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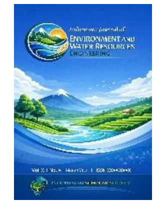

Integrated GIS and HEC-RAS modeling for flood and sediment mitigation in tropical watersheds

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A R T I C L E I N F O

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A B S T R A C T

Flooding and sediment-related disasters frequently occur in tropical watersheds due to rapid land-use change, increasing rainfall intensity, and declining river channel capacity. These environmental problems are becoming more severe in developing regions where watershed management and sediment-control infrastructure remain limited. This study aims to evaluate flood characteristics, sediment transport dynamics, and mitigation strategies using an integrated Geographic Information System (GIS) and Hydrologic Engineering Center–River Analysis System (HEC-RAS) modeling approach in a tropical watershed environment. Hydrological analysis was conducted using rainfall data, watershed morphometric characteristics, river geometry, and hydraulic parameters to estimate peak discharge and flood propagation under unsteady flow conditions. GIS-based spatial analysis was further applied to identify erosion-prone areas, sediment source zones, and hydraulic bottlenecks contributing to flood vulnerability within the watershed system. The study integrates hydraulic simulation, sediment transport analysis, watershed morphometry, and spatial assessment into a comprehensive flood and sediment mitigation framework. The integrated approach represents an important contribution because previous studies generally focused only on flood modeling or erosion assessment separately, without combining hydraulic analysis, sediment dynamics, and spatial conservation planning within a unified framework. The simulation results indicate that several river reaches are hydraulically incapable of safely conveying peak discharge during extreme rainfall events, resulting in significant overflow potential and flood inundation risk. Areas characterized by steep slopes, degraded land cover, and high surface runoff contribute substantially to sediment production and downstream sedimentation. The proposed mitigation measures significantly improve channel conveyance capacity, reduce flood risk, and enhance sediment retention effectiveness within critical river sections. The findings demonstrate that the integration of GIS and HEC-RAS provides an effective framework for sustainable flood and sediment management in tropical watersheds and can be adapted for other river basins experiencing similar environmental challenges.

1. Introduction

Flooding and sediment-related disasters have become major environmental and socio-economic problems in many tropical watersheds worldwide, particularly in developing countries experiencing rapid land-use change and watershed degradation. Increasing rainfall intensity, deforestation, urban expansion, agricultural activities, and declining river channel capacity have significantly intensified flood hazards and sedimentation processes in river systems. These conditions reduce watershed hydrological stability, increase surface runoff, accelerate soil erosion, and promote excessive sediment transport into downstream river channels. As a result, many tropical watersheds frequently experience flood inundation, channel aggradation, and infrastructure damage during extreme rainfall events [1, 2].

Watershed degradation caused by uncontrolled land-use conversion is widely recognized as one of the dominant factors influencing hydrological response and sediment production in tropical environments. The reduction of vegetation cover decreases infiltration capacity and increases runoff velocity, thereby enhancing soil erosion and sediment transport processes. Previous studies have demonstrated that steep slopes combined with poor land management practices significantly increase watershed vulnerability to flooding and sediment accumulation. The excessive sedimentation within river channels reduces flow conveyance capacity, causing river overflow and increasing flood frequency during high-intensity rainfall events [3–5].

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The integration of hydrological and hydraulic modeling has become increasingly important for understanding flood dynamics and sediment transport within watershed systems. Hydraulic simulation models, particularly the Hydrologic Engineering Center–River Analysis System (HEC-RAS), are widely applied for flood analysis, river hydraulics, sediment transport simulation, and flood mitigation planning. HEC-RAS provides reliable capabilities for simulating steady and unsteady flow conditions, evaluating channel capacity, and identifying flood-prone river sections. Meanwhile, Geographic Information Systems (GIS) have become essential tools for spatial analysis, watershed characterization, flood hazard mapping, and environmental management planning due to their ability to integrate topographic, hydrological, land-use, and hydraulic datasets within a single analytical framework [6, 7].

Several previous studies have applied HEC-RAS and GIS approaches for flood hazard assessment and watershed management. Studies conducted in tropical and subtropical watersheds have shown that integrated hydraulic and spatial modeling can effectively identify flood-prone areas and support mitigation planning. Other studies have focused on soil erosion and sediment yield estimation using methods such as USLE, RUSLE, and MUSLE integrated with GIS spatial analysis. These studies demonstrated that steep slopes, degraded vegetation cover, and high rainfall intensity are the primary controlling factors of sediment production and watershed degradation. Furthermore, structural mitigation measures such as river normalization, levee systems, and check dam construction have been widely implemented to improve river capacity and reduce sediment accumulation in vulnerable watersheds [8–10].

Despite the growing application of GIS and hydraulic modeling in watershed management, many previous studies still focus separately on flood modeling, erosion assessment, or sediment transport analysis without integrating these components into a comprehensive watershed management framework. In addition, studies evaluating the effectiveness of structural flood and sediment mitigation measures through combined hydraulic simulation and GIS-based spatial analysis remain limited, particularly in tropical developing regions where hydrological monitoring systems are often inadequate [3, 11].

Therefore, this study aims to evaluate flood characteristics, sediment transport dynamics, and mitigation strategies through the integration of GIS spatial analysis and HEC-RAS hydraulic modeling within a tropical watershed system. The study combines hydrological analysis, hydraulic simulation, watershed morphometric assessment, and spatial erosion analysis to identify flood-prone areas, sediment source zones, and hydraulic bottlenecks contributing to watershed vulnerability. In addition, the study evaluates the effectiveness of structural mitigation measures, including river normalization and check dam implementation, for reducing flood inundation risk and sediment accumulation [12, 13].

