GLOBAL WATER LEADERSHIP PROGRAMME

Global Water Partnership Eastern Africa
unicef
RWB Rwanda Water Resources Board

Mainstreaming Water Resilience into Karongi District Land Use Plan

March 2024

UK International Development
Partnership | Progress | Prosperity
Global Water Partnership
NLA National Land Authority
WATER PARTNERSHIP RWANDA
Leading Water Think Tank
IWA the international water association
YOUNG WATER PROFESSIONALS RWANDA

1. INTRODUCTION

1.1. Background and rationale

Water is a crucial resource for human health, industry, agriculture, and ecosystem sustainability. However, it is increasingly impacted by climate variability, population growth, and other hazards. One approach to preserving these resources is through catchment management based on hydrological boundaries, which includes managing water flows from rainfall-runoff within a defined area that drains into a common point. Sustainable water management is critical in Rwanda for sectors like agriculture and livestock. The Rwanda water resources strategic plan (2021-2030) emphasizes strengthening the availability of quality water resources for sustainable development. Hydrological analysis and mainstreaming water resilience into district land use plans are essential for understanding water sustainability on a catchment scale.

Rainfall-runoff models are crucial in planning and managing water resources within catchments, especially in land use development and planning. However, the success of these models often depends on the availability of monitored data, particularly rainfall spatial distribution and reliable flow data for calibration and validation. Rwanda, specifically Karongi District, needs help with ungauged or unreliable catchments and sub-catchments. The shift from centralized to decentralized water and land resources management in Rwanda aims to make decisions at the catchment, sector, and district levels, aligning with the country's green growth resilience strategy. The results from hydrological assessments will contribute to mainstreaming water resilience into district land use plans, capacity building, awareness raising in water resilience development, and proposing appropriate mitigation measures.

2. HYDROLOGICAL MODELLING

2.1.HEC-HMS Model Setup

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), developed by the U.S. Army Corps of Engineers, was employed to estimate peak flows in the delineated sub-basins. The modeling process began with the collection of essential spatial data for configuring the hydrological model. The key modeling steps included:

- Development of Design Storms
- Collection of Spatial Data (10m Digital Elevation Model, land use, land cover, soil data, river networks, Karongi District land use plan, flood hotspots, etc.)
- Establishment of a comprehensive hydrological model.

Streamflow records were unavailable for the study area to estimate the recurrence intervals for flows. Therefore, design storms and the HEC-HMS rainfall-runoff response model were used to estimate flows in rivers, streams, and gullies. HEC-HMS is widely used for rainfall-runoff modeling globally.

2.2 Sub-catchments delineation

To conduct a localized hydrological analysis, the 10m resolution Digital Elevation Model (DEM) was utilized to delineate sub-catchments/sub-basins within Karongi District. The district was divided into 92 sub-basins. This division allowed for a more detailed understanding of runoff and drainage patterns in the district, with some sub-catchments located in the Upper Nyabarongo catchment and others in the Kivu catchment.

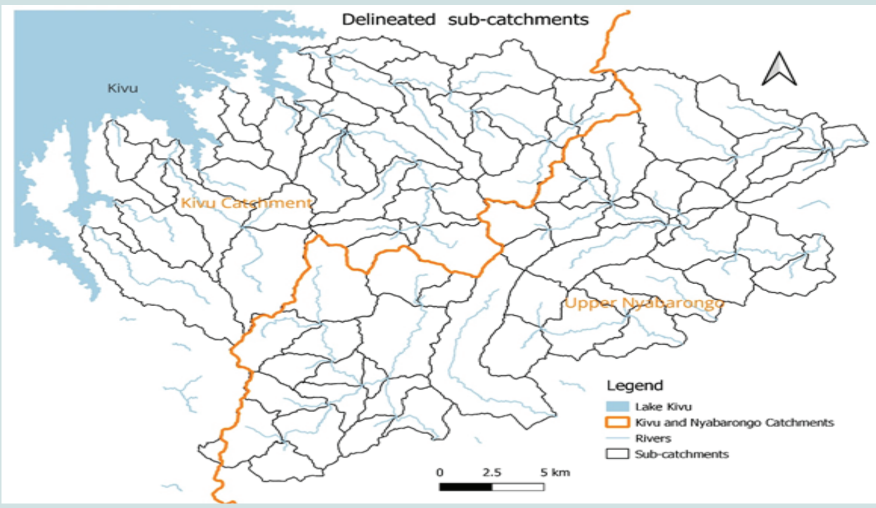

Figure 1: Delineated sub-catchments and its river system.

