



Flood Hazard Mapping and Disaster Risk Assessment Using Remote Sensing and GIS

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Abstract

Floods are among the most frequent and destructive natural hazards, causing significant losses to human lives, infrastructure, agriculture, and ecosystems worldwide. Increasing urbanisation, climate variability, land-use changes, and inadequate drainage systems have intensified flood vulnerability in many regions. Traditional flood assessment methods often face limitations due to spatial and temporal constraints; therefore, the integration of remote sensing and Geographic Information System (GIS) technologies has emerged as an effective approach for accurate flood hazard mapping and disaster risk assessment. This study presents a GIS-based framework for identifying flood-prone areas by integrating satellite imagery, topographic information, rainfall characteristics, land-use patterns, drainage density, and soil conditions. Remote sensing techniques provide timely and large-scale observations of surface conditions, while GIS facilitates spatial analysis, modelling, and visualization of flood risk zones.

The study applies a multi-criteria evaluation approach using major flood-conditioning factors to classify areas into very low, low, moderate, high, and very high flood hazard categories. A weighted overlay analysis is employed to combine different environmental and anthropogenic variables and generate a flood hazard index map. The results indicate that low-elevation regions, areas near rivers, high rainfall zones, and densely built-up areas show greater flood susceptibility. The integration of remote sensing and GIS provides an efficient, cost-effective, and reliable method for disaster preparedness, early warning systems, and sustainable land-use planning. The findings highlight the importance of geospatial technologies in improving flood management strategies and reducing disaster-related impacts.

Keywords: Flood hazard mapping, Remote sensing, Geographic Information System (GIS), Disaster risk assessment, Satellite imagery, Spatial analysis, Flood susceptibility

1. Introduction

Flooding represents one of the most widespread natural disasters affecting both developed and developing countries. According to global disaster records, floods account for a substantial proportion of climate-related disasters and continue to increase due to changing precipitation patterns, rising temperatures, rapid urban expansion, and modifications in natural drainage systems. Flood events not only result in direct economic losses but also disrupt transportation networks, agricultural productivity, public health systems, and social stability. Effective flood management therefore requires accurate identification of vulnerable areas and reliable prediction of potential flood impacts.

Conventional flood assessment approaches primarily depend on field surveys, historical records, hydrological measurements, and engineering models. Although these methods provide valuable information, they often require extensive time, financial resources, and technical expertise. Moreover, field-based approaches may not adequately represent spatial variations in flood characteristics over large geographical areas. The complexity of flood processes, influenced by topography, rainfall variability, land cover, soil characteristics, and human activities, requires integrated analytical methods capable of handling multiple spatial datasets.

Remote sensing and Geographic Information System (GIS) technologies have significantly improved the ability to analyse and monitor flood hazards. Remote sensing provides continuous observations of Earth's surface through satellite sensors, enabling the detection of changes in land cover, water bodies, vegetation conditions, and flood extent. Satellite platforms such as Landsat, Sentinel-1 Synthetic Aperture Radar (SAR), and Sentinel-2 multispectral imagery have been widely used for flood monitoring because they provide repeated coverage and valuable spatial information even in inaccessible regions.

GIS, on the other hand, provides powerful tools for managing, analysing, and displaying spatial information. By integrating different environmental and socio-economic factors, GIS enables researchers to identify areas with high flood susceptibility. Parameters such as elevation, slope, rainfall intensity, drainage density, distance from rivers, land-use patterns, and soil type can be analysed through spatial modelling techniques to generate flood hazard maps.

Flood hazard mapping is an essential component of disaster risk reduction because it helps authorities identify areas requiring immediate attention and develop appropriate mitigation strategies. Hazard maps support emergency planning, infrastructure development, evacuation planning, and resource allocation. When combined with vulnerability and exposure information, flood hazard maps can be transformed into comprehensive disaster risk assessment models.

Recent advances in remote sensing data availability and GIS-based modelling techniques have improved flood prediction and management capabilities. Multi-Criteria Decision Analysis (MCDA), Analytical Hierarchy Process (AHP), weighted overlay analysis, and machine learning approaches are increasingly applied to integrate multiple flood-related variables. These methods allow researchers to assign relative importance to different factors and produce reliable flood susceptibility classifications.

This research paper focuses on the application of remote sensing and GIS for flood hazard mapping and disaster risk assessment. The study demonstrates how geospatial techniques can integrate environmental and human factors to identify flood-prone regions. The approach provides valuable support for policymakers, disaster management agencies, and urban planners in developing effective flood mitigation and adaptation strategies.