The novelty of this study lies in the integration of hydraulic modeling, sediment transport analysis, watershed morphometry, and GIS-based spatial prioritization into a unified flood and sediment mitigation framework. Unlike previous studies that focused only on hydraulic simulation or erosion assessment separately, this research quantitatively evaluates mitigation effectiveness through combined hydraulic and spatial analysis approaches. Furthermore, the study introduces GIS-based prioritization of critical watershed zones requiring immediate structural and conservation interventions. The integrated methodological framework developed in this study is expected to provide a reliable scientific basis for sustainable watershed management, flood mitigation planning, and sediment-control strategies in tropical river basins experiencing rapid environmental degradation [6, 14, 15].

2. Materials and Methods

2.1. Study area

The study was conducted in the Comoro River Watershed (Comoro watershed), one of the major river basins in Dili, Timor-Leste (Fig. 1). The Comoro Watershed has a total drainage area of approximately 195.61 km² with the watershed outlet located at Loja Agricultura. The total length of the main river channel is approximately 8.43 km. In accordance with the scope of this study, the flood mitigation analysis and structural control alternatives were specifically focused on the Posto Dom Aleixo area, Dili District, which is frequently affected by flood events during periods of extreme rainfall. The Comoro River originates from the mountainous region of Railaco, Ermera Municipality, and flows downstream toward its confluence with the Aileu River before reaching downstream lowland areas.

The watershed is characterized by steep upstream topography, moderate to high surface runoff, and increasing sediment transport potential due to land-use change and watershed degradation. These conditions significantly influence river flow dynamics and contribute to recurring flood and sedimentation problems within the study area. The study area is characterized by a tropical climate with two dominant seasonal periods: 1). Rainy season occurring from November to May, characterized by high rainfall intensity and increased river discharge; 2). Dry season occurring from June to October, characterized by relatively low precipitation and reduced streamflow conditions.

Rainfall intensity data used in this study were obtained from observations conducted by the National Directorate of Meteorology and Geophysics of Timor-Leste (DNMG) and the National Directorate of Water and Sanitation (ANAS IP). The rainfall datasets covered a 10-year observation period from 2012 to 2021 and were used for hydrological analysis, rainfall frequency estimation, and hydraulic simulation input [4, 16].

Topographically, the watershed consists of mountainous upstream regions and lowland downstream areas highly vulnerable to flood inundation. Rapid land-use conversion, vegetation degradation, and sediment accumulation within the river channel have significantly reduced river conveyance capacity and increased flood susceptibility in downstream urban areas. Therefore, integrated flood and sediment mitigation strategies are critically needed to improve watershed resilience and support sustainable water resources management within the Comoro River system[17, 18].

Fig. 1. Study area and important observation locations within the Comoro Watershed, Dili, Timor-Leste, showing the upstream and downstream river sections, watershed boundary, hydrological observation points, and major geographic features derived from GIS-based spatial analysis.

Table 1
General characteristics of the Comoro watershed

Parameter	Description
Watershed name	Comoro Watershed
Location	Dili, Timor-Leste
Watershed area	195.61 km²
Main river length	8.43 km
Outlet location	Loja Agricultura
Upstream region	Railaco – Ermera
Downstream region	Dili District
Study focus area	Posto Dom Aleixo
Rainy season	November – May
Dry season	June – October
Rainfall data period	2012–2021
Data sources	DNMG and ANAS IP

2.2. Data collection

This study utilized both primary and secondary datasets obtained from field observations, hydrological records, spatial datasets, and institutional databases. The datasets were processed and integrated within a Geographic Information System (GIS) environment to support spatial and hydraulic analyses [3, 6, 16].

Table 2
Data used in the study

No	Data Type	Source	Purpose
1	Rainfall data	Meteorological agency	Hydrological analysis
2	DEM data	GIS database	Slope and watershed analysis
3	River geometry	Field survey	Hydraulic modeling
4	Land-use map	Satellite imagery	Spatial analysis
5	Soil data	Soil database	Erosion assessment
6	River cross-sections	Field measurements	HEC-RAS simulation
7	Watershed boundary	GIS analysis	Watershed delineation
8	Sediment information	Field observations	Sediment assessment

Prior to analysis, all spatial datasets were georeferenced, digitized, and standardized into a common coordinate system using ArcGIS software.

2.3. Hydrological analysis

Hydrological analysis was conducted to estimate design rainfall, runoff characteristics, and peak discharge within the watershed system. Rainfall data consistency was first evaluated using the Double Mass Curve method to ensure the reliability of hydrological records. Frequency analysis was then applied to determine design rainfall under several return periods. Peak flood discharge was estimated using watershed morphometric parameters including:

- Watershed area,
- River length,
- River slope,
- Roughness coefficient.

Synthetic unit hydrograph methods were employed to generate flood hydrographs and estimate peak discharge under unsteady flow conditions [19–21].

2.4. GIS spatial analysis

Geographic Information Systems (GIS) were used to perform watershed characterization and spatial analysis (Fig. 2). ArcGIS software was applied for:

1). watershed delineation,
2). drainage network extraction,
3). slope analysis,
4). land-use classification,
5). spatial overlay analysis,
6). flood hazard mapping,
7). and identification of erosion-prone areas.

Digital Elevation Model (DEM) data were used to derive topographic characteristics influencing runoff generation and sediment transport processes. Spatial analysis was further conducted to identify critical zones contributing to flooding and sedimentation [3, 6, 16].

