Mainstreaming Water Resilience into Rusizi District Land Use Plan

March 2024

1. Introduction

Rusizi District is one the 30 District constituting the Republic of Rwanda. It is located in Western Province of Rwanda. This district is experiencing significant impact of climate change dominated by flooding. , Of recently, May 2023 flooding damaged over 135 fatalities and highlighting the area's vulnerability. Historical floods in December 2019 displaced over 1,183 people and caused extensive damage to infrastructure and agriculture in this district. These incidents underscore the need for sustainable flood resilience strategies in the district.

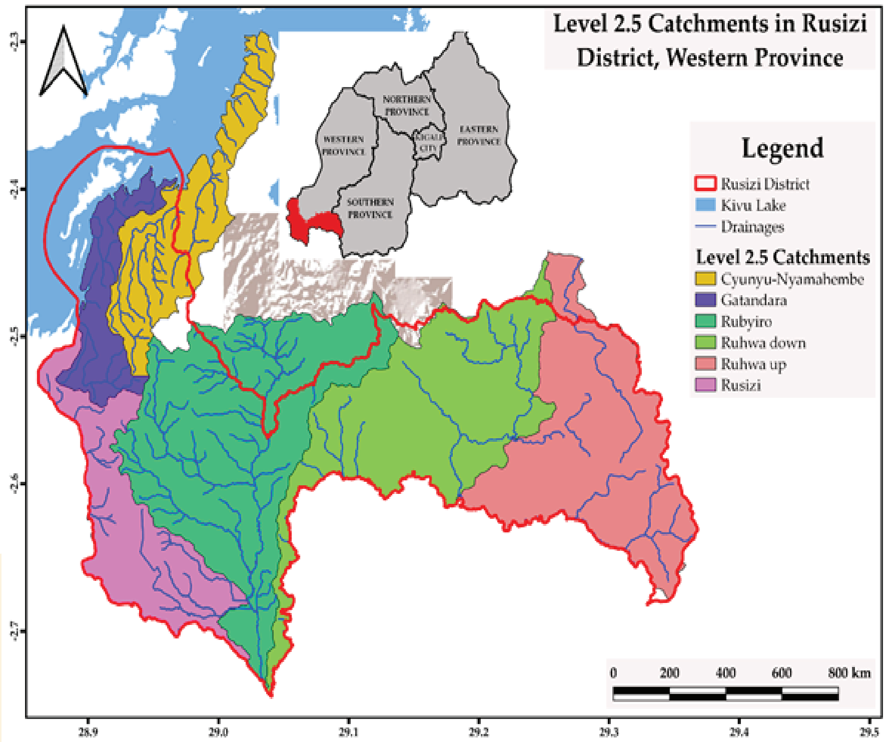


Figure 1: Level 2.5 catchments covering Rusizi district.

Hydrological and hydraulic modelling are essential tools for better planning how to address flood risks in Rusizi district. These models provide insights into water movement, predict water levels and flow velocities, and simulate flood scenarios based on catchment characteristics. Integrating hydrological and hydraulic models is crucial for assessing flood risks and developing effective mitigation measures.

The Global Water Leadership Program has facilitated the development of these models for the Rusizi district using HEC-HMS and HEC-RAS software. This effort supports the integration of water resilience in district land use plans (DLUPs) by identifying high-risk areas, evaluating potential flood impacts, and assessing the effectiveness of different mitigation strategies. The report covers hydrological analysis and flood risk assessment for each district sub-catchment, focusing on the most sensitive areas.

2. Hydrological modelling

(i) Inventory and pre-processing of input data

Inventory and pre-processing of input data are crucial for understanding hydrological components and assessing water resilience risks. Comprehensive data from continuous monitoring, augmented with research findings, are essential for reliable hydrological and hydrodynamic modelling. This section analyses meteorological data, particularly rainfall, from various gauge stations across Rwanda provided by the Rwanda Meteorology Agency (Meteo-Rwanda).

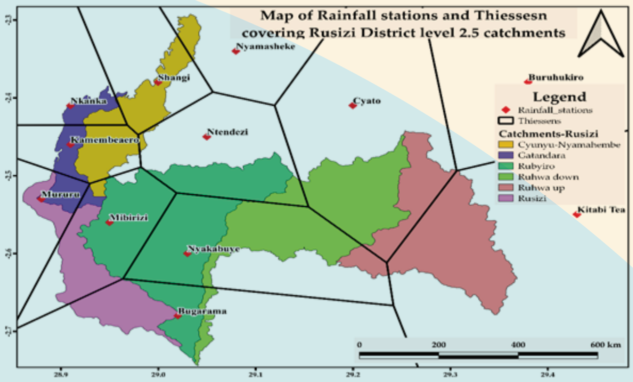


Figure 2: Rainfall stations in or near the sub-catchments with Thiessen polygons

(ii) i. Rainfall

The data, including long-term rainfall for assessing hydrological processes and short-term data for generating peak flows, are systematically processed and analyzed for consistency and homogeneity. In the Rusizi district, the average annual rainfall from 1981 to 2021 was 1600 mm, varying monthly from 22 mm to 194 mm. The Bugarama station recorded the highest monthly rainfall, followed by the Kitabi Tea station. This information is vital for understanding the dynamic behavior of the hydrological system in the area.