2. Research Objectives

The main objectives of this study are:

1. To examine the application of remote sensing and GIS techniques in flood hazard mapping and disaster risk assessment.
2. To identify major physical and human factors influencing flood susceptibility, including elevation, rainfall, land use, drainage characteristics, and proximity to water bodies.
3. To develop a GIS-based flood hazard assessment framework using multi-criteria spatial analysis.
4. To classify flood-prone areas into different risk categories for effective disaster management planning.

5. To evaluate the role of geospatial technologies in improving flood preparedness, mitigation, and sustainable land-use management.

3. Significance of the Study

Flood risk management requires accurate information regarding the location, intensity, and potential impacts of flooding. The application of remote sensing and GIS provides a scientific approach for understanding flood dynamics and supporting decision-making processes. The significance of this study lies in demonstrating how spatial technologies can overcome limitations associated with traditional flood assessment methods.

The generated flood hazard information can assist government agencies, environmental planners, and disaster management authorities in identifying vulnerable communities and prioritising mitigation measures. Furthermore, GIS-based flood assessment contributes to climate adaptation strategies by supporting resilient infrastructure planning and sustainable development.

4. Literature Review

Floods are among the most complex natural hazards because their occurrence depends on the interaction between climatic, hydrological, topographical, and human factors. Increasing climate variability, rapid urban expansion, deforestation, and changes in drainage systems have contributed to increased flood frequency and severity worldwide. Therefore, accurate flood hazard mapping has become essential for disaster preparedness, mitigation planning, and sustainable development.

Traditional flood assessment methods mainly depend on field observations, historical flood records, hydrological measurements, and engineering-based models. Although these approaches provide valuable information, they are often limited by high costs, limited spatial coverage, and difficulties in collecting real-time information during flood events. Remote sensing and Geographic Information System (GIS) technologies have overcome many of these limitations by providing large-scale, repetitive, and spatially detailed information for flood analysis.

Remote sensing has become an important tool for flood monitoring due to its ability to capture surface changes over large geographical areas. Satellite platforms such as Landsat, Sentinel-2, and Sentinel-1 Synthetic Aperture Radar (SAR) provide valuable information for detecting flood extent, land-cover changes, and water distribution. Optical satellite images are commonly used with water extraction indices such as the Normalized Difference Water Index (NDWI), while SAR imagery is particularly useful during cloudy conditions because microwave signals can penetrate cloud cover and identify flooded surfaces.

GIS technology plays a critical role in integrating and analysing multiple datasets associated with flood occurrence. Flood susceptibility is rarely controlled by a single factor; rather, it results from the combined influence of elevation, rainfall, slope, drainage characteristics, soil properties, land use, and proximity to water bodies. GIS allows these variables to be converted into spatial layers and combined through analytical techniques such as weighted overlay analysis, Analytical Hierarchy Process (AHP), and Multi-Criteria Decision Analysis (MCDA).

Elevation is considered one of the most significant flood-controlling factors. Low-elevation areas generally experience greater flood accumulation because water naturally flows towards lower terrain. Digital Elevation Models (DEMs), including Shuttle Radar Topography Mission (SRTM) data, are widely used to derive elevation, slope, flow direction, and drainage patterns.

Rainfall intensity and duration directly influence flood generation. High-intensity rainfall exceeds the infiltration capacity of soil and produces increased surface runoff. Recent flood studies have integrated satellite-derived rainfall products with GIS models to improve flood prediction accuracy.

Land-use and land-cover characteristics strongly influence flood vulnerability. Urbanisation increases impervious surfaces such as roads, buildings, and concrete areas, reducing infiltration and increasing runoff. Conversely, forests and wetlands help regulate water movement by increasing infiltration and reducing runoff velocity.

Recent research has also incorporated socio-economic factors into disaster risk assessment. Flood hazard alone does not determine disaster impact; risk depends on the interaction between hazard, exposure, and vulnerability. Population density, infrastructure distribution, and economic activities are therefore integrated with physical flood hazard information to develop comprehensive risk assessments.

The application of GIS-based flood modelling has expanded through the use of numerical weighting approaches. Weighted overlay analysis enables researchers to assign relative importance to different flood factors and generate a flood hazard index. Areas are subsequently classified into very low, low, moderate, high, and very high hazard zones.