The Karongi district land use planning and zoning were used to simulate future plans and assign CN values. Table 2 outlines typical land use categories and their associated CN values.

Description	Average % Impervious	Curve Number by Hydrologic Soil Group				Typical Land Uses
		A	B	C	D	
Residential (High Density)	65	77	85	90	92	Multi-family, Apartments
Residential (Med. Density)	30	57	72	81	86	Single-Family
Residential (Low Density)	15	48	66	78	83	Single-Family
Commercial	85	89	92	94	95	Strip Commercial, Shopping Ctrs, Convenience Stores
Industrial	72	81	88	91	93	Light Industrial, Schools, Prisons, Treatment Plants
Agricultural	5	67	77	83	87	Cultivated Land, Row crops, Broadcast Legumes
Open Land	5	39	61	74	80	Parks, Golf Courses, Greenways, Grazed Pasture
Woods (Thick Cover)	5	30	55	70	77	Forest Litter and Brush adequately cover soil
Woods (Thin Cover)	5	43	65	76	82	Light Woods, Woods-Grass combination, Tree Farms
Impervious	95	98	98	98	98	Paved Parking, shopping malls, Major Roadways
Water	100	100	100	100	100	Water Bodies, Lakes, Ponds, Wetlands

Table 1: Land Use Categories and Associated Curve Numbers

2.3 Summary of discussions.

The hydrological analysis for Karongi District is aligned with the National Vision 2050 and the National Land Use Master Plan (NLUDMP), revised and approved by the Cabinet in July 2020, which calls for the revision of district land use plans (DLUP) Clusters across the country. The findings from the modeling exercise have significant implications for water resource management, water resilience building, and disaster risk preparedness in Karongi. Localized data on runoff and peak flow can inform land use planning, infrastructure development, and flood risk reduction and mitigation efforts.

3. IN-DEPTH FLOOD RISK ANALYSIS USING HEC-RAS MODEL FOR KARONGI DISTRICT

Karongi District frequently experiences floods, resulting in considerable losses to households, agriculture, infrastructure, and the environment. This report presents a thorough flood hazard assessment using hydrological and hydraulic modeling with HEC-RAS. Prioritizing critical rivers was determined through field visits and collaboration with Karongi District officials, technicians, the National Land Authority, and the Rwanda Water Resources representatives, considering existing and planned land use.

Figure 2: A team of Water Resources Management experts, visiting Karongi district authorities.

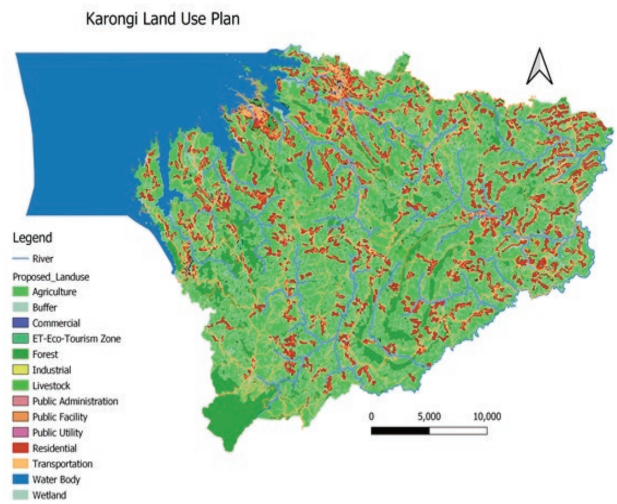

Figure 3: Karongi District Land Use Plan (Source: NLA, 2023)

The study began with hydrological modeling to derive peak flows for all rivers, which were then used in hydraulic modeling with the HEC-RAS model. Critical river prioritization involved field visits and stakeholder consultations with representatives from Karongi District, the Rwanda Water Resources Board, the National Land Authority, and the Global Water Partnership (GWP), assessing existing and planned land use along river systems, focusing on exposure and elements at risk, such as households, public infrastructure, and agricultural areas. The report also highlights a systematic methodology for mapping flood-prone areas using HEC-RAS, integrating hydrologic and hydraulic analysis.

