# A STUDY ON AN INTEGRATED WATER RESOURCES MANAGEMENT PLAN UNDER CLIMATE CHANGE FOR GRAND RIVER NORTH WEST RIVER BASIN, MAURITIUS

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## ABSTRACT

Mauritius experiences frequent flood and drought damage due to high variation in rainfall patterns, urbanization, and lack of investment in disaster risk reduction measures. The lack of integrated water resource management (IWRM) plans and threats due to climate change and rapid urbanization make Mauritius more exposed to increased risks in the near future. In this study, the catchment of Grand River North West (GRNW) was selected as a case study to investigate the implementation of an IWRM plan to address the challenges of water security and disaster management for the island. The study contained four main components: (i) climatology analysis for the past (2003–2018) and future climate (2025–2040) to assess the trends in floods and droughts under climate change, (ii) the development of a hydrological model to study the hydrological responses of the basin for extreme flooding events, (iii) a GIS-based flood risk model to develop a risk map and damage evaluation framework, and (iv) a formulation of policies based on the results coupled with the pressure and release (PAR) model. The results showed that an annual decrease in rainfall amount (~ 4%–15%) is projected with very high certainty in the near future, while extreme rainfall events exceeding 50 mm/day have a high likelihood of increasing. Due to the water and energy budget rainfall-runoff inundation (WEB-RRI) hydrological model coupled with a GIS-based risk model, the inundation damage to buildings and farmlands for future extreme events doubled. A vulnerability map for the basin was thus developed based on nine indicators to aid decision making at the village council area (VCA) level and guide financial investments for drought and flood mitigation measures. Finally, recommendations were made based on the PAR model to scale up the IWRM plan for GRNW at a national scale. The study established an end-to-end approach, including scientific, engineering, and socio-economic assessments, to enable evidence-based decision making.

**Keywords**: climate change, drought, flood, General Circulation Models, WEB-RRI.

## 1.0 INTRODUCTION

Mauritius is a small island developing state located in the southwest Indian Ocean with 1.3 million people (Martial & Mohamad, 2020) and has a surface area of 1800 km$^2$. The main economic sectors are tourism, financial services, and information and communication technologies. The island is highly vulnerable to water-related disasters caused by intense cyclones, flash floods, abnormal tidal surges, and prolonged droughts. In recent years, the increasing frequency and intensity of cyclones, torrential rains, and flash floods have threatened people's lives and livelihoods on the island, and this trend is expected to increase under climate change.

The Grand River North West (GRNW) Basin is the second largest catchment in Mauritius, with an area of 114 km$^2$ consisting of mostly young lava series geology. The catchment land use mainly comprises urbanized areas and agricultural land. The basin has undergone significant land use changes in the past decade alone caused by a combination of economic growth and real estate policies by the government, thus altering its physical properties. The basin will likely undergo a number of additional land use

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changes in the next decade with the Moka Smart City development of approximately 19 $km^2$ taking over sugarcane fields. This large-scale development will further accentuate the present water-related disaster issues in the catchment if not integrated into the overall water and land use strategies. Climate change impacts, expected increasing water demand, potential decrease in lead times, and groundwater recharge will undoubtedly put increasing pressure on the freshwater resources of the basin and increase its vulnerability to future extreme events. Therefore, this study selected the GRNW Basin as a case study to investigate the integrated water resource management (IWRM) plan and address challenges to water security and disaster management in this basin and later upscale them to the entire island. This study proposes a novel methodology to implement an IWRM plan in Mauritius through the use of statistical downscaling of GCMs to analyze past and future drought and heavy rainfall trends, and through a coupled water and energy budget rainfall-runoff inundation (WEB-RRI) and GIS-based risk model, to assess the effects of flooding within a basin in Mauritius.