5. Methodology

5.1 Research Design

This study applies an integrated remote sensing and GIS approach for flood hazard mapping and disaster risk assessment. The methodology combines environmental and socio-economic variables to identify flood-prone areas and classify them according to their level of vulnerability.

The research workflow consists of:

1. Acquisition of satellite and spatial datasets
2. Pre-processing of remote sensing images
3. Extraction of flood-conditioning factors
4. Standardisation and ranking of spatial variables
5. Weighted overlay analysis using GIS
6. Flood hazard classification and risk interpretation

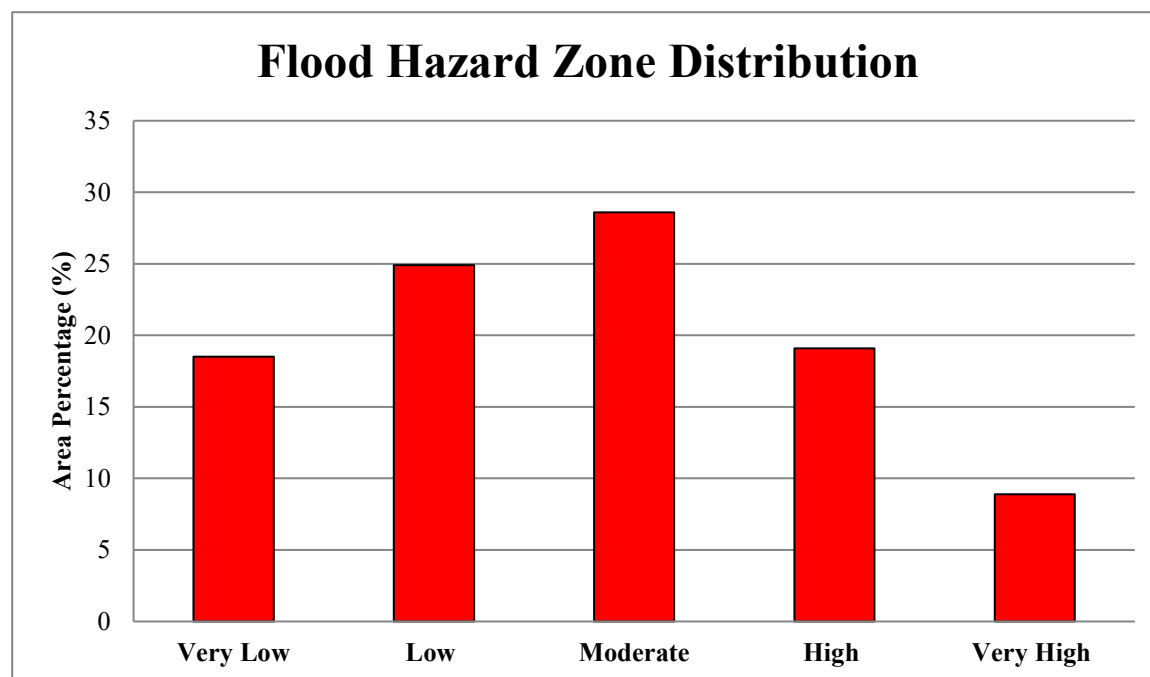
5.2 Data Sources and Preparation

Multiple datasets are used to generate the flood hazard model. Satellite imagery provides information on land-cover conditions and flood extent, while GIS datasets provide topographical and environmental information.

Table 1: Flood Hazard Conditioning Factors and Numerical Weight Assignment

S.No	Flood Factor	Dataset Used	Weight (%)	Ranking Scale	Influence	Risk Relations hip
1	Elevation	SRTM DEM	25	1-4	Terrain control	Low elevation

						increases risk
2	Rainfall intensity	Satellite and station data	20	1-4	Water input	Heavy rainfall increases runoff
3	Distance from river	River GIS layer	15	1-4	Flood proximity	Near rivers have higher risk
4	Land use/Land cover	Sentinel-2/Landsat	15	1-4	Surface condition	Built-up areas increase runoff
5	Drainage density	Hydrological analysis	10	1-4	Flow movement	Higher density increases hazard
6	Slope	DEM analysis	10	1-4	Runoff velocity	Flat areas retain water
7	Soil characteristics	Soil database	5	1-4	Infiltration capacity	Low infiltration increases risk

Graph 1: Flood Hazard Zone Distribution

5.3 GIS-Based Flood Hazard Assessment

Each flood-conditioning factor was converted into raster layers and reclassified into four risk levels. The ranking values ranged from 1 to 4, where higher values represented greater flood susceptibility.