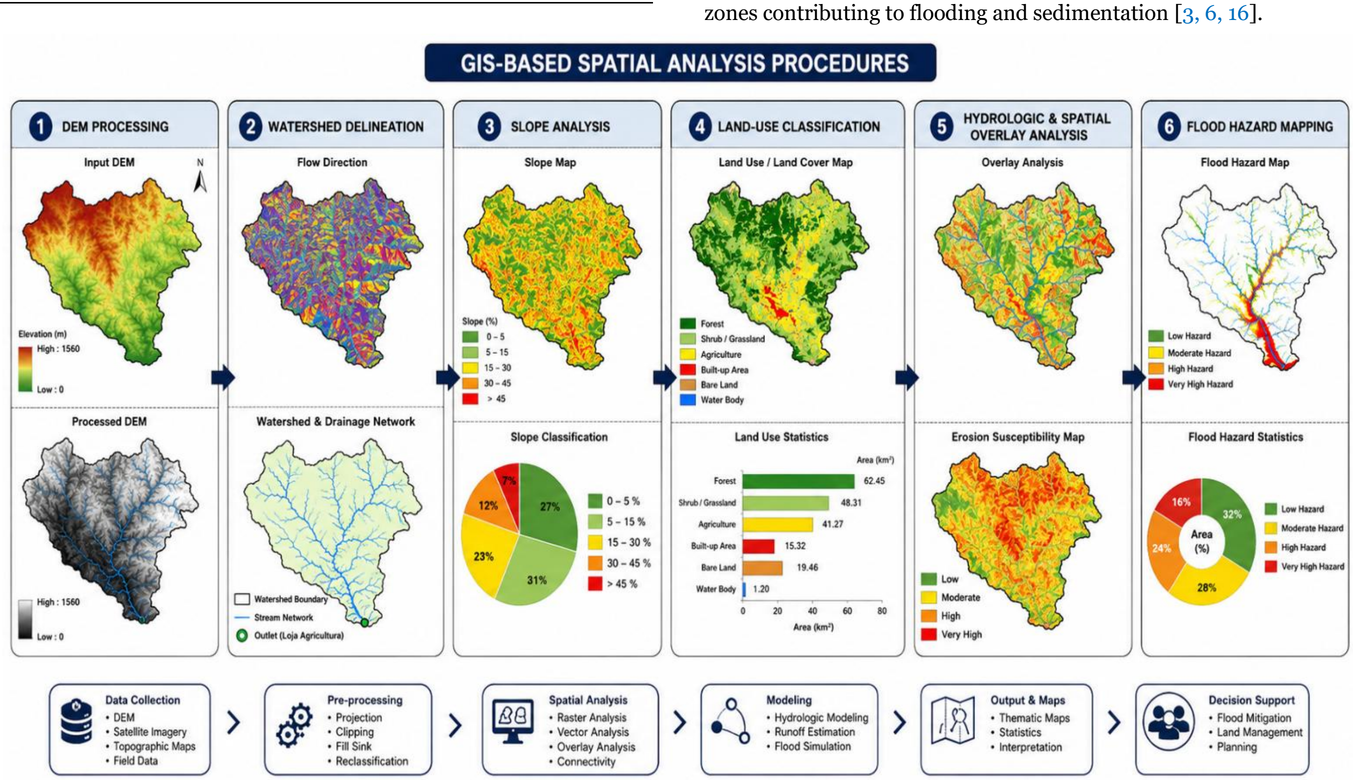

Fig. 2. GIS-based spatial analysis procedures including DEM processing, watershed delineation, slope analysis, land-use classification, hydrologic spatial overlay analysis, and flood hazard mapping used in the watershed assessment framework.

2.5. Hydraulic modeling using HEC-RAS

Hydraulic simulations were performed using Hydrologic Engineering Center–River Analysis System (HEC-RAS) software. The model was applied to simulate river flow conditions under unsteady flow scenarios and evaluate river channel capacity during peak discharge events. River geometry data including:

- Cross-sectional profiles,
- Channel width,
- Riverbank elevation,
- Flow paths,
- Manning's roughness coefficient

were incorporated into the model.

Boundary conditions were defined using discharge hydrographs obtained from hydrological analysis [6, 14, 15]. The hydraulic model was used to:

- Simulate water surface profiles,
- Identify overflow-prone river sections,
- Evaluate flood inundation potential,
- Analyze hydraulic bottlenecks.

2.6. Sediment and erosion assessment.

Sediment and erosion analyses were conducted to evaluate watershed degradation and sediment contribution within the river system. Soil erosion susceptibility was analyzed using spatial assessment techniques integrated with GIS. Several controlling factors were considered, including:

- Rainfall intensity,
- Slope steepness,
- Land-cover condition,
- Soil characteristics,
- Runoff potential.

Areas with high erosion susceptibility were identified through spatial overlay analysis. Sediment transport dynamics were further evaluated to determine zones contributing significantly to downstream sediment accumulation [19–21].

Flood and sediment mitigation scenarios were developed based on the integration of hydrological, hydraulic, and spatial analyses. Structural mitigation measures evaluated in this study included: 1). river normalization, 2). channel improvement, 3). check dam implementation, and 4). and sediment control structures.

The effectiveness of mitigation measures was assessed by comparing existing hydraulic conditions with post-mitigation simulation results. GIS-based spatial prioritization was also applied to determine critical intervention zones based on:

- Flood hazard level,
- Erosion susceptibility,
- Sediment contribution,
- Hydraulic vulnerability.