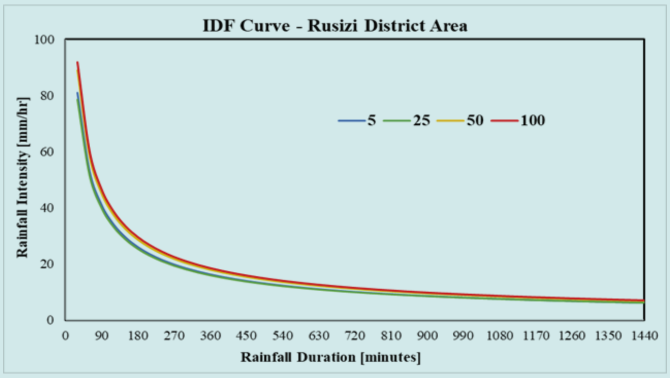
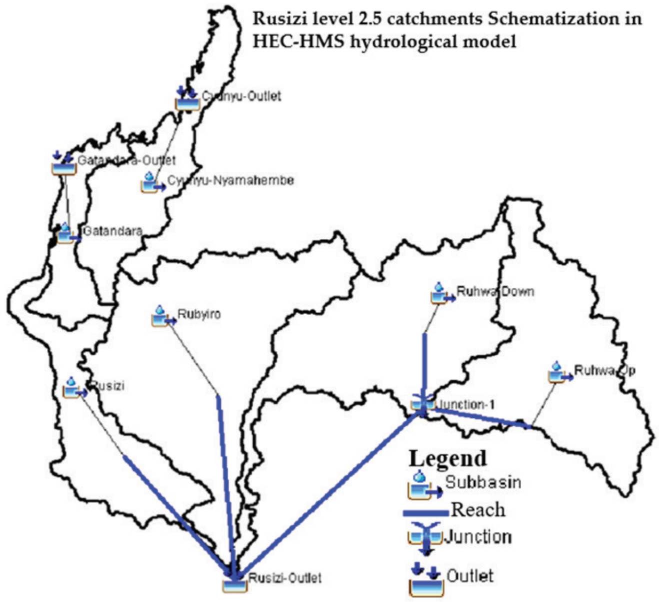


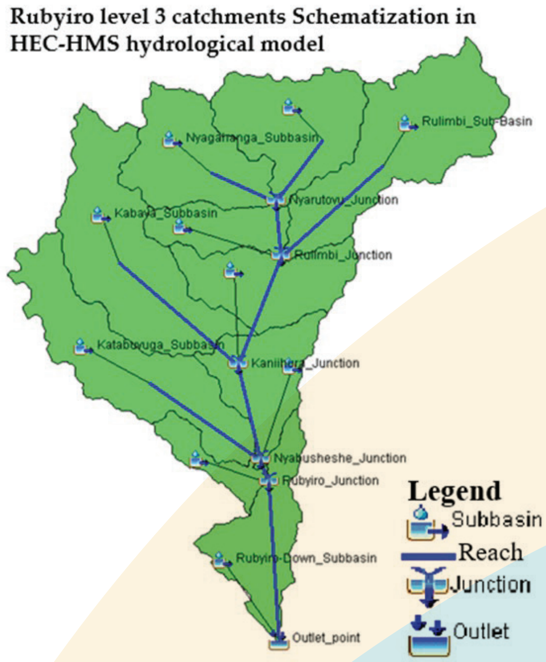
Figure 3: IDF-Curve for the entire Rusizi District area

3. Methodological approaches

3.1 Description of study area

The study area comprises six level 2.5 catchments within the Rusizi district: Ruhwa up, Ruhwa down, Rubyiro, Rusizi, Gatandara, and Cyunyu-Nyamahembe. For the continuous hydrological model, the entire level 2.5 catchment was considered to simulate and understand the district's hydrological processes over time. In contrast, the Rubyiro and Rusizi catchments were downsized to level 3 for the event-based model to increase spatial resolution and model rainfall-runoff processes at a smaller catchment scale. This was done to accurately generate hydrographs in flood-prone areas for return periods of 5, 25, 50, and 100 years. The focus on level 3 sub-catchments within the Rubyiro and Rusizi catchments was due to the majority of identified flood hotspots (9 out of 14) in these two catchments.
Two hydrological models were developed for Rusizi district: continuous and event-based models. The constant model simulates the hydrological cycle's ongoing behaviour over an extended period, allowing for the assessment of long-term hydrological processes and the development of water resilience strategies. This approach is beneficial in small and ungauged catchments with limited monitored data. On the other hand, event-based models focus on simulating specific events, such as flood events, over a shorter time frame. This approach provides insights into the hydrological processes during these events and is valuable for short-term assessments and simulating peak flow conditions.





