CREATING AN EFFECTIVE FLOOD MANAGEMENT PLAN TO IMPROVE THE STANDARD OF LIVING WITHIN THE MUDUN ELA BASIN, SRI LANKA

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ABSTRACT

Floods have been the most frequently occurring type of natural disaster in Sri Lanka for the past ten years. They account for approximately 37% of all disasters, including 47% of total housing damage and 57% of total affected persons atrributed to all disasters. The government of Sri Lanka has suffered large financial losses due to direct and indirect flood damage. This study aimed to assess the impacts of climate change and social change on extreme floods over time and propose suitable countermeasures to mitigate flood risks.This study is based on the Rainfall–Runoff–Inundation (RRI) model simulation carried out for the Mudun Ela basin. Past and future rainfall, social changes, improvements in drainage capacity, and proposed retention pond scenarios are fed into the RRI model to simulate changes in extreme inundation area and depth. Our results indicate that climate change increases the inundation area and depth, while social changes aggravate flood risks. Proposed countermeasures include flood retention ponds with drainage improvements, which may be effective at reducing the inundation area and depth and associated flood damage. Overall, this study proposes that a flood management plan with structural and non-structural measures can help to create a flood-resilient society and improve the standard of living.

Keywords: flood, rainfall–runoff–inundation model, inundation, flood-resilient, flood management

INTRODUCTION

Urban flooding poses a serious challenge to the development of cities and the lives of people who are in the vicinity. The primary factors causing urban flooding include lack of a drainage capacity, inadequate water retention, high levels of intense rainfall, encroachment and blockage of the drainage system. In May 2016, flooding occurred by overflow of the Kelani River, resulting in inland inundation along the tributary basins in the Colombo Metropolitan Region. The flooding caused economic damages amounting to 572 million U.S. dollars (DMC, 2016).

The study area of the Mudun Ela basin is approximately twenty square kilometers and is located in the lowlands in the lower reach of the Kelani River (**Figure 1**). It is also the largest urbanized area, with the total built-up area taking up 84% of the total basin area. With the rising population and inadequacy of fill lands to house them, the developmental solution has been to reclaim the available marshy areas and encroaching flood plains in the Mudun Ela basin. These kind of

Figure 1: Study area and location

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ad hoc developments will incur new flood risks and vulnerabilities, especially given the expected impacts of climate change on flood magnitude and frequency. Therefore, the objective of this research was to assess and compare the impacts of climate and social changes on extreme flooding and to propose suitable countermeasures to mitigate flood risks.

THEORY AND METHODOLOGY

This study focuses on understanding and assessing the impacts of climate change, social change, and potential countermeasures on the mitigation of flood risks. **Figure 2** shows the research framework and overall methodology of the study. The major components of the study are climate change analysis, design rainfall, hydrological modeling, and flood scenario analysis before proposing an effective flood management plan to improve the standard of living within the Mudun Ela basin.

