FLOOD HAZARD AND RISK ASSESSMENT UNDER CLIMATE CHANGE IN THE LOWER SHIRE BASIN, MALAWI

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ABSTRACT

Traditionally, people in the Lower Shire River basin of Malawi have lived and relied on floods for building their livelihoods. However, the frequency and intensity of floods, coupled with continued population growth and unsustainable land use, have increased the vulnerability of the poor such that many households are often unable to break out of the poverty cycle. There have been limited attempts to provide a holistic approach in linking the hazards and exposure as the sole determinants of people's vulnerability in the basin. Therefore, this study aimed to assess flood hazard, exposure and risk and propose policy measures for flood risk and vulnerability reduction under climate change. In the flood hazard assessment, Rainfall Run-off Inundation (RRI) model was calibrated using 2009 flood event and validated with the 2012 and 2015 flood events. For the assessment of climate change, the calibrated RRI model was applied to produce flood inundation maps based on 5-, 20-, 50- and 100-year return period. The rainfall data is the bias corrected output of three global climate models from the Coupled Model Inter-comparison Project Phase 5 (CMIP5), for both current (1986-2005) and future (2046-2065) climates. Exposure assessment focused on the affected population and the housing sector. Based on the results, there is an increasing trend of flood hazard in the future climates, therefore, more people and their livelihoods are likely to be affected and more damage and economic losses will be felt. A Pressure and Release (PAR) model was applied to guide broader policy measures for flood risk management and resilience building of the communities in the basin.

Keywords: *RRI model, GCMs, PAR model, Flood Risk Management, Resilience building.*

INTRODUCTION

In Malawi, water related disasters account for 70% of all disasters, floods being the most common and widespread (GoM, 2015). The nature and pattern of floods are changing in the face of climate change. The floods are becoming more frequent, with an expected rise in intensity. For instance, the Malawi 2015 floods affected over one million people, displacing 336,000 and killing 104 people (Kita, 2017). The floods also resulted into damage and losses estimated at US$ 335 million [a value equivalent to around 0.5% of GDP] (World Bank, 2016) with the highest number of affected people and damage and losses recorded in the Lower Shire basin. This study was conducted in the Lower Shire River basin which is located between Lake Malawi and the Zambezi River basin. Living with floods has been a reality to approximately two million residents of the basin, however, the frequency and intensity, coupled with factors such as continued population growth, unsustainable land use, limited knowledge on climate change and variability at community level to inform adaptation practices, the floods have been destructive, causing displacements, loss of human lives, increased economic losses, emergence of water-borne diseases and also affecting a much broader part of people's livelihoods. The recurrent flood events have further increased the vulnerability of the poor, increasing poverty levels such that many households are often unable to break out of the poverty cycle.

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In response to the increasing frequency of flood disasters under climate change, disaster management has evolved significantly to incorporate vulnerability assessments that are multi-dimensional and integrated (Mwale, et al., 2014). However, this has not been the case with Malawi, the Lower Shire River basin in particular. There have been limited attempts to provide a holistic approach in linking the hazard and exposure (people, economic assets infrastructure, etc.) as the sole determinants of households' vulnerability. Considering the unequivocalness of global climate change phenomena (IPCC, 2007) and notable increase of flood occurrences in the basin, this study has, therefore, been conceptualized for the following objectives: to assess the impacts of past flood events (2009, 2012 and 2015) by using RRI model; analyse future flood impacts under climate change using global climate models (GCMs); develop flood inundation maps for the Lower Shire River basin that will inform designing of appropriate counter measures; and propose policy measures for resilience building and flood risk reduction under climate change.

THEORY AND METHODOLOGY

The methodology (**Fig. 1)** for this study is based on the definition of Risk by IPCC (2007) as the combination of Hazard, Exposure, and Vulnerability (R = H x E x V). Flood is identified as a hazard while vulnerability is analysed considering the physical aspects, which are the exposure of the affected population and physical assets. To quantify the vulnerability of the potential affected people was based on the formula that calculates the number of people to be affected by grid cells in the Arc-GIS while the assessment of the inundation to houses was based on the damage curves.

