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Multi-Parameter Flood Hazard Mapping and Evacuation Route Planning Using Geographic Information Systems (GIS): A Case Study of Malang City, East Java, Indonesia

Muhammad Farid Abdillah, Hendrata Wibisana, Bagas Aryaseta

Civil Engineering Study Program, Faculty of Engineering and Science, National Development University "Veteran" East Java, Surabaya, Indonesia

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CORRESPONDING AUTHOR

*E-mail: 22035010002@student.upnjatim.ac.id

ABSTRACT

Flooding is one of the most frequent hydrometeorological disasters in Indonesia and poses significant risks to urban areas due to rapid land-use change, increasing impervious surfaces, high rainfall intensity, and inadequate drainage systems. Malang City, experiences recurrent flooding that disrupts community activities, damages infrastructure, and threatens public safety. This study aims to identify flood hazard zones and determine optimal evacuation routes using Geographic Information Systems (GIS). Flood hazard assessment was performed using the Weighted Overlay method by integrating four environmental parameters: rainfall, land use, slope, and soil type. The resulting flood hazard map was combined with GIS-based Network Analysis to determine the shortest and most accessible evacuation routes to designated evacuation points. The results indicate that 6,222.81 ha (56.00%) of the study area is classified as high-hazard, 2,771.33 ha (24.96%) as moderate-hazard, and 2,114.56 ha (19.04%) as low-hazard. High-hazard areas are predominantly associated with dense urban development, relatively flat topography, and low soil infiltration capacity. Furthermore, the Network Analysis successfully generated optimal evacuation routes through the existing road network. The integration of Weighted Overlay and Network Analysis provides a comprehensive spatial framework for flood hazard assessment and evacuation planning, supporting evidence-based flood mitigation, disaster preparedness, and sustainable urban planning in Malang City.

Contribution to Sustainable Development Goals (SDGs):

SDG 6 : Clean Water and Sanitation

SDG 11: Sustainable Cities and Communities

SDG 13: Climate Action

1. INTRODUCTION

1.1. Research Background

Flooding is one of the most frequent hydrometeorological disasters worldwide and continues to threaten human life, infrastructure, economic activities, and environmental sustainability. In Indonesia, floods occur almost every year, with varying magnitudes, affecting both rural and urban areas. Rapid urbanization, population growth, land-use conversion, and

climate variability have intensified flood hazards, particularly in cities with inadequate drainage systems and limited infiltration areas [1], [6], [8].

Malang City is one of the rapidly developing urban areas in East Java Province. Population growth and urban expansion have significantly increased the demand for residential, commercial, educational, and transportation infrastructure. These developments have altered natural land cover into impervious surfaces, reducing infiltration capacity and increasing surface runoff during rainfall events. Consequently, several districts,



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including Blimbing, Lowokwaru, and Sukun, frequently experience inundation during the rainy season [2], [3].

The interactions among several physical and environmental factors influence the occurrence of floods in Malang City. High rainfall intensity leads to substantial runoff, while land-use changes accelerate water accumulation by expanding built-up areas. In addition, relatively flat topography and variations in soil permeability affect runoff movement and infiltration capacity, increasing flood susceptibility in several urban locations [3], [6]. Therefore, flood hazard assessment should consider multiple environmental parameters simultaneously rather than relying on a single factor.

Geographic Information Systems (GIS) have become one of the most widely used spatial technologies for flood hazard assessment because they enable the integration, management, analysis, and visualization of multiple environmental datasets within a unified framework [4], [5]. GIS-based spatial analysis supports decision-making by identifying flood-prone areas and providing spatial information for disaster mitigation planning. Among various GIS techniques, the Weighted Overlay method is considered suitable for regional flood hazard assessment because it allows several environmental parameters to be integrated into a composite flood hazard index using standardized weights and scores [8], [9].

Flood hazard maps alone, however, are insufficient to support effective disaster risk reduction. During flood emergencies, communities need safe, accessible evacuation routes that minimise travel distance while avoiding hazardous areas. GIS-based Network Analysis provides an effective approach for determining optimal evacuation routes by evaluating road connectivity and accessibility between flood-prone areas and designated evacuation locations [5], [7]. Integrating flood hazard mapping with evacuation route planning therefore provides more comprehensive information for emergency preparedness and disaster management than conducting these analyses independently.