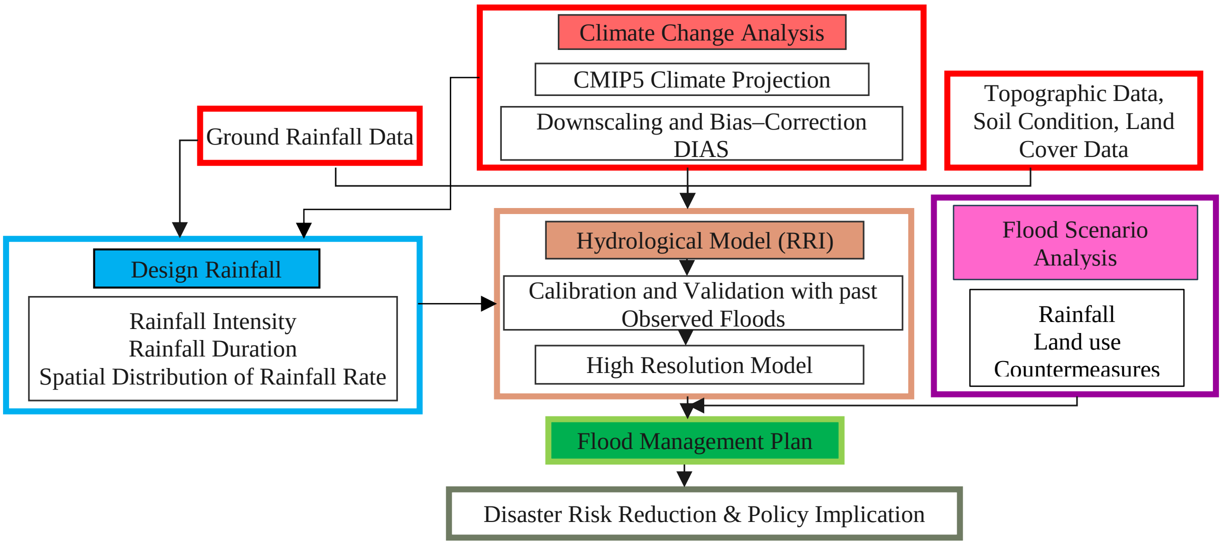

Figure 2: The research framework

1. **Climate Change Analysis**

   Statistical bias correction and downscaling is an important process for selecting General Circulation Models (GCMs). The Coupled Model Inter-Comparison Project Phase 5 (CMIP5) data analysis tool integrated into the Data Integration and Analysis System (DIAS) was used for this purpose. The selection is based on the method developed by "Nyunt et al. (2016)," which uses a scoring scheme based on the climatological monthly long-term mean spatial correlations (Scorr) and root mean square errors (RMSE) for eight key meteorological elements. The combined highest-scoring GCMs were adopted and statistical bias was corrected for rainfall in the DIAS, which followed the three-step method (Nyunt et al., 2013). Bias-corrected historical rainfall (1980–2005) and future rainfall were used in the subsequent sections.

2. **Design Rainfall**

   Frequency analysis was carried out using the Annual Maximum Series (AMS) method. In this method, the probability distribution of block maxima was applied, and the annual maximum event series of the past 25 years of rainfall data and the GCM output for future rainfall were considered. Generalized Extreme Value (GEV) and Gumbel distributions were analyzed to determine the rainfall with a relevant return period. Rainfall for the 50-year and 100-year return periods were considered the design rainfall for future scenarios.

3. **Hydrological Modeling**

   The Rainfall–Runoff–Inundation (RRI) hydrological model was used for this study. The model was calibrated using discharge data from Hanwella station for the year 2016 and validated using data from the year 2013. RRI performance was evaluated in terms of Nash Sutcliffe Efficiency (NSE).

RRI simulations were carried out for the whole Kelani River basin to calculate discharge on the basin scale for calibration and validation. For the inundation simulation, a separate RRI model was established on a local scale for the Mudun Ela basin with the calibrated parameters.

4. Flood Scenario Analysis

Different scenarios were run with selected factors, such as rainfall, social change, and proposed countermeasures to investigate the changes in inundation extent and inundation depth (see **Figure 3**). To investigate this, the RRI model, which was established on a local scale for the Mudun Ela basin with the calibrated parameters, was employed. Past observed rainfall and future rainfall, such as the 50-year and 100-year return periods, obtained by frequency analysis were applied. Land use was changed in the RRI model for future scenarios by modifying land cover and soil parameters. For this, crop lands, shrub, and other vegetation mosaic areas were considered future urban areas due to rapid urbanization. Structural countermeasures, such as improvement of the drainage capacity by increasing the width geometry parameter from 5.0 to 7.0, increasing the depth geometry parameter from 0.95 to 1.5, and introducing flood retention ponds, were introduced into the RRI scenarios. In case 2, eight available marshy areas were proposed for use as retention ponds and in case 3, two selected marshy areas were allowed to fill for future development and resettlement while proposing six marshy areas for use as retention ponds. Initially, it was confirmed that there is no need to consider introducing flood embankments along the target area by simulating the RRI model and checking the inundation pattern for the whole Kelani River basin.