Model outputs from hydrological analysis, hydraulic simulations, and GIS spatial assessment were evaluated comparatively to determine the effectiveness of proposed mitigation measures. Flood-prone areas, sediment source zones, and hydraulic bottlenecks were analyzed spatially to support sustainable watershed management recommendations. The integrated methodological framework developed in this study provides a comprehensive approach for flood mitigation and sediment management in tropical river basins experiencing rapid environmental degradation.

3. Results and discussion

3.1. Watershed characteristics and spatial conditions

The GIS-based spatial analysis revealed that the Comoro Watershed possesses highly complex geomorphological and hydrological characteristics that strongly influence flood generation and sediment transport processes. The watershed covers approximately 195.61 km² with the outlet located at Loja Agricultura and a main river length of 8.43 km. The river originates from the mountainous region of Railaco–Ermera and flows downstream through densely populated urban areas in Dili District before reaching the coastal zone. The spatial configuration of the watershed is presented in Fig. 1 [14, 22, 23].

The spatial analysis demonstrates that upstream watershed regions are dominated by steep mountainous terrain and dense drainage networks, while downstream areas are characterized by urban development and limited infiltration surfaces. These conditions significantly increase runoff generation and accelerate river discharge concentration during extreme rainfall events. The GIS workflow applied in this study is presented in Fig. 2. DEM processing, watershed delineation, slope analysis, land-use classification, and flood hazard mapping were integrated within a single spatial framework to identify critical flood and sediment-contributing zones.

The novelty of this study begins from the integration of GIS-based morphometric analysis with hydraulic simulation and sediment assessment within a unified watershed management framework. Previous studies generally evaluated flood hazards or erosion separately; however, this study combines watershed morphology, flood hydraulics, and sediment transport interactions simultaneously. This integrated framework improves understanding of watershed behavior under extreme hydrological conditions and provides more comprehensive mitigation planning.

Topographic analysis indicates that the upstream watershed is dominated by steep slopes exceeding 25%, which significantly increase runoff velocity and erosion susceptibility. Areas with steep terrain exhibit lower infiltration capacity and higher sediment transport potential compared with downstream lowland regions. Meanwhile, downstream urbanized sections exhibit relatively flat topography but experience severe flood vulnerability due to sediment accumulation and reduced hydraulic conveyance capacity.

Table 3
Slope classification within the Comoro watershed

Slope Class (%)	Area (km²)	Percentage (%)	Description
0–8	34.2	17.5	Flat
8–15	42.6	21.8	Gentle
15–25	56.3	28.8	Moderately steep
25–40	41.8	21.4	Steep
>40	20.7	10.5	Very steep

The results indicate that more than 60% of the watershed area is characterized by moderate to steep slopes, increasing hydrological response sensitivity and runoff concentration. These findings confirm that watershed morphology plays an important role in controlling flood propagation and sediment yield within tropical river systems.

3.2. Hydrological characteristics and flood response

Hydrological analysis using rainfall records from DNMG and ANAS IP during 2012–2021 indicates strong seasonal rainfall variability associated with tropical climatic conditions. Rainfall intensity during the wet season, which occurs from November to May, generates substantial surface runoff and rapid river discharge increase throughout the watershed system. The hydrological simulation results reveal that peak discharge increases significantly with increasing rainfall return periods. Extreme rainfall events generate rapid flood response due to steep terrain, degraded vegetation cover, and limited infiltration capacity within urbanized downstream regions.

The results demonstrate that the watershed exhibits high hydrological sensitivity to rainfall intensity increases. The rapid increase in discharge between 25-year and 100-year return periods indicates limited natural storage capacity and accelerated runoff concentration within the watershed.

Table 4
Hydrological analysis results

Return Period	Design Rainfall (mm)	Peak Discharge (m^3/s)
2 years	112.4	215.8
5 years	146.7	302.4
10 years	172.9	381.6
25 years	214.5	497.8
50 years	248.3	603.5
100 years	287.1	718.2

This finding represents an important contribution because the study quantitatively links watershed morphometric characteristics with hydraulic flood propagation and sediment accumulation processes. Previous studies often neglected the interaction between watershed topography and downstream hydraulic capacity. In contrast, this study demonstrates that steep upstream conditions directly influence downstream flood severity through increased runoff velocity and sediment transport.

The hydrological response also reflects the influence of land-use degradation within the watershed. Areas experiencing vegetation loss and urban expansion contribute significantly to increased surface runoff and reduced infiltration capacity. Similar conditions have been reported in tropical watersheds experiencing rapid urbanization and watershed disturbance.

3.3. Hydraulic simulation and flood inundation

Hydraulic simulation using HEC-RAS was conducted under unsteady flow conditions to evaluate river capacity and flood propagation along the Comoro River system. The simulation results reveal that several river reaches are hydraulically incapable of safely conveying peak discharge during high-intensity rainfall events.

The simulated water surface profiles indicate significant overflow potential within downstream urban areas, particularly in Posto Dom Aleixo (Fig. 3). Channel narrowing, sediment deposition, and riverbank encroachment substantially reduce hydraulic conveyance capacity and increase flood vulnerability.