Several previous studies have successfully applied GIS for flood hazard mapping using Weighted Overlay, Multicriteria Decision Analysis (MCDA), or Analytical Hierarchy Process (AHP). Other studies have focused on optimizing evacuation routes using Network Analysis. However, relatively few studies have integrated flood hazard assessment and evacuation route planning into a single spatial framework, particularly for urban flood management in Malang City [8]–[10]. This limitation indicates the need for an integrated approach that not only identifies flood-prone areas but also supports evacuation planning during flood events.

Accordingly, this study integrates Weighted Overlay analysis based on four environmental parameters—rainfall, land use, slope, and soil type—with GIS-based Network Analysis to produce flood hazard maps and optimal evacuation routes in Malang City. The findings are expected to provide practical spatial information for disaster mitigation, urban planning, and emergency response while supporting sustainable flood risk management.

1.2. Literature Review

1.2.1. Urban Flood Hazard

flooding has become one of the most significant environmental challenges in rapidly developing cities, driven by the combined

effects of climate variability, urban expansion, and land-cover changes. Unlike riverine flooding, urban floods are strongly associated with increasing impervious surfaces, insufficient drainage capacity, and uncontrolled land-use conversion, which reduce infiltration and accelerate surface runoff [1], [6], [8]. These conditions increase both the frequency and severity of inundation, particularly in densely populated urban areas.

Recent studies have shown that flood occurrence is controlled by the interaction of several physical and anthropogenic factors rather than by rainfall alone. Consequently, flood hazard assessment requires a multi-parameter approach capable of representing the spatial variability of environmental conditions [8]–[10]. This understanding has encouraged the widespread adoption of Geographic Information Systems (GIS) as a spatial decision-support tool for flood hazard assessment.

1.2.2. Geographic Information Systems (GIS)

Geographic Information Systems (GIS) have become an essential technology for analysing spatial phenomena because they enable the collection, storage, integration, processing, analysis, and visualization of geographically referenced data [4], [7]. In flood hazard studies, GIS facilitates the integration of multiple thematic layers such as rainfall, land use, topography, soil characteristics, and hydrological information into a unified analytical framework.

Compared with conventional mapping techniques, GIS provides greater efficiency in spatial data processing and supports evidence-based decision making through accurate thematic mapping [4], [5]. Its ability to combine multiple environmental datasets has made GIS one of the most widely adopted tools for flood hazard assessment, disaster mitigation planning, and urban spatial management.

1.2.3. Geographic Information Systems (GIS)

The selection of environmental parameters plays a crucial role in determining the reliability of flood hazard assessment. Previous studies consistently identify rainfall, land use, slope, and soil type as the principal factors influencing flood susceptibility because each parameter affects runoff generation through different hydrological processes [6], [8].

Rainfall is the primary triggering factor, determining the volume of water entering the watershed system [3], [6]. Land use influences infiltration capacity through the proportions of impervious and pervious surfaces, with urbanised areas generally generating higher runoff than vegetated areas [8], [9]. Slope controls runoff velocity and water accumulation, while soil type affects infiltration according to soil permeability [6]. Therefore, integrating these four parameters provides a more comprehensive representation of flood hazard than analysing each factor independently.

1.2.4. Flood Hazard Mapping Methods

Various methods have been developed to assess flood hazards, including hydrodynamic modelling, Analytical Hierarchy Process (AHP), Multicriteria Decision Analysis (MCDA), machine learning techniques, and GIS-based Weighted Overlay analysis [8].

Hydrodynamic models such as HEC-RAS are capable of simulating flood depth and inundation extent with high accuracy. However, these models require detailed hydraulic information,

river cross-section data, and extensive calibration, making them less practical for regional-scale studies with limited data availability. Machine learning algorithms offer high predictive power but depend on large historical datasets and model training procedures that may not be available in all study areas.