3.2 Hydraulic modelling

Data collection and Stakeholders Consultation

A field visit was conducted to collect data for flood modeling in Rusizi District using HEC-RAS, preceded by a literature review to identify stakeholders and map floodplain areas. During the visit, data were gathered through stakeholder consultation, site observation, and the SW maps app—a free GIS mobile tool for collecting and sharing geographic information. Photographs documented flooding characteristics, affected rivers, and associated risks.

Stakeholders such as district officials, sector leaders, and the Rusizi community were engaged to understand water resilience risks based on local experiences and knowledge. Interactions provided valuable insights into flood frequency, extent, and depth.

At a stakeholder consultation meeting, district officials recommended visiting key sites, including Muganza, Bugarama, Bweyeye, and others, to map critical areas for the project.

The panel emphasized the importance of considering community perspectives on water management and focusing on agricultural sites in flood-prone areas.

Figure iii 1: Stakeholders consultation meeting

In total ten hotspots were identified during this field visit and their locations are illustrated in Figure 3 7. Table 3 1 shows their location from sector to village level according to the administrative boundaries.

Mainstreaming of Water Resilience into Rusizi District Land Use Plans

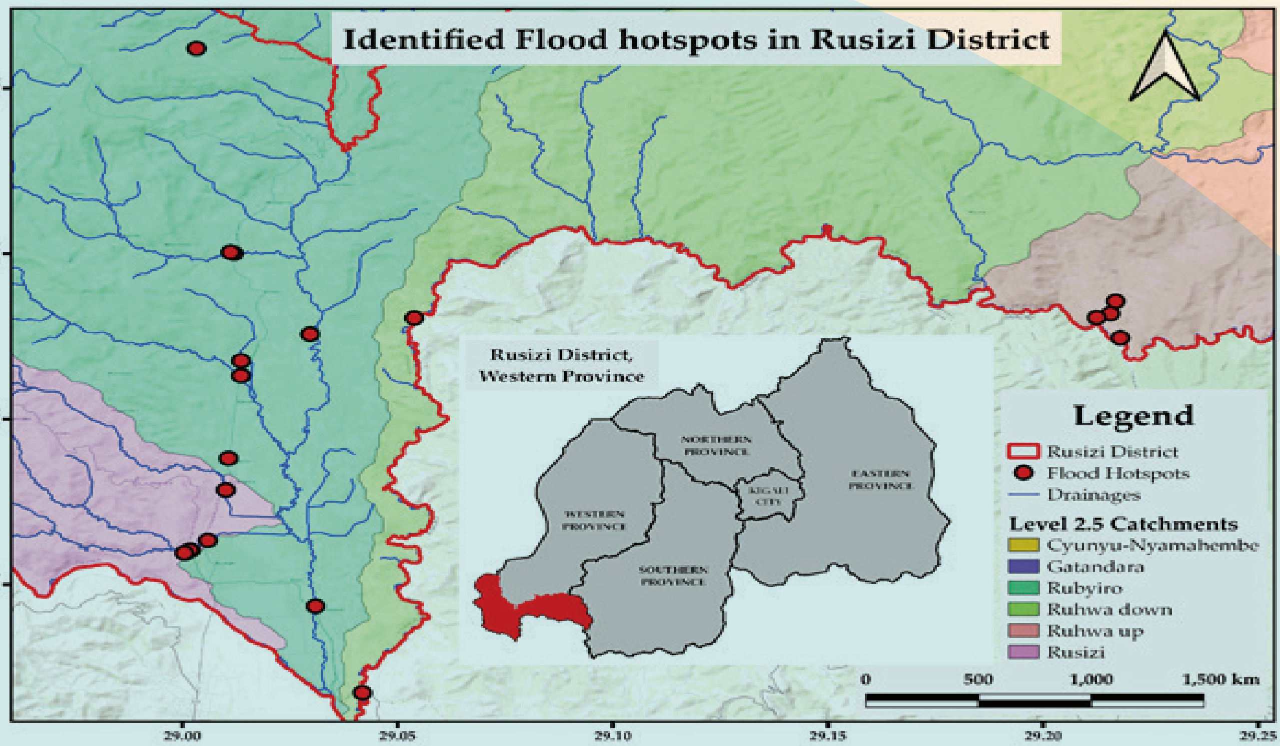


Figure iii 2: Map of identified flood hotspots in Rusizi District

3.3 Hydraulic model results

The flood model outputs were acquired from the 2D HEC-RAS model simulations for events of 25, 50 and 100 years return periods. The streamflow generated from HEC-HMS were used as inflow boundary conditions in the flood hydraulic model. Based on the hydrological model domain and river network, the inflow into the modelled channels from upstream areas was used as a boundary condition. Flood inundation maps were produced with the pre-processed DEM, that was refined to enhance the hydrodynamic model results. The flood maps were produced for 25, 50 and 100-years return periods for all the identified flood hotspots.