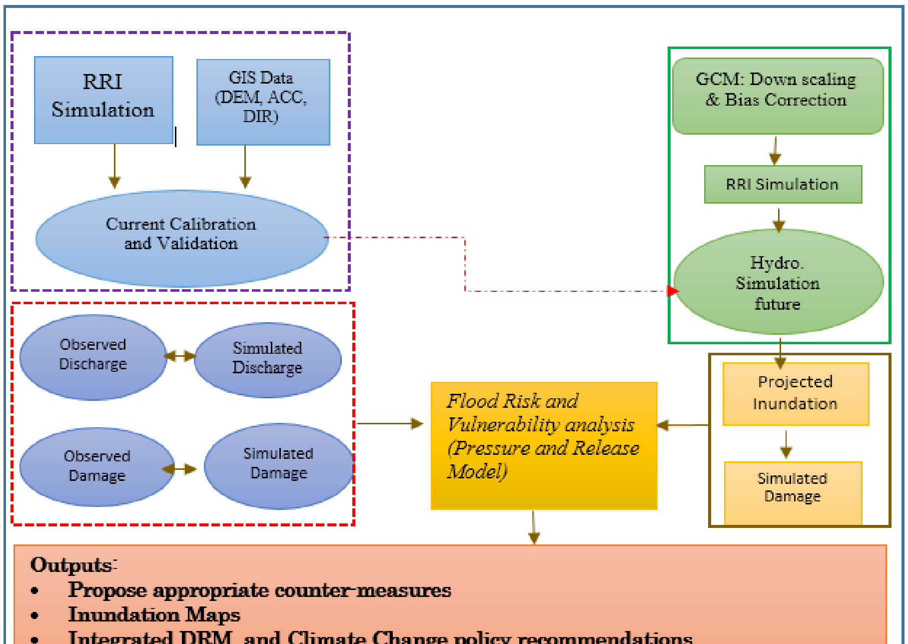


Fig.1. Methodological approach of the study

Flood Hazard Assessment: The RRI model was used to simulate the inundation in the Lower Shire River basin. The RRI is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously by applying the 2-D diffusive wave model to calculate the flow on the slope and 1-D diffusive wave model to calculate the channel flow (Sayama, 2015). For physical representation of the model, lateral subsurface, infiltration and surface flow is simulated. Lateral subsurface flow is based on the discharge-hydraulic gradient relationship while the vertical infiltration is estimated based on the Green-Ampt model. The RRI model was set up for the entire Shire River basin on a 1-km resolution to simulate flood discharge and inundation areas of the past three major floods as part of calibration (2009 flood event) and validation (2012 and 2015 flood events) by setting boundary conditions at the Mangochi-Lake Outlet and Liwonde Barrage hydrological stations with observed discharge from three stations of Chiromo, Liwonde Barrage and Mangochi-Lake Malawi outlet. The simulated results, showing extent of inundation was compared to the flood image obtained from MASDAP (www.masdap.mw). All the simulated results were verified with the 2015 Malawi Post Disaster Needs Assessment (PDNA) Report.

Exposure Assessment: For assessing the impact of climate change, three Global Climate Models

(CanESM2@r5i1p1, GFDL-CM3@r1i1p1 and ACCESS1.0@ens_mean) from CMIP5 under the RCP8.5, with bias corrected rainfall data, for both current (1986-2005) and future (2046-2065) climates, were selected based on their performance to represent the basin's climate conditions by analysing the GCM regional applicability using the Root Mean Square Error (RMSE) and Spatial Correlation (Scorr) for each model. The basin average rainfall data was applied in the calibrated RRI model to produce current and future discharges which were then used to produce flood inundation maps with precipitation corresponding to 5-, 20-, 50-, and 100-year return period. From this point, flood inundations extent, number of affected people and damage to houses were estimated. Inundation maps were produced applying these conditions and cases to the calibrated RRI for the above mentioned return periods.

Vulnerability Assessment: A Pressure and Release (PAR) model was applied to guide in proposing holistic policy measures for reducing the root causes and dynamic pressures of vulnerability. The PAR model shows the progression of vulnerability from the root causes through dynamic pressures to unsafe conditions which lead to a disaster. It emphasizes a need to look at broader conceptualizations of how communities become unsafe, including looking beyond the threat of exposure to investigate social sources of vulnerability. These sources of vulnerability are found in how people actually live within floodplains, and the social, economic and political processes that impact the choices they make to mitigate flood risks (Wisner et al., 2004).