AHP and MCDA have been widely adopted because they enable the integration of multiple flood-related parameters through weighted decision-making. Nevertheless, these approaches often rely heavily on expert judgement, introducing subjectivity into the weighting process. In contrast, GIS-based Weighted Overlay analysis offers a practical, transparent approach by integrating classified environmental parameters into a single flood hazard index using standardised weights and scores [9], [10]. This method is particularly suitable for regional flood hazard assessment because it can be implemented efficiently using commonly available spatial datasets while producing outputs that are easily interpreted by decision-makers.

1.2.5. GIS-Based Network Analysis for Evacuation Planning

Flood disaster management should not only identify hazard-prone areas but also provide practical guidance for emergency response. GIS-based Network Analysis enables the evaluation of transportation networks to determine optimal evacuation routes based on road connectivity, travel distance, and accessibility [5], [7].

Previous studies have demonstrated that Network Analysis improves evacuation efficiency by identifying the shortest path between vulnerable locations and designated evacuation points. However, many studies optimise evacuation routes without accounting for the spatial distribution of flood hazards. Consequently, recommended routes may still pass through highly vulnerable areas, reducing evacuation safety. Integrating flood hazard maps with Network Analysis therefore provides a more comprehensive framework for disaster mitigation by considering both route efficiency and hazard avoidance.

1.2.6. Research Gap

Although numerous studies have investigated flood hazard mapping and evacuation route optimization, several research gaps remain:

1. Most studies focus only on flood susceptibility mapping without integrating evacuation planning.
2. Studies on evacuation routes generally emphasise the shortest path while overlooking flood hazards along the route.
3. Research integrating Weighted Overlay and GIS-based Network Analysis within a single framework remains limited, particularly for the urban environment of Malang City.
4. Existing studies often use broader regional scales, whereas city-scale assessments are required to support local disaster management and urban planning.

1.2.7. Novelty

The novelty of this research lies in integrating Weighted Overlay analysis of four environmental parameters (rainfall, land use, slope, and soil type) with GIS-based Network Analysis to produce both flood hazard maps and optimal evacuation routes

for Malang City. Unlike previous studies that examined flood susceptibility or evacuation planning separately, this study combines both analyses within a single spatial framework to support disaster mitigation, emergency preparedness, and sustainable urban planning

1.3. Research Objective

This study aims to:

1. Identify flood-prone areas in Malang City using a GIS-based Weighted Overlay approach by integrating rainfall, land use, slope, and soil type.
2. Determine optimal evacuation routes from flood-prone areas to designated evacuation points using GIS-based Network Analysis.
3. Provide spatial information that supports flood disaster mitigation and urban planning in Malang City.

2. MATERIALS AND METHODS

2.1. Study Area

This study was conducted in Malang City, East Java Province, Indonesia. These districts were selected because they represent rapidly developing urban areas with high population density, intensive land-use change, and recurring flood events. Rapid urban expansion has increased impervious surfaces while reducing natural infiltration areas, resulting in higher surface runoff during the rainy season.

Geographically, Malang City is located between 7°44'–8°00' South Latitude and 112°31'–112°39' East Longitude. The study area is characterised by diverse topography, ranging from relatively flat urban plains to moderately sloping terrain. Variations in land use, rainfall distribution, and soil characteristics make the study area suitable for multi-parameter flood hazard assessment. The administrative boundaries of the study area are presented in Figure 1.

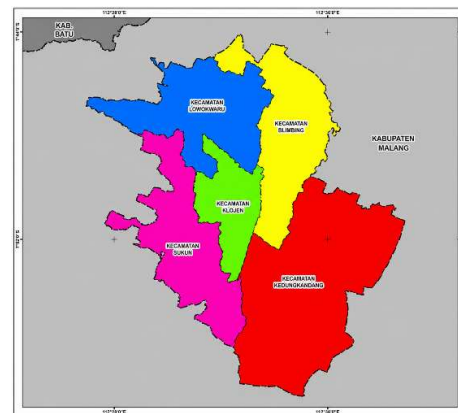


Fig. 1 Study Area of Malang City

2.2. Research Data

Flood hazard assessment was performed using spatial and non-spatial datasets obtained from government agencies and open geospatial sources. All datasets were projected into the same coordinate reference system and preprocessed before spatial analysis