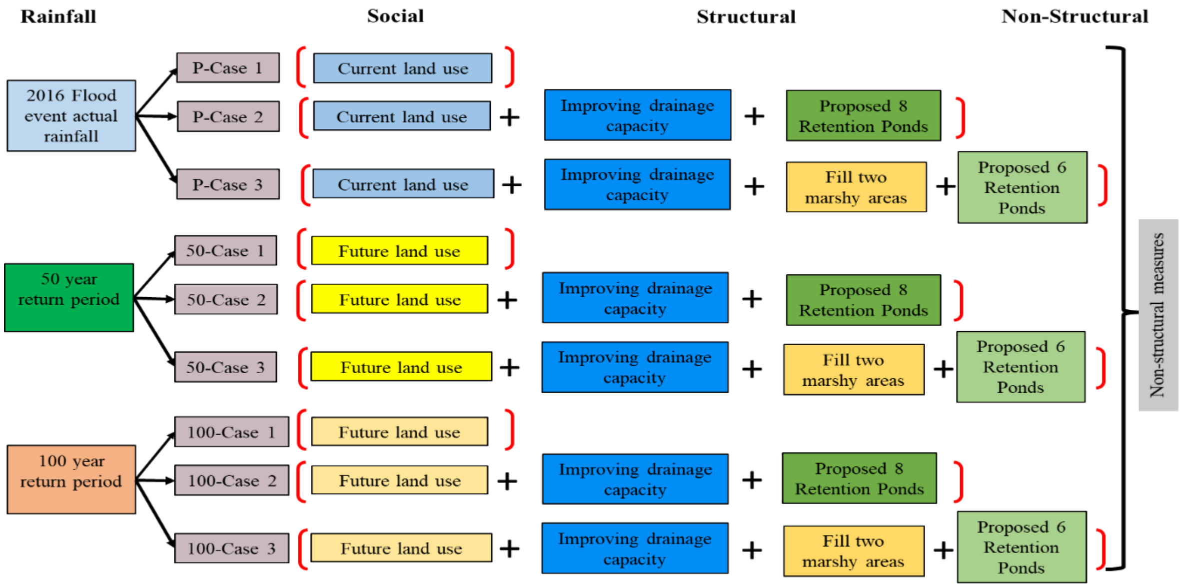

Figure 3: Selected scenarios for analysis

This study focused on three rainfall events: past observed (262 mm/day), future design 50-year (336 mm/day) return period, and future design 100-year (373 mm/day) return period. For each of these events, in order to reduce the inundation area and depth, and improve the standard of living, Mudun Ela basin was analyzed using a set of three possible cases to find an appropriate solution for mitigating flood risks.

Case 1: Only land use change for the rainfall event

Case 2: Land use change for the rainfall event, improved existing drainage capacity and construction of retention ponds in eight available marshy areas (retention ponds R1–R8, see **Figure 4**)

Case 3: Land use change for the rainfall event, improved existing drainage capacity, development of two existing marshy areas by filling (marshy area R7 and R8) and constructing retention ponds in six available marshy areas (Retention pond R1–R6, see **Figure 5**)

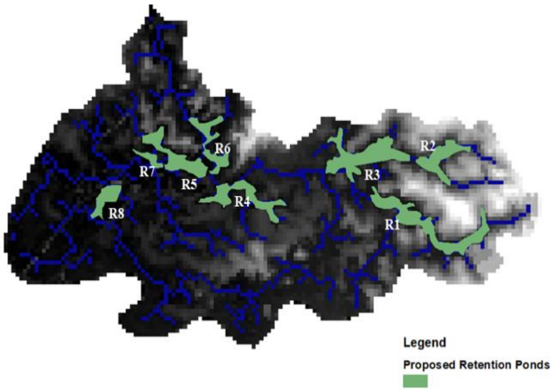

Figure 4: Retention ponds in eight available marshy areas (R1–R8)