DATA

Daily precipitation data (1979-2015) was obtained from the Department of Climate Change and Meteorological Services, while as daily discharge data (1981-2015) was collected from the Department of Water Resources, Malawi. The Arc-GIS-30 seconds resolution data of Digital Elevation Model (DEM), flow accumulation (ACC) and Flow direction (DIR) were obtained from Hydro-SHEDS dataset. Land cover data was obtain from the Department of Surveys, Malawi. For climate change assessment, 35-year observed daily rainfall was uploaded in the DIAS system based at Tokyo University. The bias corrected rainfall data for both current (1986-2005) and future (2046-2065) climate conditions were downloaded from the DIAS.

RESULTS AND DISCUSSION

Discharge Simulation: The analysis of the past flood inundation was conducted by using the RRI model and identified the flood prone areas, flood duration and depth were calculated. For the model calibration, the 2009 flood event was simulated by using the observed local rainfall data. Model validation was done for the 2012 and 2015. The validation of the results showed a better matching of the simulated and observed discharges with boundary conditions setting at Lake Outlet and at the Liwonde Barrage hydrological stations. All the simulated discharges were compared with the observed discharges at Chiromo hydrological station. In this study, RRI model represented well the conditions of the basin and the performance indices (NSE, RMSE) were found quite satisfactory.

Risk (Exposure) Assessment: The calibrated RRI model was used with the bias corrected data from the CMIP5 under the RCP8.5 for Present (1986-2005) and Future (2046-2065) climates to produce current and future discharges which were then used to produce flood inundation maps with precipitation corresponding to 5-, 20-, 50-, and 100-year return period. The assessment of climate change, from the selected 3 GCMs, show that future average annual monthly precipitation (**Fig. 4**) will increase by 16.6 percent during the wet season (December to March). The increase in Carbon Dioxide concentration in the atmosphere bring about a positive feedback

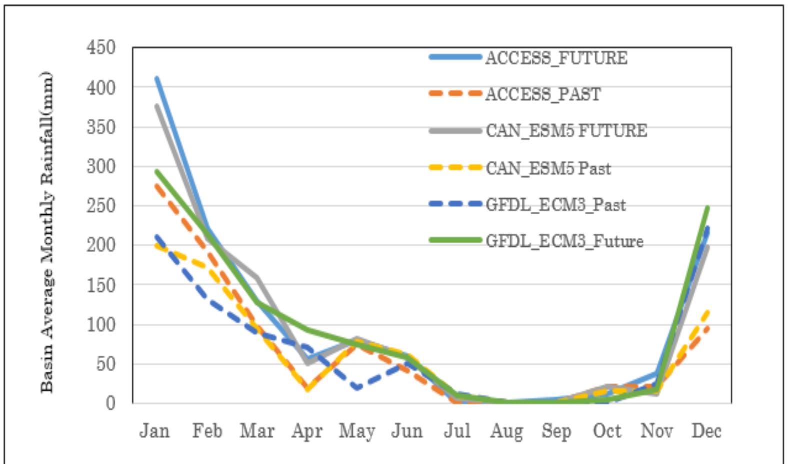


Fig4. Comparison of past and future Basin average monthly precipitation

mechanism effect to the global climate "with an increase in temperature causing an increase evaporation and subsequently leading to increased precipitation" (Nyunt et al, 2013). The results of RRI simulation for each GCM, both past and future were observed at Chiromo hydrological station in the Lower Shire basin. The results show future increase in peak annual discharge of 42% at Chiromo discharge station. Moreover, the river discharge is also showing a 45% increase in discharge during the wet season (December to April), the days above a threshold of $5600m^3/s$ from an average of 64 to 86 days per year. On the other hand, the average days of low flow ($<170m^3/s$) to be 11% lower and the maximum days of low flow per year are also going to decrease by 17 %. The simulated annual maximum discharges for current (1986 to 2005) and future (2046-2065) climates and extreme discharges are presented in **Figures 5 and 6** respectively.