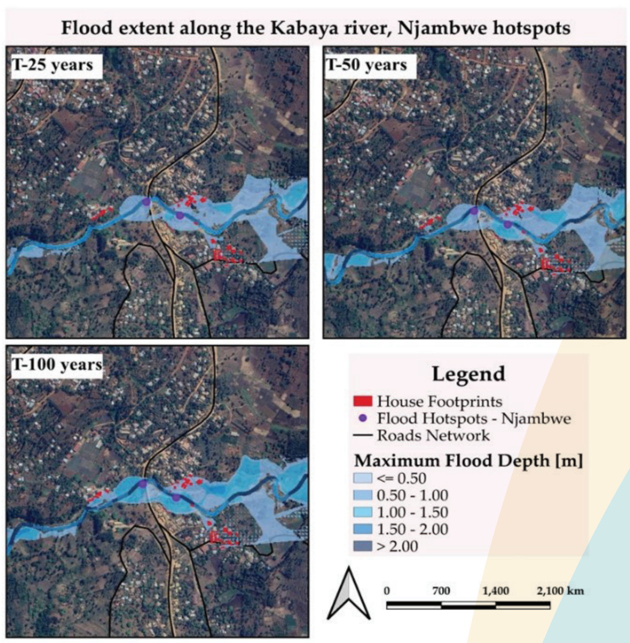
Additionally, house footprints were added on the map to illustrate the number of houses exposed to flooding in each flood prone region.

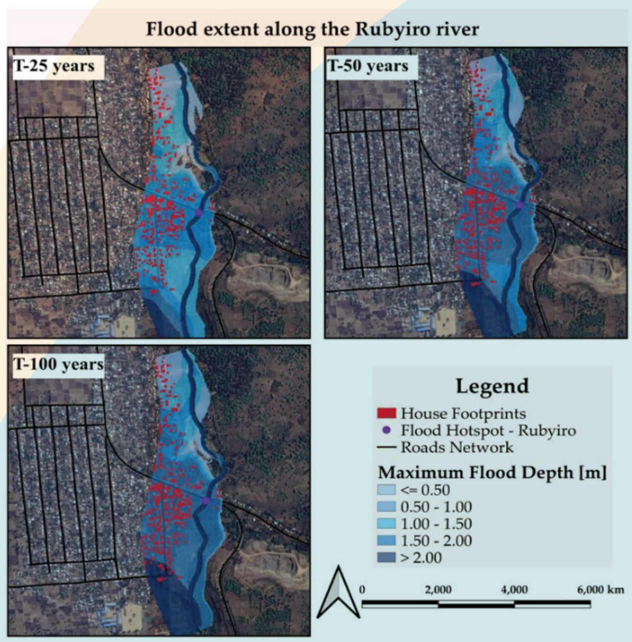
The presented figures of the flood extent in different hotspots indicate house footprints in each hotspot. The house footprints were accessed using Google Earth Engine from Open Buildings. Table 3 2 shows the number of exposed houses in each identified flood hotspot as indicated in red colour in the maps

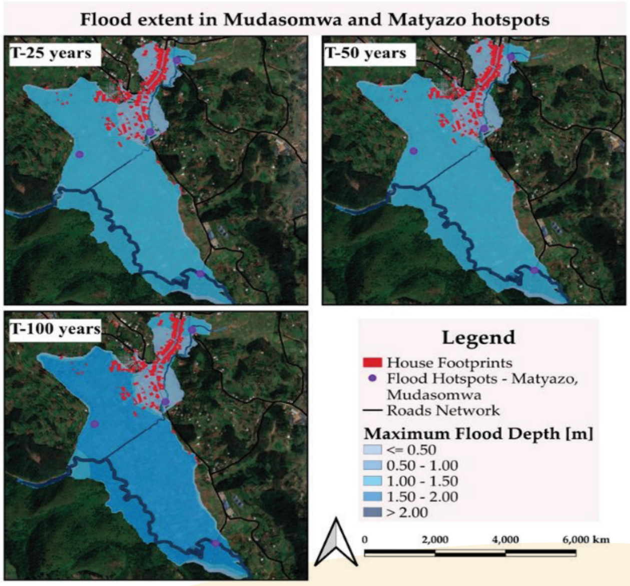
In total ten hotspots were identified during this field visit and their locations are illustrated in Figure 3 1.