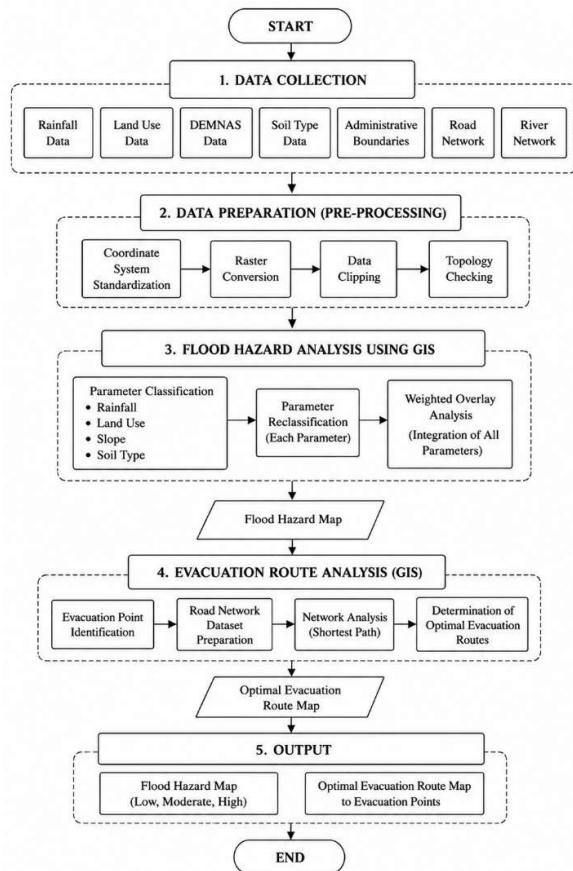
Table 1. Research Data

Data	Source	Purpose
Administrative boundary	BIG / BPS	Study area boundary
Rainfall	BMKG	Rainfall parameter
Land use	BIG / RDTR Kota Malang	Land use parameter
DEMNAS	BIG	Slope analysis
Soil type	BBSDLP	Soil parameter
Road network	OpenStreetMap	Network Analysis
River network	BIG	Flood analysis
Evacuation locations	Field survey / BPBD	Destination points

All spatial data were processed in ArcGIS Pro using spatial analysis tools, including raster processing, reclassification, weighted overlay, and Network Analysis.

2.3. Research Workflow

The research methodology consisted of four major stages:

**Fig. 2** Research Workflow

2.4. Flood Hazard Analysis

Flood hazard analysis was conducted using the Weighted Overlay method by integrating four environmental parameters: rainfall, land use, slope, and soil type. Each parameter was classified into several categories according to its contribution to flood susceptibility and assigned a corresponding score. The classified raster layers were subsequently combined using the Weighted Overlay tool available in ArcGIS. *Land Use Analysis*

The overall flood hazard index was calculated using the following equation:

$$FHI = \sum_{i=1}^n (w_i \cdot s_i)$$

where:

- **FHI** = Flood Hazard Index
- **W** = Weight of each parameter
- **S** = Score of each parameter
- **n** = Number of parameters

The resulting flood hazard index was classified into three categories:

- Low
- Moderate
- High

2.4.1. Rainfall Analysis

Rainfall data were obtained from BMKG and processed to represent the spatial distribution of annual rainfall across the study area. Rainfall values were classified into several classes according to flood susceptibility levels. Areas with higher rainfall intensity had higher flood susceptibility scores because greater precipitation increases runoff.

Table 2. Rainfall Classification

No.	Rainfall Class	Rating	Weight	Score
1	>2500 mm (Very Wet)	5	5	25
2	2001–2500 mm (Wet)	4	5	20
3	1501–2000 mm (Moderately Wet)	3	5	15
4	1001–1500 mm (Dry)	2	5	10
5	<1000 mm (Very Dry)	1	5	5

2.4.2. Land Use Analysis

Land-use data were classified into several categories including residential areas, agricultural land, plantations, forests, and open land. Urban land uses dominated by impervious surfaces were assigned higher scores due to their limited infiltration capacity, whereas vegetated land covers received lower scores.