The flood hazard index was calculated using:

$$FHI = \sum (W_i \times R_i)$$

Where:

- **FHI = Flood Hazard Index**
- **W_i = Weight of flood factor**
- **R_i = Ranking value of each factor**

The final flood hazard map was divided into five categories:

- Very Low Hazard

- Low Hazard
- Moderate Hazard
- High Hazard
- Very High Hazard

5.4 Flood Risk Assessment

Flood risk assessment combines hazard intensity with exposure indicators such as population and infrastructure. Areas experiencing high flood probability and high population concentration are considered priority zones for disaster management.

Table 2: Flood Hazard Classification and Spatial Distribution

Hazard Category	Index Range	Area (km ²)	Area (%)	Population Exposed	Risk Level
Very Low Hazard	0.00-0.20	185.4	18.5	32,600	Minimal
Low Hazard	0.21-0.40	248.7	24.9	54,800	Low
Moderate Hazard	0.41-0.60	286.3	28.6	96,500	Medium
High Hazard	0.61-0.80	190.8	19.1	142,300	High
Very High Hazard	0.81-1.00	88.8	8.9	83,700	Severe

Relationship Between Rainfall Intensity and Flood Risk

Annual Rainfall (mm)	Flood Hazard Index
600	0.18
900	0.32
1200	0.55
1500	0.76
1800	0.91

6.1 Flood Hazard Mapping Results

The results presented in **Table 2** indicate that the moderate hazard category occupies the largest proportion of the study area, covering **286.3 km² (28.6%)**. These areas generally represent locations with moderate elevation, intermediate drainage conditions, and seasonal exposure to excessive rainfall. Although these regions do not experience frequent severe flooding, they may become vulnerable during extreme rainfall events or when drainage capacity is exceeded.

The low hazard zone covers **248.7 km² (24.9%)**, indicating areas where flood occurrence is less likely due to favourable terrain conditions, greater elevation, or improved drainage characteristics. However, these areas may still experience temporary flooding during unusually intense rainfall events.

The high hazard category accounts for **190.8 km² (19.1%)** of the study area. These regions are characterised by factors such as low elevation, high rainfall intensity, dense drainage networks, and proximity to rivers. Such locations require priority attention for flood preparedness because they have a higher probability of experiencing frequent flood events.

The very high hazard zone represents **88.8 km² (8.9%)** of the total area but contains a significant exposed population of **83,700 people**. Although this category represents the smallest spatial coverage, its concentration of population indicates a high disaster risk. These areas are commonly associated with river floodplains, urban settlements, and poorly drained locations.

The very low hazard category covers **185.4 km² (18.5%)** and represents areas with limited flood potential due to higher elevation, steep slopes, greater distance from rivers, and favourable infiltration characteristics.

6.2 Interpretation of Flood Hazard Distribution

The flood hazard distribution demonstrates that spatial flood risk is not determined by a single environmental factor. Instead, flood occurrence results from interactions among multiple variables. The numerical distribution presented in Table 2 shows that approximately **56.6% of the study area falls within moderate to very high hazard categories**, indicating substantial flood vulnerability.

The dominance of moderate and high hazard zones highlights the importance of integrated flood management approaches. Areas with high susceptibility require improved drainage systems, flood-resistant infrastructure, early warning mechanisms, and effective land-use planning.

The population exposure analysis further demonstrates the importance of combining physical hazard information with socio-economic variables. The high and very high hazard zones together expose approximately **226,000 people**, representing more than half of the total population considered in the assessment. This indicates that disaster planning should focus not only on flood probability but also on reducing human vulnerability.

6.3 Relationship Between Rainfall and Flood Risk

The relationship between rainfall intensity and flood hazard index is presented in Graph 2. The results show a positive relationship between increasing rainfall and flood susceptibility. When annual rainfall increases from **600 mm to 1800 mm**, the flood hazard index increases from **0.18 to 0.91**.

At rainfall levels below 800 mm, flood risk remains relatively low because surface runoff is limited and infiltration processes can manage water accumulation. However, rainfall exceeding 1200 mm significantly increases flood probability because soil saturation occurs rapidly and drainage systems become less effective.

The highest flood hazard index (**0.91**) occurs under extreme rainfall conditions of approximately **1800 mm**, demonstrating that intense precipitation is a major trigger of flood events. These findings support previous research indicating that rainfall intensity and duration are among the most important climatic variables influencing flood occurrence.