3.1 Data Collection and Processing

a. Topographic Data: - A high-resolution Digital Elevation Model (DEM 10m) for the study area has been collected from the RWB and preprocessed to remove errors and inconsistencies.
b. Hydraulic Data: River geometry data, including cross-sections, bridge, and culvert information, were collected during the field visit and satellite observation.
c. Land Use and Land Cover Data: Land use and land cover data for the study area have been collected from RWB, and the planned land use is from NLA. These data have been integrated into an ArcGIS environment for easy input into HEC-RAS.

3.2 Approach

3.2.1 HEC-RAS Model Setup:

a. Flow Data: - Flow conditions were specified using peak flows (design discharge) from the HEC-HMS model for specific river reach.

b. Boundary Conditions: - Boundary conditions were defined at the upstream and downstream control points.

c. Material Properties: - Appropriate Manning's roughness coefficients were assigned to different land cover types.

3.2.2 HEC-RAS Model Analysis:

a. Unsteady-State Analysis: Considering the specified flow conditions, the analysis was conducted to simulate flood events.
b. Model Calibration: - The model was calibrated using field observed data, including flood marks from the field, to adjust parameters to match actual hydraulic behavior and flood levels.

3.2.3 Floodplain Mapping:

a. Results Interpretation: - HEC-RAS output, including water surface profiles and floodplain maps, was analyzed.

b. Mapping: GIS tools created flood-prone area maps based on the HEC-RAS output. The validation was done by comparing them with field observations and historical flood extents.

3.2.4 Prioritized Rivers for Flood Modeling

Before data collection activities, a stakeholders consultation meeting was held at the Karongi District office to discuss and deliberate on the priority rivers and the existing district land use plan. The participants in the workshop included the consultant, Karongi district representatives, NLA and RWB technicians, and the representative from the GWP. The meeting helped to plan the fieldwork itinerary given the objectives of the assignment.

3.2.5Hydraulic Modeling and Flood Risk Analysis

Hydraulic modeling and flood risk analysis are critical components of flood risk management and disaster preparedness. Hydraulic modeling uses advanced computational models to simulate water flow and inundation patterns, identifying high-risk zones and vulnerable infrastructure. Flood risk analysis combines these results with vulnerability assessments to evaluate potential impacts on communities and assets. This information aids policymakers, planners, and emergency responders in making informed decisions regarding land use, infrastructure development, and mitigation measures, enhancing resilience and reducing the impact of flooding. The HEC-RAS hydraulic modeling focused on rivers impacting households and public facilities, producing flood hazard maps for Nyabahanga, Kibirizi, Gisayo, and Musogoro rivers, providing detailed insights into flood-prone areas.

