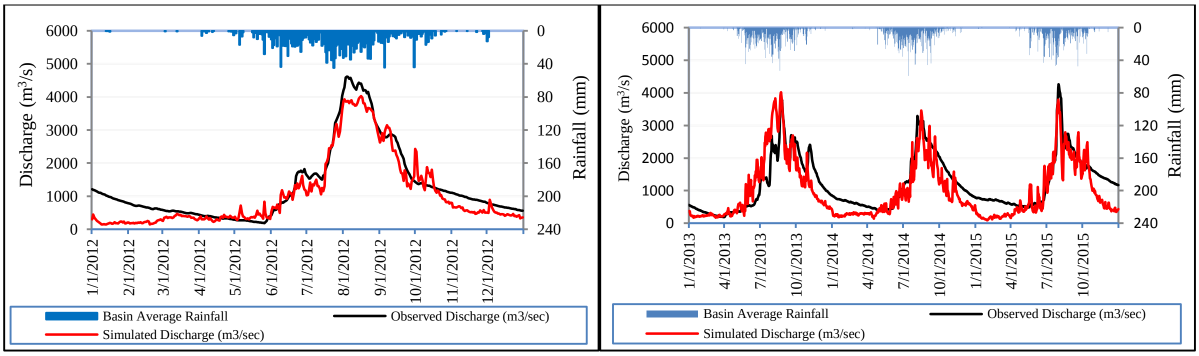

Figure 3. Model calibration result of comparative

Satellite-based data were applied to calculate floodwater indices such as NDVI, LSWI, MLSWI and water bodies **Figure 4**. Among then the MGBM method was the best to identify the extent of flooded areas. Flood inundation extent was validated during the flood period (24th -31st Aug, 2015).

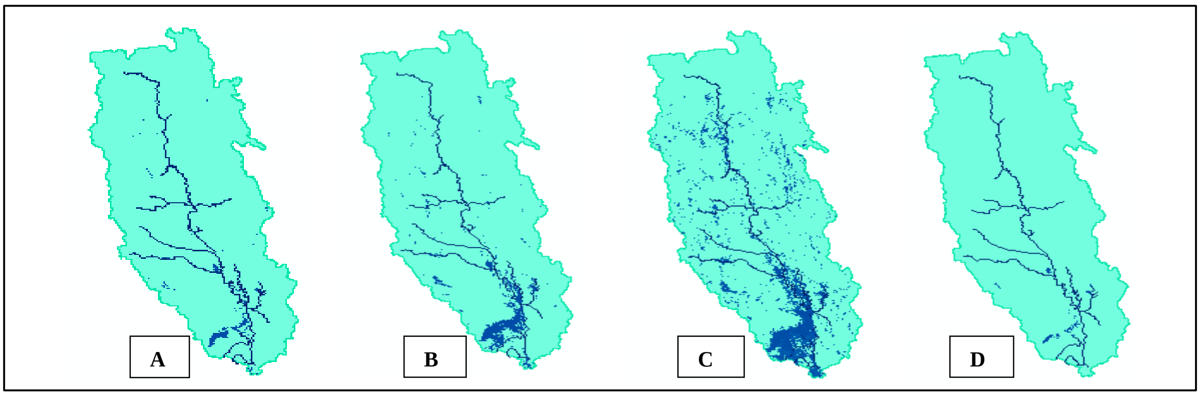

Figure 4: Flood extent area from applying the different water indices for LSWI (A), NDVI (B) MLSWI (C) and Permanent water bodies (D)

One of the purpose of this study was to develop the flood hazard maps from RRI model simulations for the flood management of flood risks. Flood inundation maps of 10, 50 and 100 years return periods were prepared with the application of GIS tools. **Figure 5** shows the comparison of flood inundation area for different return period by RRI model. The flood inundated areas by RRI model were obtained as 5404 km^2, 6320 km^2 and 6568 km^2 for 10, 50 and 100 year return periods.