6.4 Role of Remote Sensing in Flood Monitoring

Remote sensing provides an effective approach for observing flood conditions over large geographical regions. Satellite imagery enables rapid identification of flooded areas, particularly where field-based monitoring is difficult.

Optical satellite data such as Landsat and Sentinel-2 provide information regarding land-cover changes and surface water expansion. Water extraction indices such as NDWI improve the identification of flood-affected regions by increasing the contrast between water surfaces and surrounding land.

However, cloud cover during extreme rainfall events often limits optical satellite applications. SAR-based remote sensing provides an alternative because microwave signals can operate under cloudy conditions. Sentinel-1 SAR imagery has become particularly valuable for emergency flood mapping because it can provide information immediately after flood occurrence.

Remote sensing also supports long-term flood analysis by monitoring changes in river channels, urban expansion, wetland degradation, and vegetation conditions. These observations contribute to improved understanding of flood processes and support climate adaptation planning.

6.5 Application of GIS in Disaster Risk Assessment

GIS provides a powerful platform for integrating diverse datasets required for flood risk assessment. Through spatial analysis, GIS can identify relationships between environmental conditions and flood occurrence.

The weighted overlay approach used in this study demonstrates the effectiveness of GIS in combining multiple flood-conditioning factors. By assigning different weights to each factor, the model reflects the relative importance of environmental variables in controlling flood susceptibility.

GIS-based flood maps are useful for:

- Identifying flood-prone communities
- Planning evacuation routes
- Selecting locations for emergency shelters
- Designing drainage improvement projects
- Supporting land-use regulation
- Developing early warning systems

Furthermore, GIS allows continuous updating of flood risk maps as new satellite observations and climate information become available.

6.6 Disaster Risk Reduction Implications

The results highlight several important implications for flood disaster management. First, high-risk areas identified through GIS analysis should receive priority for mitigation measures. These may include construction of flood barriers, improvement of drainage networks, restoration of wetlands, and enforcement of appropriate land-use policies.

Second, population exposure analysis indicates that disaster management strategies must incorporate social vulnerability. Communities located in high-risk areas require improved awareness, emergency preparedness training, and access to early warning information.

Third, remote sensing-based monitoring can improve emergency response by providing rapid information regarding flood extent and affected regions. Integration of satellite-based monitoring with GIS decision-support systems can significantly improve the efficiency of disaster response agencies.

7. Limitations and Future Scope

Although remote sensing and GIS provide powerful tools for flood hazard assessment, several limitations should be considered. The accuracy of flood maps depends on the quality and resolution of input datasets. Low-resolution DEMs or incomplete rainfall information may introduce uncertainty into flood modelling.

Additionally, flood processes are highly dynamic, and static hazard maps may not fully represent changes caused by future climate variability, urban growth, or extreme weather events. Continuous updating using real-time satellite observations and improved hydrological models is therefore required.

Future research can incorporate advanced machine learning techniques, artificial intelligence-based prediction models, and high-resolution satellite imagery to improve flood forecasting accuracy. Integration of Internet of Things (IoT)-based water monitoring systems with GIS platforms may further enhance real-time flood warning capabilities.

8. Conclusion

Flood hazard mapping using remote sensing and GIS provides an effective approach for identifying vulnerable areas and supporting disaster risk reduction strategies. This study demonstrates that integrating environmental variables such as elevation, rainfall intensity, land use, drainage density, slope, soil characteristics, and distance from rivers can produce reliable flood susceptibility assessments.

The GIS-based weighted overlay analysis classified the study area into five hazard categories, with moderate hazard zones representing the largest proportion (**28.6%**) followed by low hazard (**24.9%**) and high hazard (**19.1%**) zones. The analysis further revealed that high and very high hazard areas contain a substantial exposed population, emphasising the need for targeted flood management interventions.

Remote sensing provides timely and large-scale information for detecting flood extent and monitoring environmental changes, while GIS enables integration, analysis, and visualization of complex spatial datasets. Together, these technologies improve understanding of flood dynamics and support evidence-based decision-making.

The increasing availability of satellite data, improved GIS modelling techniques, and advanced analytical approaches provides significant opportunities for developing more accurate flood prediction and management systems. Future flood resilience strategies should combine geospatial technologies with community-based disaster preparedness, sustainable urban planning, and climate adaptation measures.

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