## 2.0 METHODOLOGY & DATA

The research framework adopted in this thesis uses an end-to-end approach, as shown in Figure 1. By linking science and technology, engineering solutions, and socio-economic considerations, decision makers have the possibility of making sound decisions based on cross-sectoral, multidimensional, and evidence-based approaches. Thus, the methodology used can be divided into four main parts:

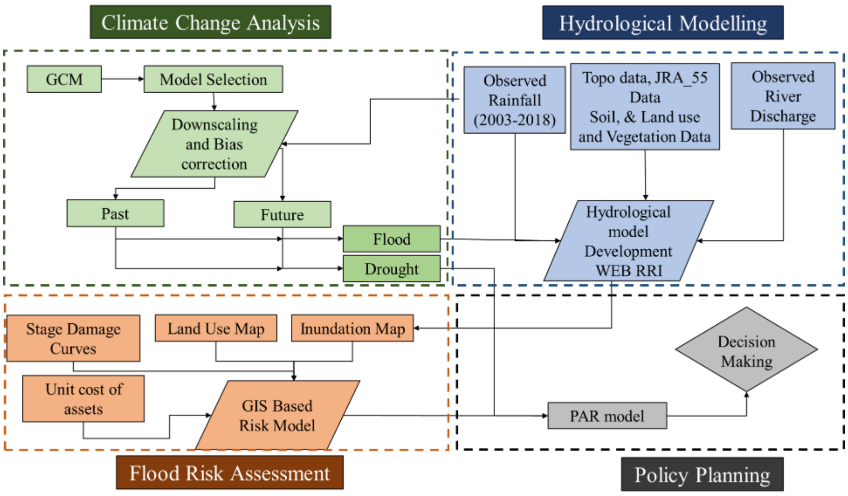

**Figure 1: Research framework**

i. Climate analysis for past (2003–2018) precipitation data was performed to identify the climate signals. The future climate was analyzed using the CMIP-5 climate projection tool in the Data Integration & Analysis System from 2025–2040. The global circulation models (GCMs) were selected based on an evaluation of seven key meteorological parameters and statistically downscaled and bias-corrected for the Mauritius domain. The future climate was projected for the RCP8.5, to determine future precipitation trends on the island.

ii. Hydrological modeling for the GRNW Basin was developed using the WEB-RRI model (Rasmy et al., 2019) to study the hydrological response of the basin to future flood events.

iii. A GIS-based model was established to calculate the vulnerability index at a village council area (VCA) scale to identify areas of priority investment, which was calculated using the following formula: $Vulnerability = Exposure + Susceptibility - Resilience$.
Indicators to evaluate the exposures of each VCA were separated into the following categories: (a) risk to loss of life, measured as inundation exceeding 50 cm intersecting buildings; (b) access to highways and metro lines, measured as inundation height > 50 cm crossing main roads and metro lines; and (c) economic damages calculated from the depth damage curve methodology. The indicators that were chosen to represent susceptibility were: (a) new developments within the catchment that will influence the basin characteristics–percentage of VCA subject to land use change; (b) velocity of flow, measured as a proxy to slope derived from a digital elevation model (DEM); (c) the number of flood prone areas already identified and the number of previous records from the Land Drainage Authority; and (d) the environmentally sensitive areas (area of wetlands and forested lands in each VCA). The indicators that were used for assessing resiliency were: (a) presence of shelters and evacuation centers and number of shelters in the VCA, and

(b) drainage projects and flood control measures (number of dams or levees). A weighted score was assigned to the indicators based on their relative importance, and a vulnerability map was developed.

iv. Policy planning was based on the findings of the climate analysis, WEB-RRI, and GIS risk model outputs, and using the pressure and release (PAR) model framework, the root cause, dynamic pressures, and unsafe conditions were identified.

***Data***

For the purpose of this study, meteorological data and river discharge data were used for climate change impact assessment and robust model development. The respective stations are shown in Figure 2. A DEM with a resolution of 60 m was also used for the model construction as well as MODIS (MCD15A2H), JRA-55 3-hour temporal resolution, and 0.125° spatial resolutions for air temperature, wind speed, specific humidity, and surface pressure, and 0.56° spatial resolution for downward radiations, respectively. These data were interpolated to the model grid resolution of 60 m and a model temporal resolution of 1 h using a linear interpolation method.