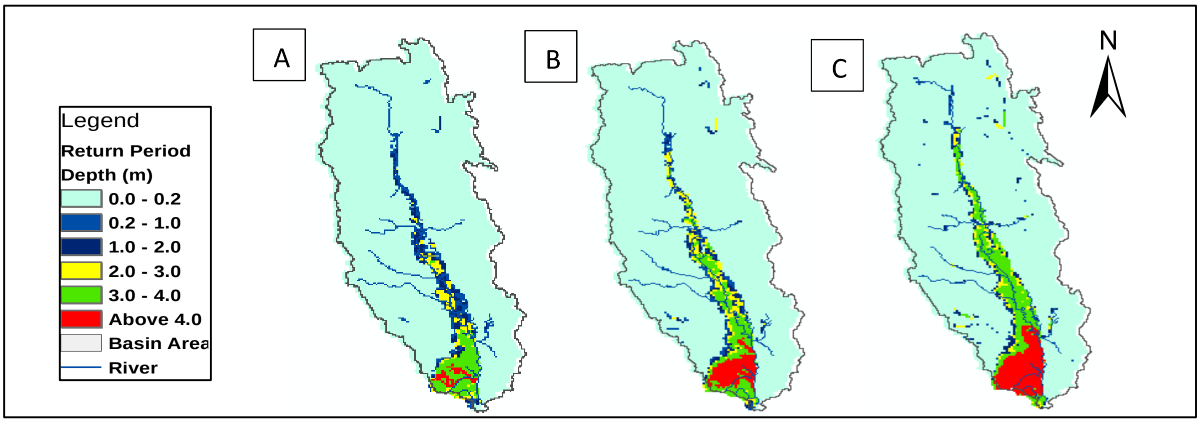

***Figure 5. Inundation Map for 10year (A), 50year (B), 100 year (C) return periods by RRI* model**

To select the optimum solution for the flood mitigation measures, the flood inundation extent area, with new proposed countermeasures, was calculated and the flood scenario results were compared. It indicated that dam constructions and levee construction modification not only in the main river but also in the tributaries was the most effective countermeasure. Floods would be prevented by these proposed mitigation measures. **Figure 6** show the spatial distribution of flood extend area by different countermeasures.

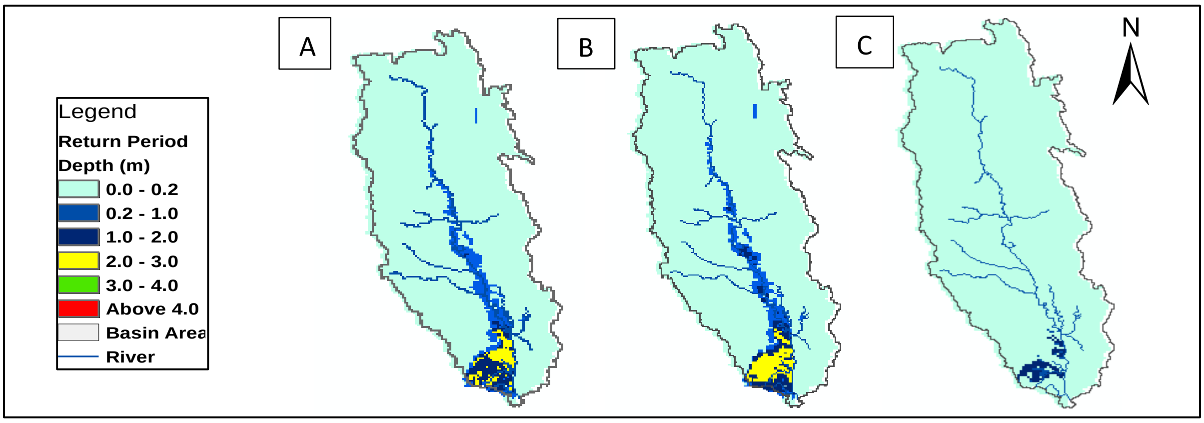

Figure 6. The spatial distribution of flood extend area by different countermeasures for 3m high embankment construction(A), dam constructions(B) and combination of embankment with dam constructions(C).

To assess the effects of the climate change, daily bias-corrected precipitation data was used for 16 years with current (1990-2005) and the future (2046-2061) climate conditions. Monthly bias corrected precipitation was analyzed to evaluate the future flood risk. Generally, monthly rainfall is will increase in the future as shown in **Figure 7**. The results of the annual monthly precipitation analysis showed an increase about 14.68% in future, subsequently leading to more inundation.