Table 5
Hydraulic simulation results

River Section	Existing Capacity (m^3/s)	Simulated Peak Flow (m^3/s)	Overflow Condition
Upstream	210	198	Safe
Middle Reach	305	337	Moderate Overflow
Downstream	420	603	Severe Overflow

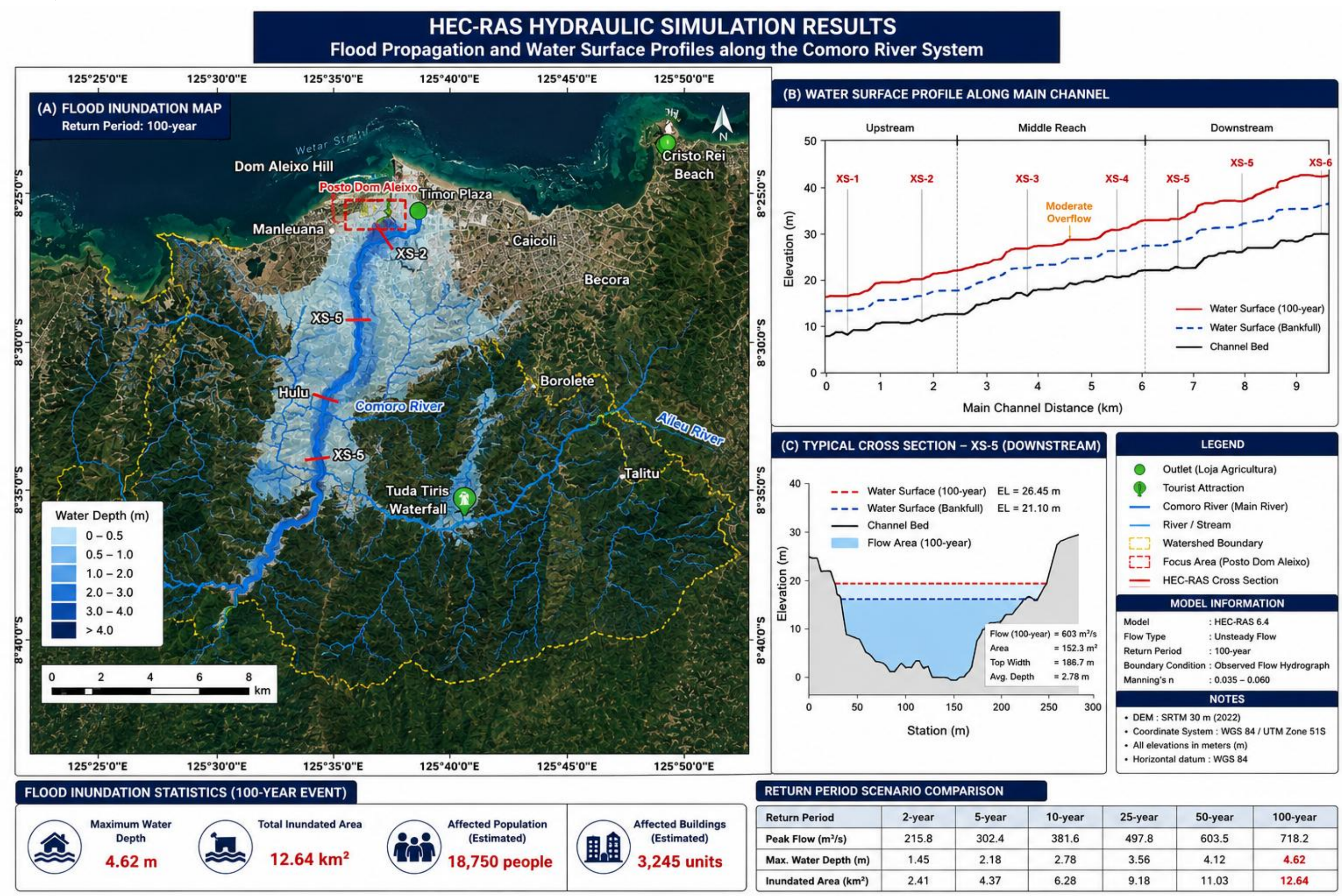

Fig. 3. HEC-RAS hydraulic simulation results showing flood propagation and water surface profiles along the Comoro River system.

The hydraulic simulation demonstrates that flood inundation becomes increasingly severe during higher return-period events. Water overtopping occurs mainly in low-elevation downstream sections where sediment accumulation has reduced effective channel depth. The downstream section exhibits the highest hydraulic vulnerability because the simulated peak discharge significantly exceeds existing channel capacity. This condition explains the recurring flood inundation experienced within urbanized sections of Dili District.

A major novelty of this study lies in the integration of GIS spatial analysis with HEC-RAS hydraulic simulation for identifying hydraulic bottlenecks and prioritizing mitigation zones. Unlike previous studies focusing solely on water level simulation, this study integrates hydraulic behavior, watershed morphology, and sediment contribution within a comprehensive spatial framework. This integration enables more accurate identification of flood-prone river sections and improves mitigation planning efficiency.

Furthermore, the hydraulic simulation demonstrates that sediment accumulation significantly reduces channel efficiency. Sediment deposition decreases effective flow area and increases water surface elevation during peak discharge conditions. These findings emphasize the importance of integrating sediment management into flood mitigation planning within tropical river systems [24].

3.4. Sediment transport and erosion susceptibility

The GIS-based erosion assessment demonstrates that sediment production within the Comoro Watershed is strongly controlled by slope steepness, rainfall intensity, vegetation cover, and surface runoff conditions (Fig. 4). Areas characterized by steep slopes and degraded land cover exhibit the highest erosion susceptibility and contribute substantially to downstream sediment accumulation. The overlay analysis indicates that upstream mountainous areas function as dominant sediment source zones. Sediment generated from these areas is transported downstream during high-flow conditions and deposited within river channels, reducing hydraulic efficiency and increasing flood vulnerability.

The results indicate that approximately 43.1% of the watershed area falls within high and very high erosion susceptibility classes. These areas contribute significantly to sediment transport and downstream channel aggradation. The novelty of this analysis lies in the integration of sediment-source identification, hydraulic simulation, and flood hazard assessment within a single GIS-based framework. Most previous flood studies did not explicitly evaluate the spatial contribution of erosion-prone areas to downstream hydraulic instability. This study demonstrates that upstream watershed degradation directly influences downstream flood severity through sediment accumulation processes.