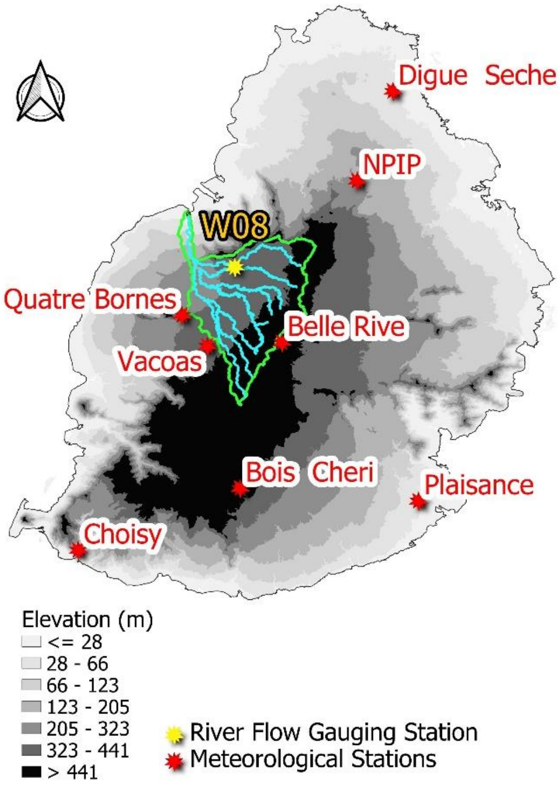


**Figure 2: Location of gauging stations and the GRNW Basin**

## 3.0 RESULTS AND DISCUSSION

### 3.1 Drought Analysis

The historical rainfall records over the last 10 years (2008–2018) for eight stations (Figure 2) were analyzed, and it was identified that the average dry spells were observed to have been increasing for short (0–5 days), medium (5–10 days), and long spells (>10 days), as shown in Figure 3.

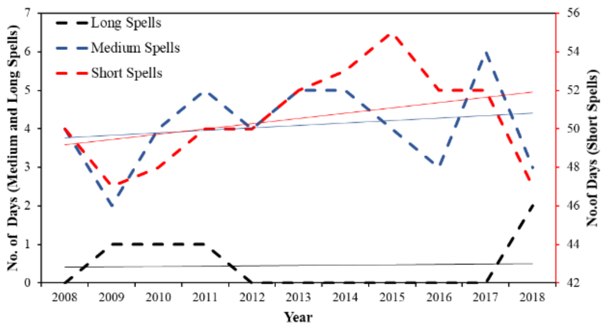


**Figure 3: Average historical dry spell trend**

The trend was seen to be prolonged for future GCM simulations, and the probability of occurrence for long dry spells was observed to increase significantly compared to the observed records, as shown in Figure 4. The same trend was also confirmed in the average annual average change in precipitation, where all four models showed a decrease ranging from 4% to 15%, as illustrated in Figure 5.

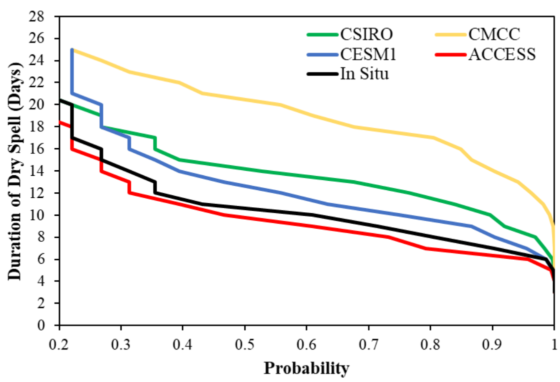


**Figure 4: Probability of dry spell occurrence comparison**

The reduction in rainfall will very likely render the dry winter season even drier and reduce the overall precipitation during the wet summer season, as shown in Figure 6. A regional precipitation decrease predicted by all the

GCMs can be further evidenced from the CMIP 5 tool in the Data Integration and Analysis System (DIAS), whereby an increase in annual sea level pressure (Figure 7(a)) and geopotential heights (Figure 7(b)) in the Mauritius region causes subsidence and cloud formation is suppressed. This mechanism is supported by the outward long-wave radiation increase over the region (Figure 7(c)), causing an overall decrease in rainfall (Figure 8(d)). Figure 8 illustrates the ACCESS 1.3 observations, which were consistent in the three other models. Through the clear and consistent evidence obtained from the climate change analysis, it can be deduced that drought conditions will become more prominent in Mauritius and impose a significant threat to water security.