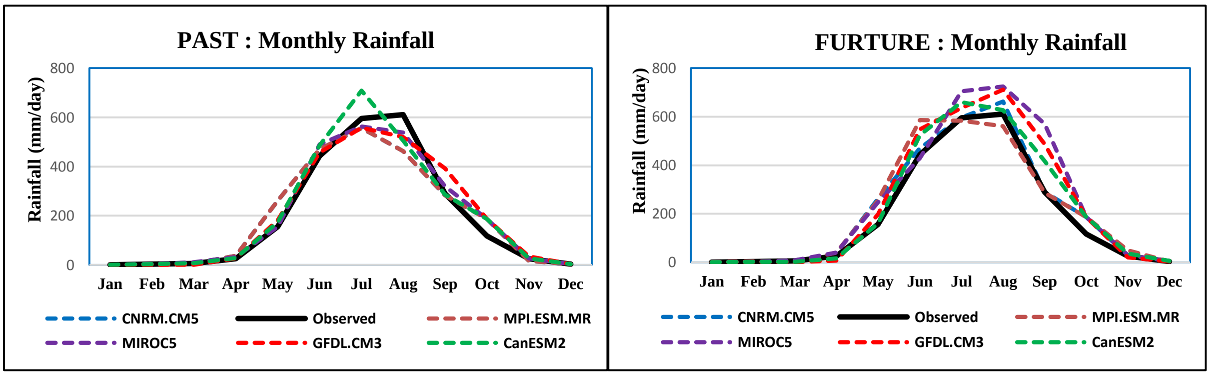

Figure 7. Comparison between past and future monthly rainfall

Figure 8 shows the frequency of extreme rainfall events for present and future RCP8.5 emission scenario. The present and future precipitation were from bias-corrected Model daily precipitation. The probability of extreme precipitation increases under the RCP8.5 scenario and this increasing trend of precipitation may intensify floods in the Sittaung River Basin in the future due to the impacts of climate change.

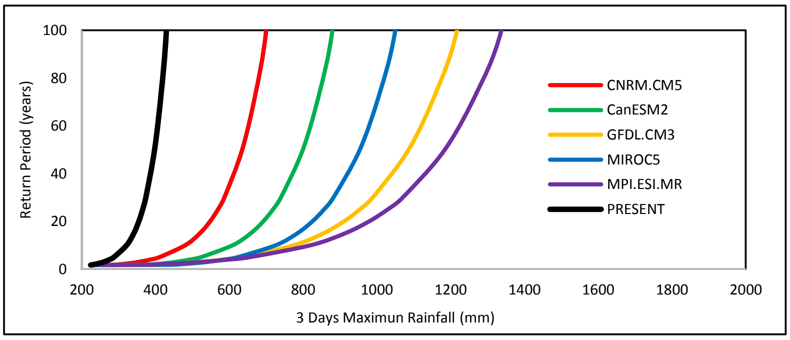

Figure 8. Probability of analysis precipitation under the future and climate condition

The annual maximum daily peak discharge from past (1990 to 2005) and future (2046 to 2061) discharges are demonstrated in **Figure 9**. These discharge values for current and future climate conditions were simulated at Madauk Station by the calibrated RRI model with daily bias-corrected GCM model data. From these results, future daily flood peak discharges increase about 15.2 % by the MIROC5 model, 11.2 % by the Can-ESM2 model, 9.2 % by the MPI_ESM_MR model, 5.5 % by the CNRM-CM5 model and 5.2 % by the GFDL_CM3 model for the maximum daily discharge from 2046 to 2061 over the Sittaung River Basin.