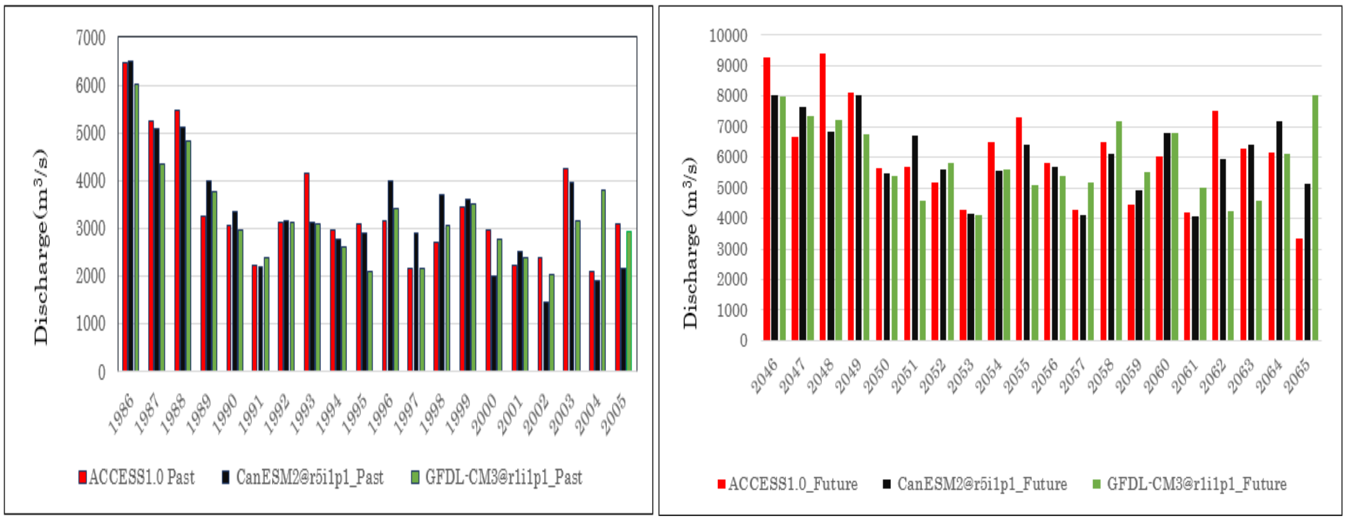


Figure 5: Annual maximum discharge under Current and Future climates at Chiromo station

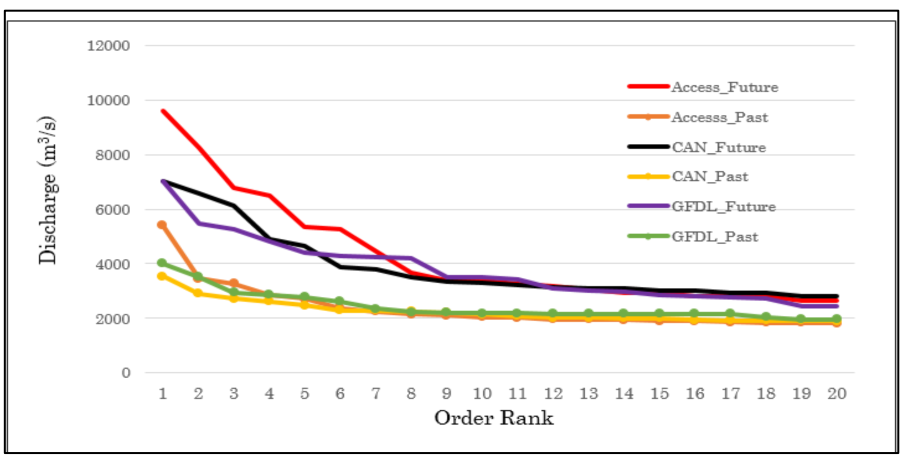


Figure 6: Extreme Daily Discharges (Present and Future Climate)