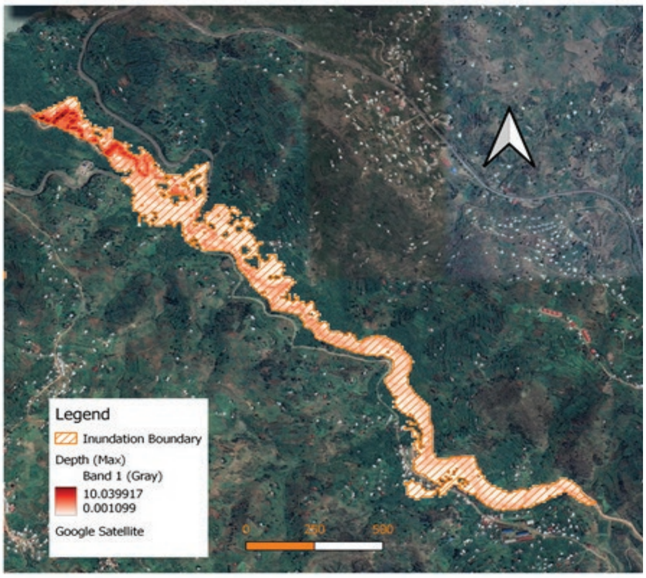

Figure 4: Flood risk map of Nyabahanga Rive

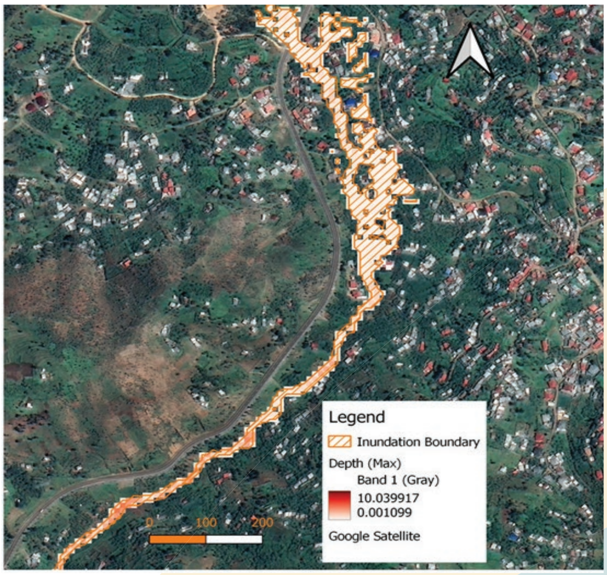

Figure 4: Flood risk map of Nyabahanga River

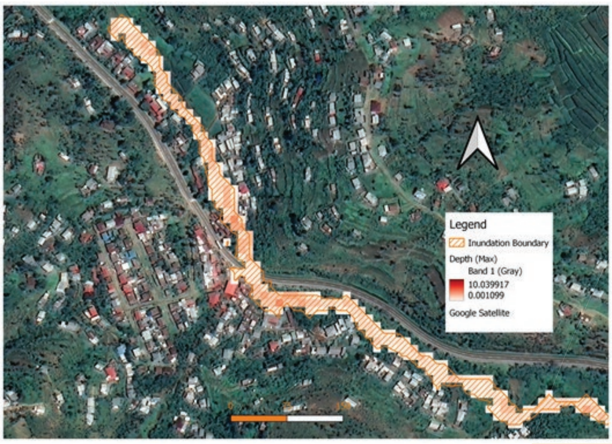

Figure 6: Flood risk map of Gisayo Stream

Figure 7: Flood risk map of Musogoro River

Based on the above flood risk maps, the analysis of inundation area boundaries highlights some existing households and agricultural areas located within the flood risk areas. The shapefiles of flood risk areas generated from the HEC-RAS model and the developed model were submitted to facilitate spatial planning of the district land use plan. The model results present some defects due to an inaccurate digital elevation model (DEM), river morphology change, etc. The model should be updated for a more accurate outcome when an updated and high-resolution DEM is available.

4. FINDINGS AND RECOMMENDATIONS

During this assignment, the following findings have been analyzed, and then formulated some related recommendations:

a. *Identification of Vulnerable Areas for Targeted Mitigation Measures:*

• Conduct a comprehensive flood risk assessment to identify vulnerable areas prone to flooding. This was done considering factors such as topography, hydrology, historical flood data, and climate change projections.
• Utilize advanced modeling techniques, including hydrological and hydraulic modeling, to assess the potential extent and depth of flooding.
• Prioritize vulnerable areas based on the level of risk and potential impact on communities, infrastructure, and the environment.

b. *Integration/Mainstreaming of Flood Hazard Data into Land Use Planning Regulations:*

• Incorporate the findings from the flood risk assessment into land use planning regulations and zoning ordinances.
• Establish setback requirements and land-use restrictions in flood-prone areas to minimize exposure to risk.
• Implement land-use policies that promote sustainable development and discourage construction in high-risk zones.
• Ensure that building codes and standards incorporate measures to enhance resilience against flooding, such as elevated foundations and flood-resistant materials.

c. *Implementation of Sustainable Drainage and Hydraulic Structures:*

• Develop and implement sustainable drainage systems to manage surface water runoff and reduce the risk of flooding.
• Integrate green infrastructure, such as permeable pavements, green roofs, and rain gardens, to enhance natural drainage processes.
• Construct and maintain hydraulic structures, such as levees, dams, and retention basins, to mitigate flood impacts and protect critical infrastructure.
• Regularly inspect and upgrade existing drainage systems to ensure they meet evolving flood resilience standards.

d. *Community Engagement Programs for Flood Risk Awareness:*

• Establish community outreach programs to raise awareness about flood risks and the importance of preparedness.
• Conduct educational campaigns and capacity building to inform residents about flood response procedures.
• Foster partnerships with local schools, community organizations, and businesses to promote a culture of resilience and preparedness.
• Encourage the development of community-based early warning systems, utilizing technology and local knowledge to alert residents about impending floods.

e. *Policy Advocacy/options and Funding Mechanisms:*

• Advocate for policies at the local, regional, and national levels that prioritize and support flood risk mitigation measures.
• Explore funding mechanisms/opportunities, such as grants, subsidies, and insurance incentives, to encourage the implementation of flood-resilient infrastructure and practices.
• Seek partnerships with governmental and non-governmental organizations to access additional resources for comprehensive flood risk management initiatives.

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