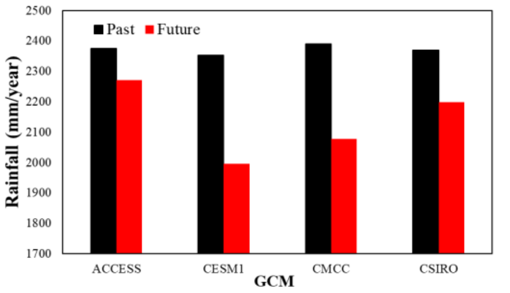


**Figure 5: Change in annual average precipitation**

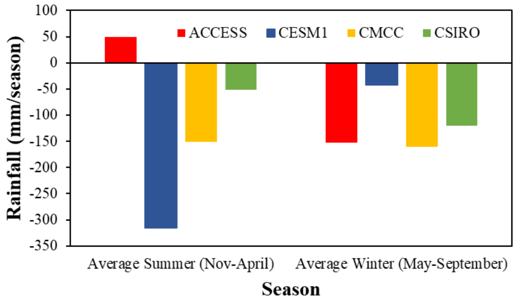


**Figure 6: Change in average seasonal precipitation**

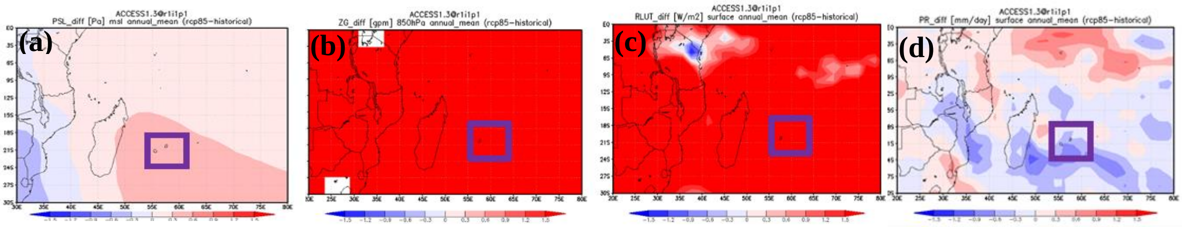


**Figure 7: Climatological difference of ACCESS 1.3 model between past and future; (a) sea level pressure; (b) geopotential height; (c) outward long wave radiation; (d) rainfall**

### 3.2 Heavy Rainfall Analysis

An increasing trend in rainfall greater than 50 mm was identified using innovative trend analysis for the historical data, as shown in Figure 8(a). The same trend was observed when analyzing the future rainfall simulations: all four models showed very high certainty that extreme rainfall (>50 mm) would continue to increase in the future, as depicted in Figure 8(b). Therefore, there is a very high likelihood that climate change will cause an increase in extreme rainfall occurrence and, as a consequence, flood risks will increase.