These results suggest an explicit potential increase of flood risks in the Lower Shire River basin, thus increasing the probability of more people to be inundated together with their livelihoods assets, more damage to infrastructure such as people's homes, bridges, schools, hospitals, among others. Comparison of the inundation maps under current and future climates show that the flood inundation depth will increase more significantly in the future by 47 percent than current climate condition which is 23 percent. On the flood exposure, out of 1.3 million people within the basin, 14-28 percent are estimated to be affected by the 5-and 100-year return period respectively under current climate condition, while 21- 42.5 percent will be affected by the 5 and 100-year return period respectively under future climate condition. Besides, all models show inundation depth of more than 3 metres, with Access model showing a larger extent of inundations as compared to the CAN and GFDL models (**Fig. 7**). These results signify that more damage to houses, people's livelihoods assets (mainly agriculture), and critical infrastructure such as roads and bridges under future climate conditions should be expected. **Fig. 8** show the inundation maps of the Lower Shire basin under the 5-, 20-, 50-, and 100-year return period based on the ACCESS model analysis.

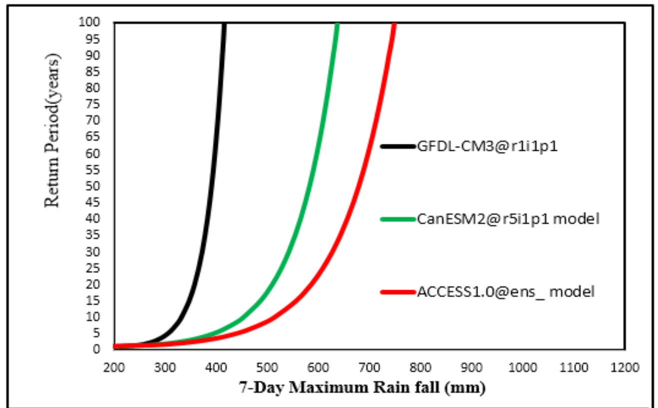
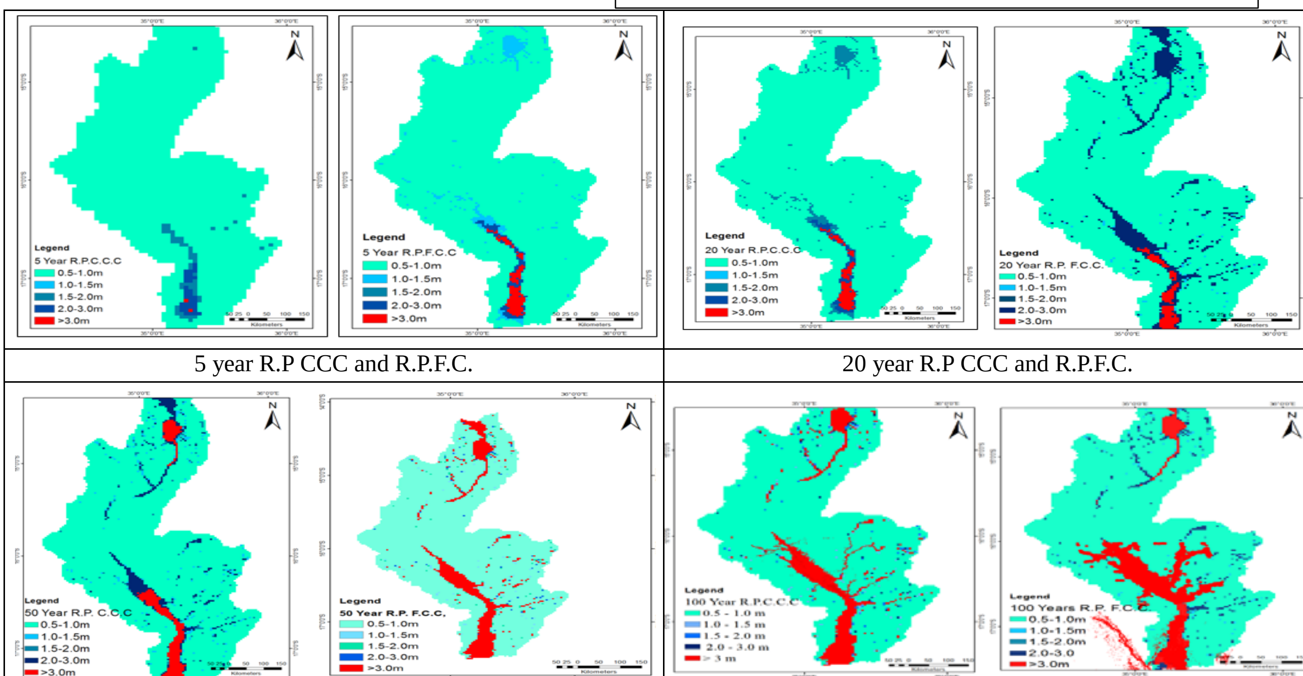


Fig7. Gumbel probability distribution of precipitation under the future climate condition



5 year R.P CCC and R.P.F.C. | 20 year R.P CCC and R.P.F.C.