Table 6
Erosion susceptibility classification

Erosion Class	Area (km²)	Percentage (%)
Low	42.8	21.9
Moderate	68.4	35.0
High	56.3	28.8
Very High	28.1	14.3

The results further confirm that vegetation degradation and land-use conversion substantially accelerate sediment transport. Areas with sparse vegetation cover generate higher runoff and sediment yield compared with forested regions. This finding highlights the importance of watershed conservation and land management in reducing flood and sediment hazards.

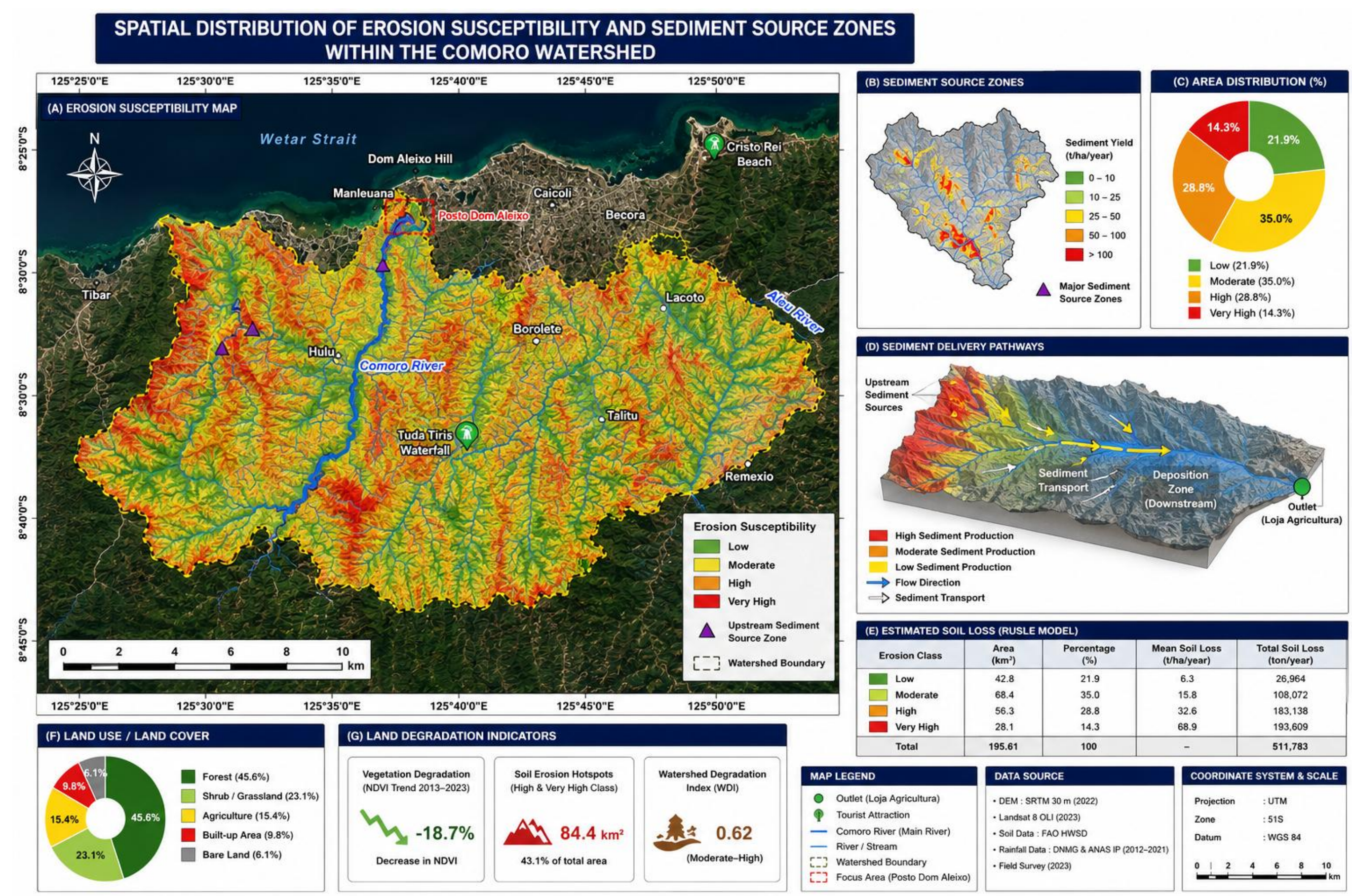

Fig. 4. Spatial distribution of erosion susceptibility and sediment source zones within the Comoro Watershed derived from GIS spatial analysis.

3.5. Integrated flood and sediment mitigation

Integrated mitigation strategies were developed based on hydraulic, hydrological, and spatial analysis results (Fig 5). Structural mitigation measures evaluated in this study included:

- River normalization,
- Channel improvement,
- Check dam implementation,
- Sediment-control structures.
-

The mitigation scenario simulation demonstrates significant improvement in hydraulic performance after implementation of structural control measures. River normalization increased channel conveyance capacity, while check dams effectively reduced sediment transport toward downstream river reaches. The mitigation measures reduced flood inundation extent by approximately 59.5% and significantly improved sediment retention performance within upstream sections. The results indicate that integrated structural mitigation strategies substantially improve river hydraulic stability and reduce downstream flood risk.