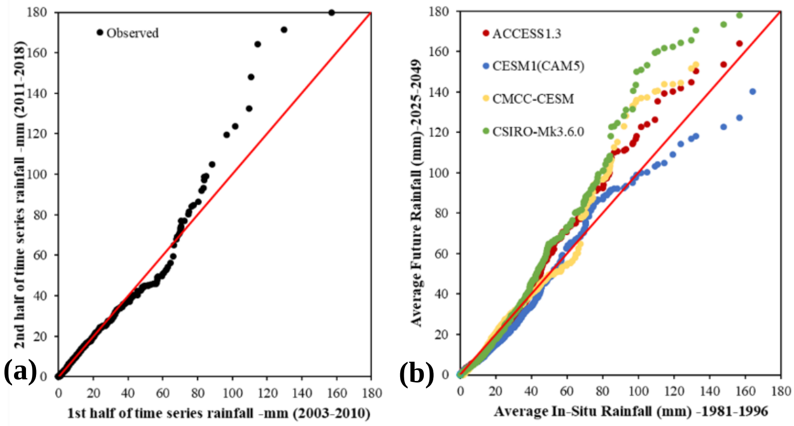


**Figure 8:Innovative trend analysis for (a) observed data and (b) future simulations**

#### 3.2.1 Hydrological model development

An event-based simulation was conducted using the WEB-RRI hydrological model to analyze the impacts of flooding within the basin. The W08 station readings (Figure 2) were used to calibrate and validate the model and the model performance was evaluated using MBE, RMSE, and NSE parameters. The model was reasonably well calibrated with NSE = 0.42, MBE = 0.13 $m^3/s$, and RMSE = 3.40 $m^3/s$ for 2013–2014 shown in Figure 9(a).

The model was then well validated to a satisfactory NSE = 0.41, MBE = -0.08 $m^3/s$, and RMSE = 2.06 $m^3/s$ for 2015–2016 as shown in Figure 9(b). The resulting inundation map from the simulated past and future rainfall was then used to calculate the damage caused by future extreme events. It was determined that the ACCESS 1.3 model caused the simulated maximum inundation area (Figure 9(c)).

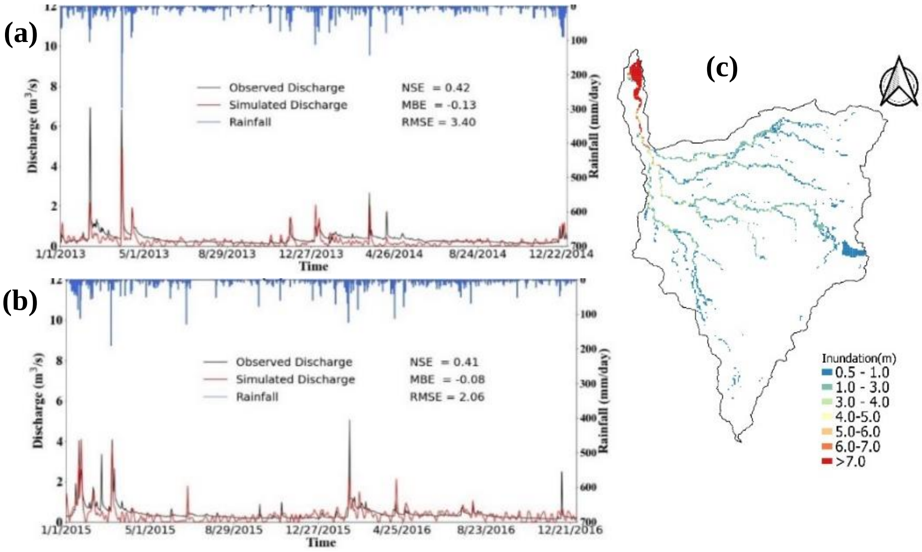


**Figure 9: Simulation of WEB-RRI model (a) calibration; (b) validation; (c) inundation map**

### 3.2.2 GIS-based risk model development

The high level of confidence in an increase in extreme precipitation and high certainty in an increase in urbanization show that the flood risks will likely worsen within the GRNW Basin. Therefore, a GIS-based risk model was employed to identify the areas in the catchment most vulnerable to flooding to guide decision-making.

#### 3.2.2.1 Direct losses calculations

The number of buildings and the area of farmland were compared for the 2013 past flooding event and the maximum simulated inundation of the ACCESS 1.3 model. The damage cost calculated by the stage damage methodology doubled, as illustrated in Figure 10 for both built-up areas and farmland.