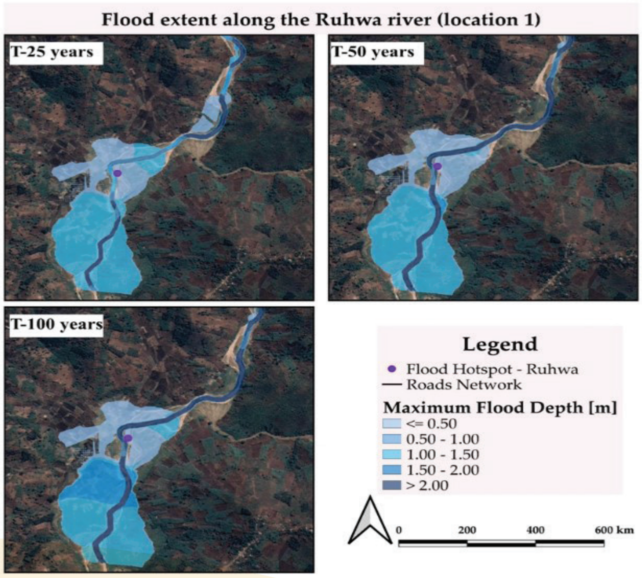
#	Flood Hotspot	Houses Exposed
1	Cyarugara	599
2	Cyarukara	384
3	Njambwe	93
4	Matyazo-Mudasomwa	491
5	Rubyiro-Bridge	0
6	Nyagashenyi	66
7	Katabuvura	2156
8	Rubyiro	366
9	Ruhwa river (location 1)	0
10	Ruhwa river (location 2)	0
11	Rungunga	542