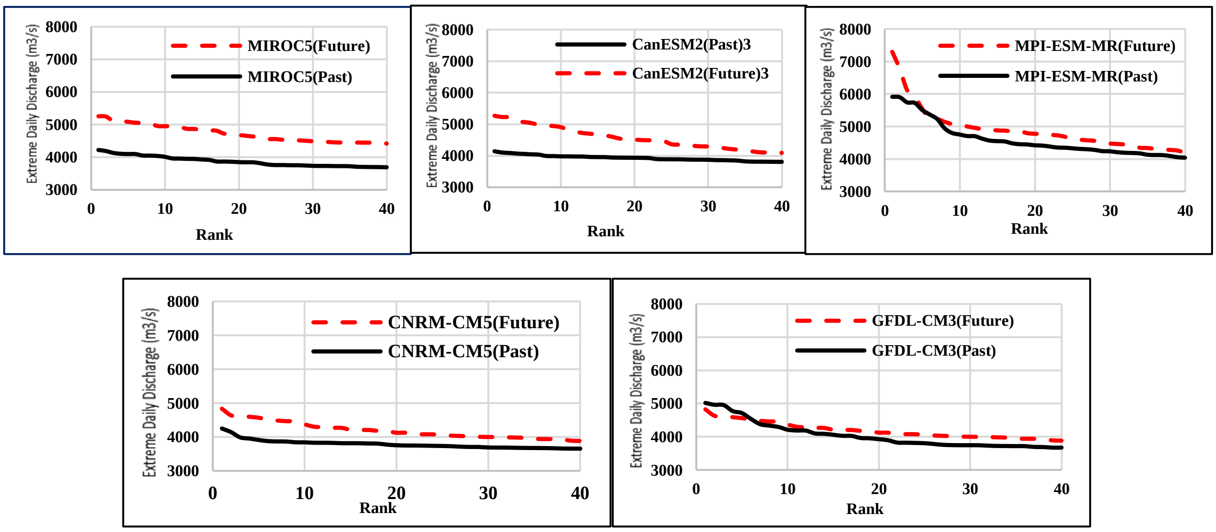

Figure 9. Comparison of past and future daily discharge under RCP8.5 scenario

CONCLUSION AND RECOMMENDATION

The main objectives of this study were to analyze the past flood events (2012-2015) by using RRI model, to propose additional countermeasures of flood risks, to develop the flood inundation maps for flood risk management in the Sittaung River and to investigate the change in precipitation and river flows under the future climate condition in the Sittaung River basin. RRI model calibration and validation were conducted by comparing observed discharge with simulated discharge data of 2012-2015 flood events. The model result gave satisfactory information with the observed hydrograph for river discharge data of Madauk station. In addition, flood inundation analysis by MODIS Satellite-based data were applied to calculate floodwater indices such as NDVI, LSWI and MLSWI. Among the three, MLSWI method showed good results for identifying the extent of flooded areas. Flood inundation extent area was validated with the flood period from 24th to 31st August, 2015. According to the RRI results of simulated discharges, the inundation depth rose up to above 4 m and total inundated area was 5404 km^2 at 50 years return period. Floods hazard maps for different return period of 10-, 50- and 100- years were developed based on frequency analysis. Obtained flood inundation areas were 5404 km^2, 6320 km^2 and 6568 km^2 for 10-, 50- and 100- year return periods respectively. Considering the effects of climate change, five models from CMIP5 Global Climate Models were selected based on their performance scores, and the selected models data were bias corrected for current (1990-2005) and future (2046-2061) under the RCP8.5 emission scenario. The climatic 3-day maximum rainfall data was analyzed to obtain annual maximum rainfall and from those annual maximum, extreme rainfall scenarios of the different return period were calculated. The results showed increasing of precipitation and extreme flood discharges under future climate conditions.

The inundation analysis indicated that the proposed countermeasures contribute to a reduction of inundated area with 50 year return period flood event. According to the RRI Model simulated discharges, 6320 km^2 (19% of study basin) would be inundated by 50-year return period without countermeasure. In case of the proposed countermeasure, flood extent of inundation would be reduced about 1460 km^2 of flood inundation area by 3m high embankment/levee construction, about 1876 km^2 by dams construction and about 5668 km^2 (16% of study basin) by combination of embankment and multi-purpose construction. This means that the government and all stakeholders should critically consider the construction of countermeasures for flood mitigation under future climate change conditions.

This study therefore recommends to further investigate on the construction of the multi-purpose dams as well as the Levees in order to reduce the impacts of floods risks in the basin. The study further recommends for multi-stakeholders collaboration in Flood Risk Management and Climate Change adaptation measures.

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