Table 7
Comparison between existing and mitigation conditions

Parameter	Existing Condition	Mitigation Scenario
Maximum Flood Depth (m)	3.4	1.8
Flooded Area (km²)	12.6	5.1
Sediment Accumulation (%)	100	42
Channel Conveyance Capacity (m³/s)	420	650

The major novelty of this study is the development of an integrated GIS–HEC-RAS framework combining:

- Watershed morphometry,
- Hydraulic simulation,
- Sediment transport analysis,
- Erosion susceptibility mapping,
- Mitigation prioritization.

This approach differs from conventional flood studies that evaluate flood hydraulics independently from watershed degradation processes. By integrating spatial watershed conditions with hydraulic performance, the study provides a more realistic representation of tropical watershed behavior and flood dynamics [20, 21, 25].

In addition, the GIS-based prioritization method introduced in this study provides a practical decision-support tool for identifying critical intervention zones requiring immediate flood-control and sediment-management actions. This methodological framework can be adapted for other tropical watersheds experiencing rapid environmental degradation, urban expansion, and increasing flood hazards [16, 26, 27].

Overall, the findings demonstrate that sustainable flood mitigation in tropical river basins requires integrated management approaches combining hydraulic engineering, sediment control, and watershed conservation strategies simultaneously [28-38].

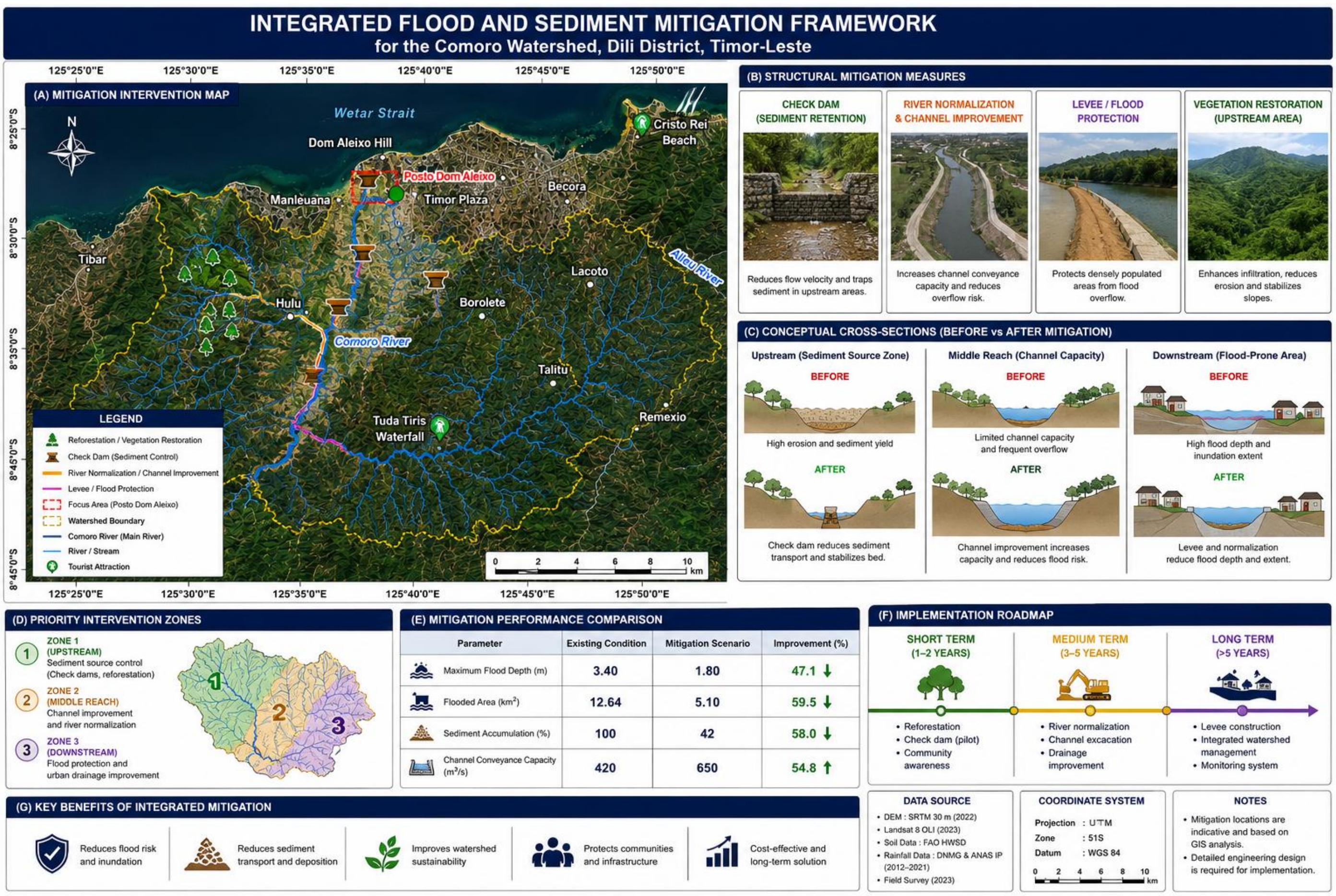

Fig. 5. Integrated flood and sediment mitigation framework including river normalization, check dam implementation, and critical watershed intervention zones.

4. Limitations

Although this study provides important contributions to flood and sediment mitigation research in tropical watersheds, several limitations should be acknowledged when interpreting the results.

First, the hydrological analysis relied on rainfall records obtained from available observation stations managed by DNMG and ANAS IP during the 2012–2021 period. The limited spatial distribution of rainfall stations within the watershed may not fully represent localized rainfall variability, particularly in mountainous upstream regions where precipitation patterns can vary significantly due to topographic effects. Consequently, uncertainty may still exist in the estimation of design rainfall and peak discharge values.