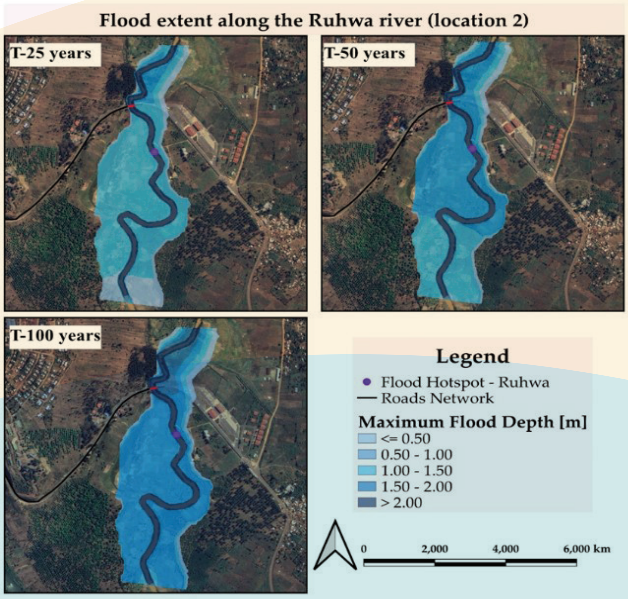
ii. Illustration of flooding extent

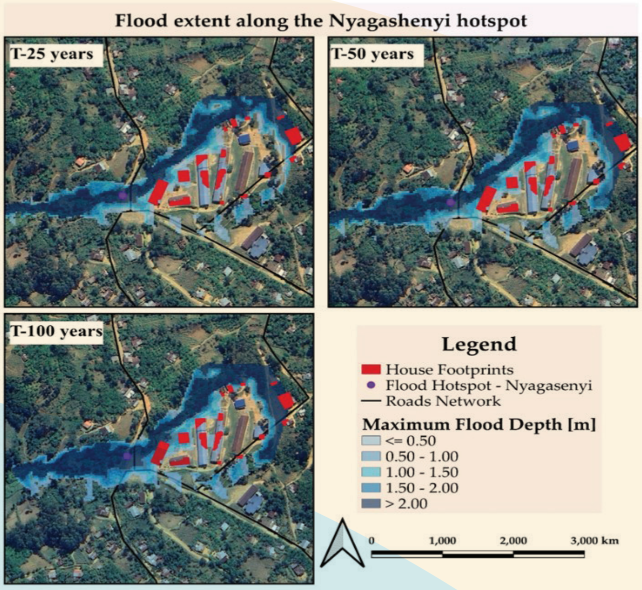


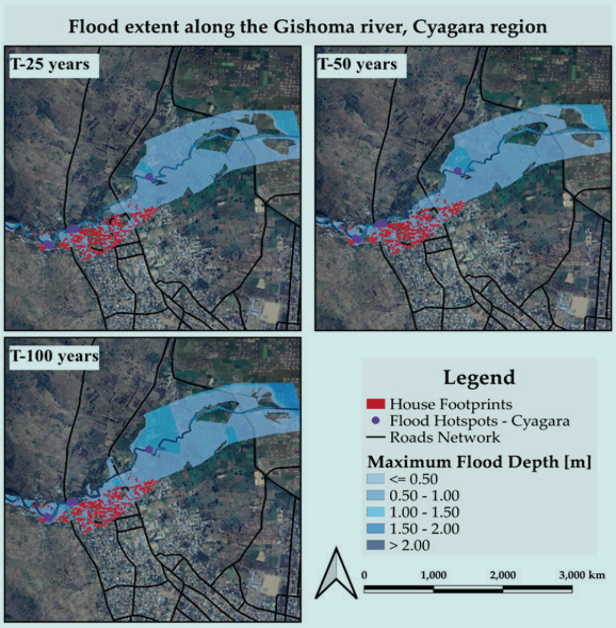


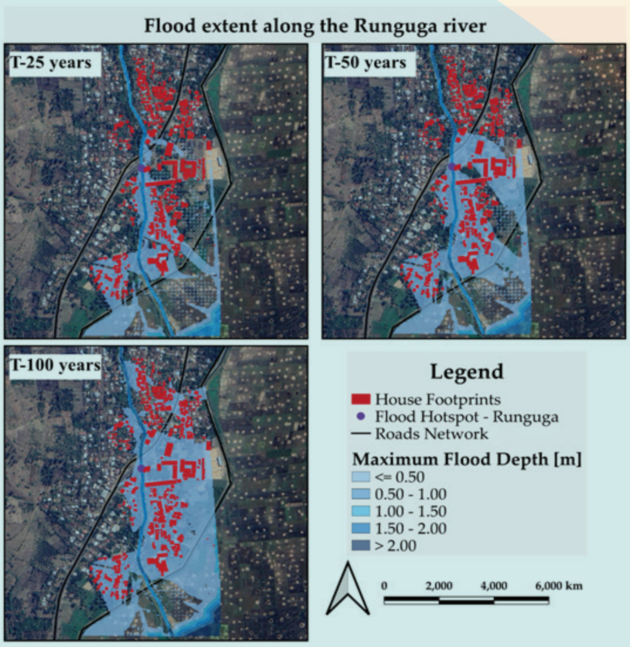

Flood extent in Mudasomwa and Matyazo hotspots
T-25 years
T-50 years
T-100 years
Legend
House Footprints
Flood Hotspots - Matyazo, Mudasomwa
Roads Network
Maximum Flood Depth [m]
<= 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
0
2,000
4,000
6,000 km


Flood extent along the Ruhwa river (location 1)
T-25 years
T-50 years
T-100 years
Legend
Flood Hotspot - Ruhwa
Roads Network
Maximum Flood Depth [m]
<= 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
0
200
400
600 km


Flood extent along the Ruhwa river (location 2)
T-25 years
T-50 years
T-100 years
Legend
Flood Hotspot - Ruhwa
Roads Network
Maximum Flood Depth [m]
<= 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
0
2,000
4,000
6,000 km


Flood extent along the Nyagashenyi hotspot
T-25 years
T-50 years
T-100 years
Legend
House Footprints
Flood Hotspot - Nyagasenyi
Roads Network
Maximum Flood Depth [m]
<= 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
0
1,000
2,000
3,000 km


Flood extent along the Gishoma river, Cyagara region
T-25 years
T-50 years
T-100 years
Legend
House Footprints
Flood Hotspots - Cyagara
Roads Network
Maximum Flood Depth [m]
<= 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
0
1,000
2,000
3,000 km


Flood extent along the Runguga river
T-25 years
T-50 years
T-100 years
Legend
House Footprints
Flood Hotspot - Runguga
Roads Network
Maximum Flood Depth [m]
<= 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
0
2,000
4,000
6,000 km

4. Proposed measures to enhance water resilience in Ruzizi District

4.1 Proposed nature-based solutions / Measures

Proposed nature-based solutions (NBS) are crucial in enhancing flood resilience and ecosystem functions by prioritizing locations based on their potential effectiveness and ecosystem services. In the predominantly rural district with agriculture as the primary economic driver, suitable NBS solutions include sustainable agricultural practices, ecosystem health improvement, and biodiversity conservation. These interventions mitigate flood risks and enhance agricultural productivity, soil health, and natural resource conservation. Aligning NBS with land use planning and zoning promotes a synergistic approach to environmental resilience and agricultural sustainability. This strategic alignment ensures that NBS implementations are tailored to the area's specific needs, maximizing their effectiveness and long-term benefits for the environment and local communities.

4.2 Conservation agriculture

Conservation agriculture (CA) is a sustainable farming approach that aims to optimize crop yields while preserving and enhancing the health of the soil, minimizing environmental impacts, and promoting long-term agricultural sustainability. Fundamental principles of conservation agriculture include minimal soil disturbance (such as reduced or no-tillage), permanent soil cover (using crop residues or cover crops), and diversified crop rotations.

Conservation Agriculture plays a pivotal role in mitigating floods, namely by:

1. ***Promoting soil Health and structure:*** CA practices, such as minimal tillage and soil cover, help maintain soil structure and reduce soil erosion. Healthy soils with improved structure are better equipped to absorb and infiltrate water, reducing surface runoff and mitigating soil erosion during heavy rainfall.
2. ***Increasing water infiltration and retention:*** Conservation agriculture enhances water infiltration and retention in the soil by preserving soil structure and organic matter content. This helps prevent surface runoff and reduces the risk of flash flooding by allowing water to penetrate into the soil profile, replenishing groundwater reserves, and maintaining stable hydrological processes.
3. ***Reducing surface runoff:*** Using crop residues or cover crops as soil cover helps shield the soil surface from direct rainfall impact, minimizing surface runoff and soil erosion. This is particularly important in sloping or vulnerable areas where runoff can lead to soil loss, sedimentation of waterways, and increased flood risk downstream.
4. ***Improving drainage:*** CA practices promote the development of natural soil structures, such as macropores and aggregates, which enhance soil porosity and drainage capacity. This reduces waterlogging and surface ponding in fields, mitigating the risk of waterlogging-induced crop damage and localized flooding.
5. ***Enhancing floodplain management:*** CA supports restoring and preserving natural floodplain ecosystems, such as wetlands and riparian zones, which act as valuable buffers against flooding. By minimizing soil disturbance and preserving natural vegetation, CA contributes to maintaining the functional integrity of floodplains, enhancing their capacity to attenuate floodwaters and reduce flood risk for downstream areas.
6. ***Boosting climate resilience:*** CA practices contribute to building climate resilience by improving soil health, enhancing water efficiency, and reducing vulnerability to extreme weather events, including floods. By adopting CA techniques, farmers can adapt to changing climatic conditions and mitigate the adverse impacts of flooding on agricultural productivity and livelihoods.

4.3 Afforestation and Reforestation

Afforestation and reforestation are critical practices for increasing forest cover and restoring ecosystems, with afforestation establishing forests on previously non-forested land and reforestation restoring forests on deforested or degraded land. These practices are critical for flood mitigation as forests regulate the hydrological cycle by intercepting rainfall, reducing surface runoff, and enhancing soil infiltration. Trees slow down water movement, allowing percolation into the ground, and their roots stabilize soil, preventing erosion and promoting infiltration. Forests act as natural reservoirs, absorbing excess water during heavy rainfall and releasing it gradually during dry periods, reducing peak flow and flood risk. They also provide ecosystem services that support biodiversity, habitat preservation, water regulation, and floodplain management, contributing to overall flood resilience.

4.4 Establishing Buffer Zones

Buffer zones, or riparian areas, are strips of vegetation along water bodies like rivers, lakes, and wetlands, serving as protective barriers and offering ecological, hydrological, and social benefits. They are crucial for flood mitigation as they absorb and slow down floodwaters, reducing velocity, erosion, sedimentation, and damage to infrastructure and land. Additionally, buffer zones act as natural filters, trapping pollutants from runoff, improving water quality, and protecting aquatic ecosystems. They also stabilize streambanks, prevent erosion, and maintain river channel integrity. Beyond flood mitigation, buffer zones provide habitat for wildlife, supporting biodiversity and ecological resilience by serving as refuges for native species and maintaining ecological connectivity along water corridors.

4.5 Rainwater Harvesting

Rainwater harvesting collects and stores rainwater for irrigation, domestic supply, and groundwater recharge, using systems ranging from simple rooftop collectors to complex rain gardens and permeable pavements. This technique reduces surface runoff and relieves pressure on stormwater systems during heavy rainfall, mitigating flooding and soil erosion. It also aids in groundwater recharge, maintaining levels during dry periods, and sustaining river baseflows. Additionally, rainwater harvesting promotes water conservation and climate resilience by diversifying water sources, reducing reliance on centralized systems, and lowering energy consumption for water treatment. Community-based initiatives further empower individuals and communities to manage their water resources sustainably, enhancing flood resilience and adaptation to climate change.

Flood extent along different hotspots before and after proposed NBS in the Rusizi district for 50-years return period