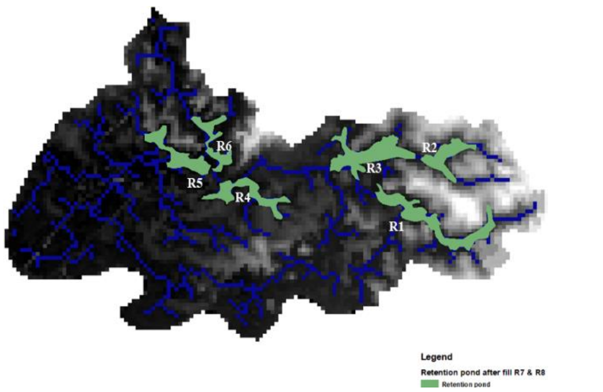

Figure 5: Retention ponds in six available marshy areas (R1–R6) after filled R7 and R8

DATA

This study required hydro-meteorological and topographical data. Local datasets including the observed rainfall time-series data were obtained from the Department of Meteorology, Sri Lanka, and observed discharge time–series data was obtained from the Department of Irrigation, Sri Lanka. Free topographical data was obtained from HydroSHEDS, provided by the U.S. Geological surveys, and were used in the RRI models. Spatial resolutions of 15 arc-second (approx. 450 m) and 2 arc-second (approx. 60 m) were used for the basin and local scales, respectively.

RESULTS AND DISCUSSION

1. Climate Change Analysis

Climate change analysis was conducted in the study area using past rainfall from 1980 to 2005 to select GCMs. The CMIP5 data platform provides access to data achieved by 61 models from 30 different organizations around the world in DIAS. For the study area, only 44 model outputs were obtained for eight meteorological elements. Eight models were selected based on their high score results. Out of these eight models, three models were rejected; one model, CNRM-CM5-2, was rejected because it did not show any data and two models, MPI-ESM-P and CanCM4, because they did not show results for future scenarios. Therefore, five GCMs were accepted for further analysis, ACCESS1.0, ACCESS1.3, CNRM-CM5, MPI-ESM-LR and MPI-ESM-MR. Bias correction using ground-level rainfall was subsequently performed, and past rainfall for 1980–2005 and future rainfall for 2075–2100 were modeled.

Figures 6 and 7 show an increase in extreme daily rainfall from past to future. This indicates that the flood hazards and flood risks will be increased in the future.