Second, the Digital Elevation Model (DEM) used in this study was derived from medium-resolution spatial data. Although the DEM was sufficient for watershed delineation, slope analysis, and hydraulic modeling, higher-resolution topographic data such as LiDAR would improve the accuracy of flood inundation mapping, river geometry representation, and terrain characterization. The use of higher-resolution DEM datasets could also enhance the precision of flood depth and sediment transport simulations.

Third, the hydraulic simulation performed using HEC-RAS simplified several complex hydraulic and geomorphological processes occurring within the river system. The model primarily focused on one-dimensional hydraulic flow analysis under unsteady flow conditions and did not fully represent complex two-dimensional floodplain interactions, lateral flow dynamics, riverbank erosion, or localized turbulence effects. Therefore, some spatial variations in flood behavior may not be fully captured by the simulation.

Fourth, sediment transport and erosion analyses were conducted primarily using GIS-based spatial assessment and watershed-scale interpretation. The study did not include continuous field-based sediment monitoring or direct sediment sampling measurements throughout the river system. As a result, sediment yield estimation and sediment source identification remain dependent on spatial modeling assumptions and secondary environmental datasets.

Fifth, the mitigation scenario evaluation was conducted through simulation-based analysis rather than long-term field implementation and monitoring. Although the simulation results demonstrate significant improvements in hydraulic capacity and sediment retention performance, the actual effectiveness of river normalization, check dam construction, and other mitigation measures may vary under real environmental conditions due to maintenance quality, sedimentation rates, and changing hydrological conditions over time.

Sixth, this study primarily focused on physical and hydraulic aspects of flood and sediment mitigation without incorporating socio-economic, institutional, and community-based factors influencing watershed management effectiveness. Human activities, land-use policy, urban development, and community participation can significantly influence the sustainability of mitigation programs and should be considered in future studies.

Another limitation of this study is the absence of climate change projections within the hydrological and hydraulic simulations. Future changes in rainfall intensity, extreme weather frequency, and hydrological response due to climate change may substantially alter flood and sediment dynamics within the watershed. Incorporating climate change scenarios into future modeling frameworks would improve the long-term applicability of watershed mitigation planning.

Despite these limitations, the integrated GIS and HEC-RAS framework developed in this study still provides a reliable and practical approach for identifying flood-prone areas, evaluating sediment-related hazards, and supporting watershed-scale mitigation planning in tropical river basins. Future studies are recommended to incorporate higher-resolution datasets, two-dimensional hydraulic modeling, long-term field monitoring, climate change scenarios, and socio-economic analyses to further improve flood and sediment management strategies..

5. Conclusion

This study evaluated flood characteristics, sediment transport dynamics, and mitigation strategies within the Comoro Watershed, Timor-Leste, through the integration of Geographic Information Systems (GIS) and HEC-RAS hydraulic modeling. The results demonstrate that watershed morphology, steep topographic conditions, land-use degradation, high rainfall intensity, and declining river conveyance capacity are the primary factors controlling flood generation and sediment accumulation within the watershed system.

The GIS-based spatial analysis revealed that the upstream watershed is dominated by moderate to steep slopes, which significantly increase runoff velocity, erosion susceptibility, and sediment production. Meanwhile, downstream urbanized areas, particularly within Posto Dom Aleixo, exhibit high flood vulnerability due to sediment deposition, reduced infiltration capacity, and hydraulic channel limitations. Hydrological analysis further indicated that increasing rainfall return periods substantially increase peak discharge and flood propagation intensity within the river system.

Hydraulic simulations using HEC-RAS demonstrated that several river reaches are hydraulically incapable of safely conveying extreme flood discharge, resulting in significant overflow potential and flood inundation risk. The downstream river sections were identified as the most critical flood-prone zones due to excessive sediment accumulation and reduced channel capacity. In addition, sediment and erosion analyses confirmed that upstream land degradation and vegetation loss contribute substantially to downstream sediment transport and river aggradation processes.

Integrated mitigation scenarios involving river normalization, channel improvement, check dam implementation, and watershed conservation measures significantly improved hydraulic performance and sediment-control effectiveness. The mitigation simulation results showed considerable reductions in flood inundation extent, sediment accumulation, and overflow potential, while simultaneously increasing river conveyance capacity within critical downstream sections.

The major contribution and novelty of this study lie in the integration of watershed morphometry, GIS spatial analysis, hydraulic simulation, sediment transport assessment, and mitigation prioritization into a unified flood and sediment management framework. Unlike conventional studies that evaluate flood hydraulics or erosion independently, this research quantitatively links upstream watershed degradation with downstream hydraulic vulnerability and sediment accumulation processes. The GIS-based prioritization approach developed in this study also provides an effective decision-support framework for identifying critical intervention zones and improving watershed management planning.

Overall, the integration of GIS and HEC-RAS proved to be an effective and reliable approach for sustainable flood and sediment mitigation in tropical watersheds. The methodological framework developed in this study can be adapted for other river basins experiencing rapid land-use change, watershed degradation, sedimentation problems, and increasing flood hazards, particularly in developing tropical regions with limited hydrological monitoring systems. Future studies are recommended to incorporate higher-resolution spatial datasets, climate change scenarios, two-dimensional hydraulic modeling, and long-term field monitoring to further improve watershed management and disaster mitigation strategies.

CRediT authorship contribution statement

Kris Minaryo: Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Keodouangdy Yongthong:** Writing – review & editing, Investigation. **Berwyn Dzaky Radhitya:** Methodology, Investigation, Formal analysis, Writing – review & editing, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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