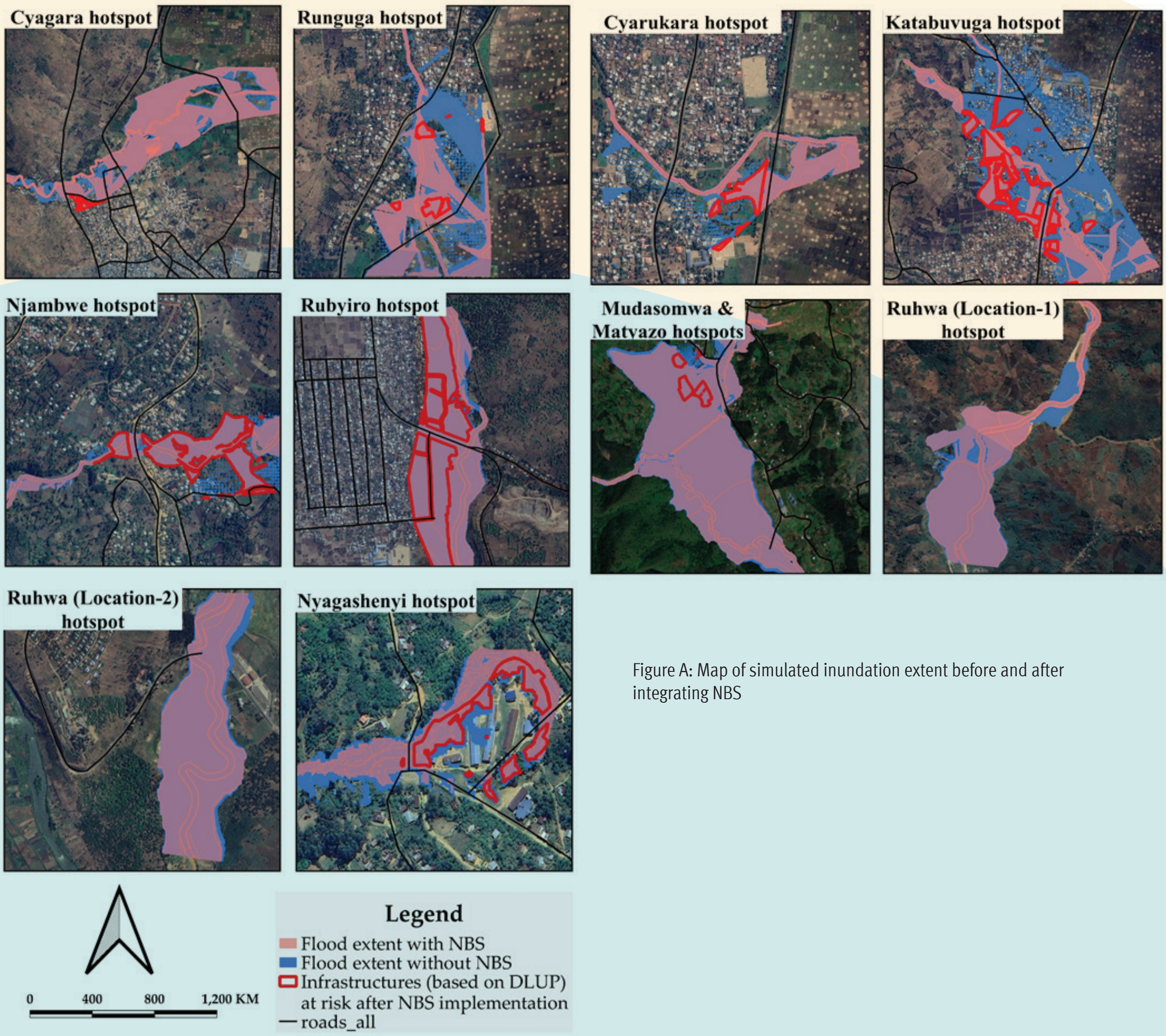


Figure A: Map of simulated inundation extent before and after integrating NBS

Figure A shows changes in flood extents in Rusizi district's hotspots after modeling nature-based solutions (NBS) in HEC-RAS. Minimal changes were seen along the Ruhwa River (Ruhwa location-1, location-2, and Mudasomwa & Matyazo), likely due to the extensive coverage of Nyungwe forest in the catchment areas, leaving less room for additional NBS. In contrast, significant changes were observed in hotspots like Runguga, Nyagashenyi, Cyarukara, and Katabuvuga, highlighting the effectiveness of NBS in upstream areas. The District Land Use Plan (DLUP) helped identify land use patterns in flood-prone regions and infrastructures needing relocation. Despite NBS implementation, areas like Njambwe, Rubyiro, Katabuvuga, and Nyagashenyi still showed high infrastructure exposure to floods, suggesting further DLUP assessments for relocation for rapidly degrading riverbanks, such as the Nyagashenyi river, riverbank protection strategies like riprap or gabion structures are recommended to prevent erosion and protect nearby lands and infrastructure.

5. Conclusion

Integrating nature-based solutions (NBS) within the land use plan of the Rusizi district has shown effectiveness in reducing flood risks. By targeting vulnerable areas, such as agricultural zones with steep slopes and regions with sparse forest cover, and implementing tailored NBS interventions, there have been significant reductions in peak discharge values and changes in flood extents. The use of HEC-HMS and 2D HEC-RAS models has provided valuable insights into the impacts of NBS on hydrological processes and flood extents, emphasizing the importance of combining hydrological and hydraulic modelling with land use planning for effective flood mitigation strategies.

6. Recommendations

Enhanced data collection:

The 10-meter spatial resolution DEM data was used to assess the impacts of nature-based solutions (NBS) on flood risk mitigation in the Rusizi district, upstream of hotspots and within floodplains. However, limitations in the DEM data impacted the accuracy of inundation depth and extent, particularly in the lowland area of Bugarama and identified hotspots. These discrepancies affected the precision of modelling outcomes, highlighting the need for accurate and high-resolution data for effective flood modelling and risk assessment. Future studies and flood management initiatives in the Rusizi district should prioritize obtaining more detailed topographical data to improve the reliability and effectiveness of flood modelling efforts.

Integrated Land Use Planning:

Collaborative efforts between land use planners, environmental experts, and local communities should be strengthened to integrate NBS seamlessly into district-wide land use planning. This includes identifying suitable relocation areas for infrastructures at risk and implementing additional flood mitigation measures, such as riverbank protection initiatives, in rapidly degrading areas.

Community Engagement and Capacity Building

Engaging local communities in flood risk awareness programs, promoting sustainable land management practices, and building local capacity for NBS maintenance and monitoring will enhance the long-term resilience of the district against flood hazards.

Address

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