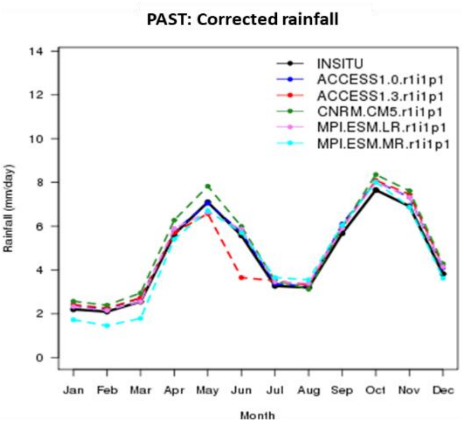

Figure 6: Past climatology

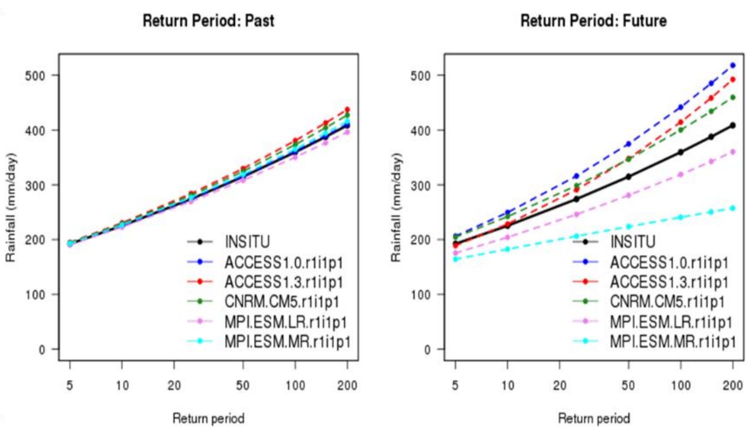

Figure 7: Future climatology

2. Design Rainfall

Climate change is expected to cause high intensity rainfall in the future. Here, Gumbel distribution was chosen because it was a better fit for the data. Design rainfall was calculated by modifying the 2016 extreme flood event using a conversion factor. **Figure 8** illustrates the frequency analysis using the annual maximum series method and **Table 1** shows the rainfall design for different return periods.

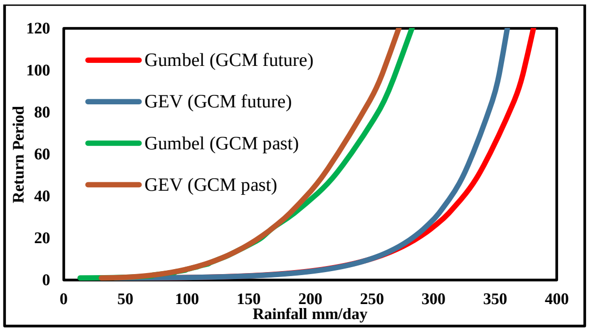

Figure 8: Frequency analysis using Annual Maximum Series method

Table 1: Rainfall design for 10-, 25-, 50-, & 100-year return period

Return Period	GEV	Gumbel	Conversion factor	Design Rainfall (mm/day)
10	248.7	249.0	0.95	249.0
25	293.1	299.1	1.14	299.0
50	324.3	336.4	1.28	336.0
100	353.9	373.3	1.42	373.0

3. Hydrological Modeling

The RRI model was calibrated and validated for the Kelani River basin model using measured discharge at Hanwella station. The calibration of the RRI model using observed discharge data from 2016 resulted in NSE = 0.86, PBIAS = −20.7 and RMSE = 41.0 m^3/s, as shown in **Figure 9**. For the validation, **Figure 10** shows the performance of RRI using discharge data of 2013, in which NSE = 0.91, PBIAS = −18.3 and RMSE = 59.7 m^3/s. As per the NSE values obtained from calibration and validation, the performance of the RRI model was acceptable with adjusted parameters, suggesting that the model represents the actual conditions of the basin.