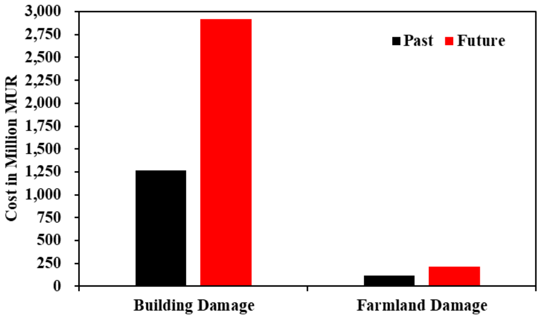


**Figure 10: Damages to buildings and farmlands between past and future maximum inundations**

#### 3.2.2.2 Vulnerability map development

Sub-areas known as VCAs with similar physical characteristics and level of risks based on weighted indicators were then identified, as depicted in Figure 11. Climate change and land-use changes were seen to increase the hazard and exposure of the basin to flooding, while resilience measures were seen to be lacking in all of the VCAs. The upstream regions with agricultural land use were observed to have low flood vulnerability. However, the PL2 VCA located downstream was identified to have a very high flooding risk, while Moka, St Pierre, and VP5 VCAs were determined to be highly vulnerable to flooding events, and seven of the VCAs were considered to have moderate vulnerability. VCAs are affected by three main flooding mechanisms: (i) high-density urban areas and lack of drainage capacity, (ii) fluvial inundation worsened by floodplain encroachment, and (iii) downstream low-lying

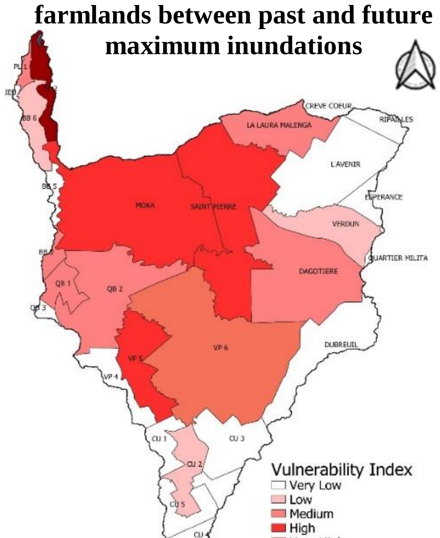


**Figure 11: Vulnerability map**

regions with low drainage gradients. Therefore, depending on the severity of the vulnerability and type of flooding, flood risk actions need to be taken accordingly.

### 3.3 Evidence-based Policy Planning

Through the PAR model, mitigation measures for drought and flood events have been formulated to contribute to a policy plan for the application of an IWRM plan at the national level.

#### 3.3.1 Drought mitigation measures

The existing 14 MCM Bagatelle Dam (located in Moka VCA) is proposed to be enlarged in view of the very likely seasonal and annual rainfall decrease and increased water demand caused by urbanization in the river basin. This measure needs to be investigated further. Upstream river channels have been proposed to divert through agricultural land to feed the dam. Irrigation efficiency is proposed to be improved for the basin, while diversifying from sugar cane monocrop cultivation to less irrigation intensive crops. Small reservoirs have been proposed in the upstream regions of inundated agricultural land for irrigation.

#### 3.3.2 Flood mitigation measures

Areas of high vulnerability require immediate action to reduce risk. Bagatelle Dam, located upstream of high-risk areas, is proposed to act as a flood control device by storing the diverted river flows responsible for downstream inundation. Low-lying downstream areas require a combination of storm surge protection measures and hard structural measures or even relocation of residences. Inhabited high-risk areas along floodplains will require measures such as dikes and embankments. However, it is proposed that the flood peak be attenuated well before it reaches the urbanized regions through the use of retention ponds and nature-based solutions. New developments such as the Moka Smart City will need to be closely monitored in terms of land use plans and looked at in an overall catchment scale to avoid increasing vulnerability.

## 4.0 CONCLUSION AND RECOMMENDATION

It was determined that there is a very high likelihood that rainfall over Mauritius will continue to decrease in the near future because of a projected increase in sea level pressure and an increase in geopotential height causing cloud suppression and decreased rainfall. However, it is highly likely that extreme rainfall events will increase in the near future. The resulting increase in drought conditions and high-intensity flash floods will severely impact water resources and the risk of loss of life and infrastructural damages in the country. Through the WEB-RRI model and a GIS risk-based model, the simulated direct damages incurred were seen to double compared to the worst recent flood event in the basin (March 2013). A vulnerability map proposed at the VCA level making use of the existing administrative structure was proposed to guide policymaking and investment strategies while the PAR model was used to identify the root causes, dynamic pressures, and unsafe conditions caused by drought and flood events to provide an IWRM plan for Mauritius


## 5.0 ACKNOWLEDGEMENTS

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