50 year R.P CCC and R.P.F.C. | 100 year R.P CCC and R.P.F.C.

Fig. 8. Inundation maps (Current and Future) for Different Return Periods under the ACCESS model

Based on the results of flood risk assessment for the anticipated future climate change impacts, a Release model from the PAR model (**Fig. 9)** was applied to guide in proposing integrated policy measures for reducing the root causes and dynamic pressures of vulnerability in the Lower Shire basin. This model stresses that vulnerability reduction must be an exercise in interdisciplinary thinking and decision making, and address fundamental beliefs about hazard creation and amelioration - including who ought to be responsible for addressing social sources of vulnerability in society (Wisner, et al., 2004). The assessment of climate change in this study has shown that increased inundation under future climate change will be experienced in the Lower Shire basin which translate to more people, including their sources of livelihoods i.e. cash and food crops will be affected. There is therefore a need for community resilience building initiatives as well as implementation of the flood risk reduction measures. For building communities resilience to floods, this study proposes the establishment of targeted social safety nets programmes; the establishment and strengthening of community based early warning system that comprise of four inter-related elements: risk knowledge, monitoring and warning service; dissemination and communication and response capability. The study further proposes the establishment of evacuation centers in the basin that can perform multiple uses e.g. as evacuation sites during flooding and as nursery/elementary schools and adult learning centers during the dry season; hence overcoming the problem of high illiteracy rates which is prevalent in the basin. There is also need for DRM and climate change partnership & coordination through policy planning and implementation. This is by considering that vulnerability to disasters has many drivers that require a cross-sectoral approaches to achieve reduction of disaster risks, thereby, building a community resilient to flood disasters. For the flood hazard management, this study propose the construction of the flood control multi-purpose dams that can be used as climate change adaptation measure by the local communities through small scale irrigation during the dry season so that the crops that may have been washed away by floods, can be recovered through irrigation.

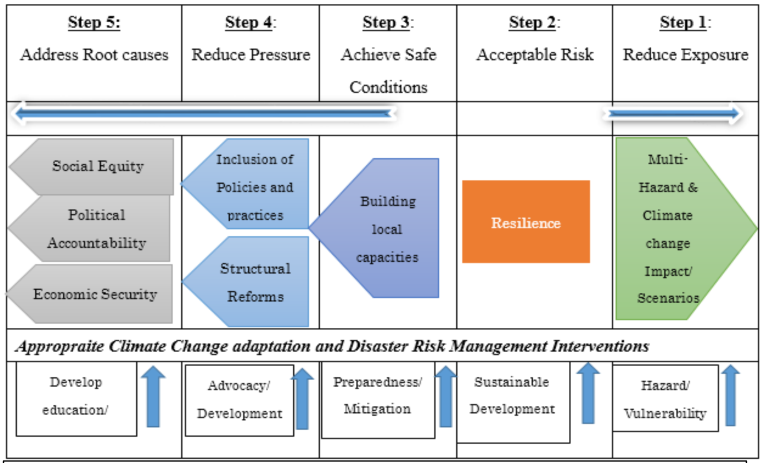


Fig. 9. The PAR Model and Uncertainty (Adapted and modified from Wisner et al, 2004)

RECOMMENDDATION

This study recommends on the improved understanding of the exposure, sensitivity, adaptability and vulnerability of physical, ecological and social systems to climate change; evaluation of climate mitigation options in the context of development, sustainability and equity at national and district levels in different sectors ; investigation of the construction of multi-purpose dams along the main Shire River channel; investigation on the durable Solutions for sustainable livelihoods and resilience building in the context of flood hazards; and utilization of the RRI and GCM models for the analysis of water related hazard under climate change in other River basins of Malawi.

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