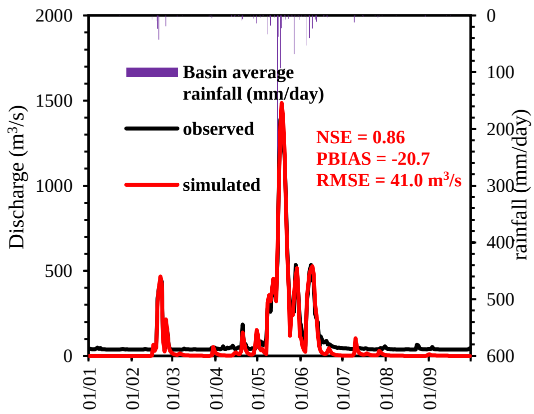

Figure 9: RRI calibration-2016 observed discharge data

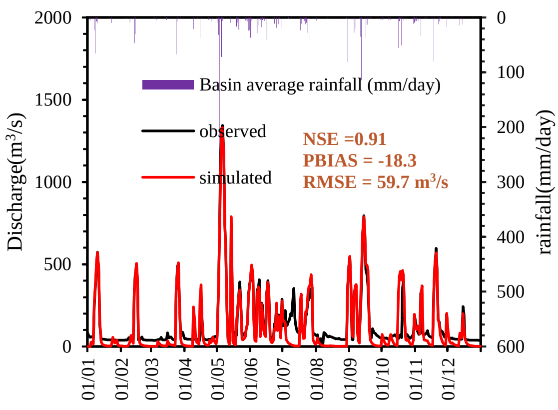

Figure 10: RRI validation-2013 observed discharge data

4. Flood Scenario Analysis

Figure 11 shows the inundation area and depth for whole scenarios for past and future rainfall events. Inundation area and depth significantly decreased when introducing flood retention ponds as a mitigation measure. The scenario of filling marshy areas R7 and R8 (case 3) did not show significant differences in inundation effects compared to constructing eight retention ponds (case 2). Marshy areas R7 and R8 can be filled using dredged materials from other proposed retention pond areas (R1–R6). Thus, people who are living in high inundation areas, including encroaching canals and canal reservations, can be potentially resettled within these filled areas. In addition, developing marshy areas R7 and R8 allows for their use in other infrastructure developments, including flood protection measures within the basin.

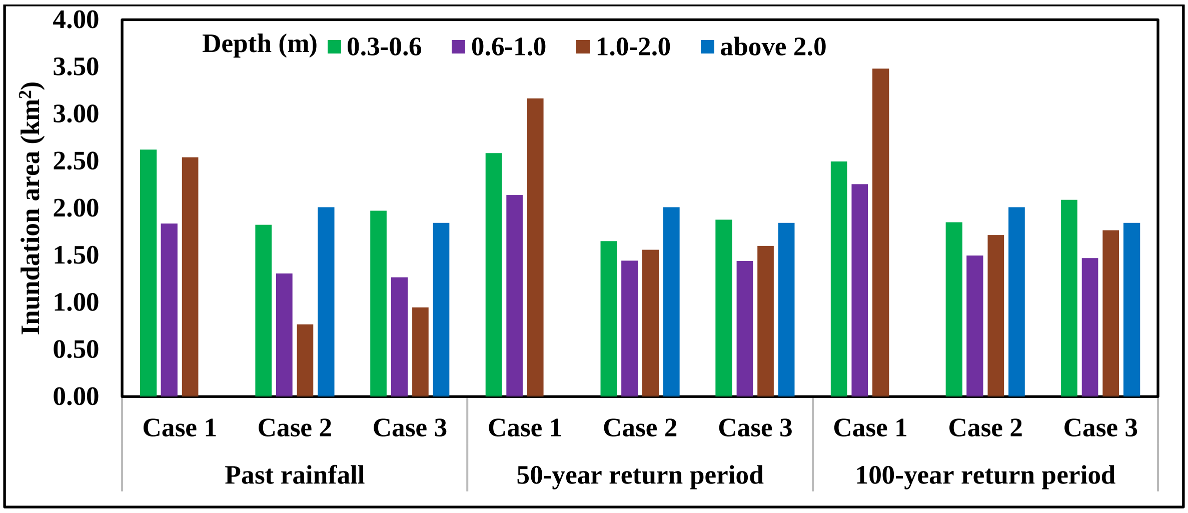

Figure 11 : Inundation area and depth results from all scenarios for past and future conditions with different rainfall and return periods

CONCLUSIONS AND RECOMMENDATIONS

In this study, it was shown that urbanization has adverse impacts on flood risk, since the inundated area and inundated depth increases with increased urbanization. Improving drainage capacity and introducing water retention ponds can help to decrease the inundated area and inundated depth. According to the results, filling the marshy areas R7 and R8 (case 3) does not cause more damage to the basin compared to all retention scenarios (case 2). Retention areas R7 and R8 can thus be developed using dredging materials from other proposed ponds, and these filled lands can be used for population resettlements. Therefore, case 3 is the most comprehensive solution found in this study. Therefore, a flood management plan with structural and non-structural measures can help to create a flood-resilient society and improve the standard of living. It is important for persons of authority and policy makers to keep in mind that various non-structural countermeasures for different areas are strongly recommended to mitigate flood risks.

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