2.4.3. Slope Analysis

Slope information was derived from DEMNAS using the Slope tool in ArcGIS. The resulting slope values were classified into several categories representing terrain steepness. Areas with relatively gentle slopes tend to retain surface water longer and therefore exhibit higher flood susceptibility.

Table 3. Land Use Classification

No.	Land Use	Score
1	Rice Fields, Bare Land	90
2	Agricultural Land, Dryland Farming, Residential Areas	70
3	Shrubs, Bushes, Grassland	50
4	Plantation	30
5	Forest	20

Table 4. Slope Classification

No.	Slope (%)	Description	Weight	Score
1	0 – 3	Flat	0.25	90
2	3 – 8	Gently Undulating	0.25	75
3	8 –15	Undulating	0.25	40
4	15 –30	Gently Hilly	0.25	20

2.4.4. Soil Analysis

Soil type data were obtained from BBSDLP and classified according to soil permeability. Soil types with lower infiltration capacity were assigned higher flood susceptibility scores because they generate greater surface runoff during rainfall events.

Table 5. Soil Type Classification

No.	Soil Type	Class	Rating	Weight	Score
1	Alluvial, Planosol, Gray Hydromorphic, Groundwater Laterite	Very Fine	5	4	20
2	Latosol	Fine	4	4	16
3	Brown Volcanic Soil and Mediterranean Soil	Medium	3	4	12
4	Andosol, Podzolic, Podzol	Coarse	2	4	8
5	Regosol, Lithosol, Grumosol, Rendzina	Very Coarse	1	4	4

2.4.5. Weighted Overlay

The classified parameter layers were integrated using the Weighted Overlay tool in ArcGIS. Each parameter was assigned a weight based on its relative contribution to flood occurrence, following the weighting scheme established in the TA. The overlay analysis produced a Flood Hazard Index raster, which was subsequently classified into low-, moderate-, and high-hazard zones for spatial interpretation.

2.5. Evacuation Route Analysis

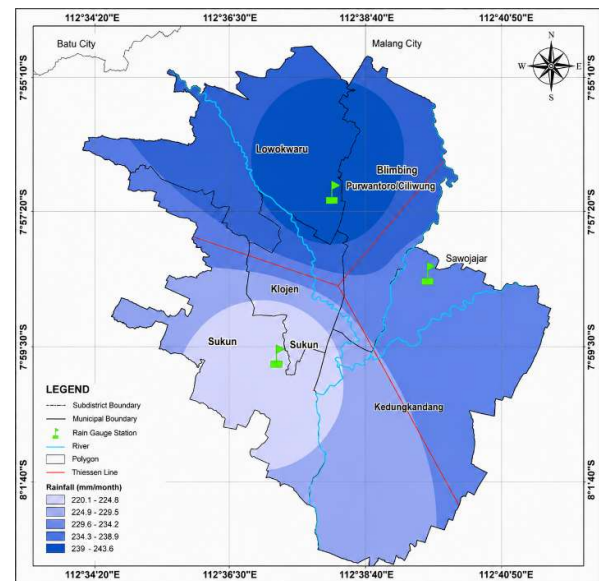
Optimal evacuation routes were determined using the Network Analyst extension in ArcGIS. The road network dataset was prepared by establishing network topology and connectivity. Flood-prone residential areas were defined as origin points, while designated evacuation locations served as destination points.

The shortest path algorithm was applied to identify routes with minimum travel distance through the existing road network. The resulting routes were evaluated alongside the flood hazard map to ensure that evacuation paths minimise exposure to high-hazard areas. The final output consists of spatially optimized evacuation routes connecting vulnerable areas to designated evacuation locations.

3. RESULT AND DISCUSSION

3.1. Rainfall Distribution Analysis

Rainfall is one of the primary factors influencing flood occurrence because it directly affects the volume of surface runoff generated during precipitation events. Based on rainfall data from BMKG, the spatial distribution of rainfall in the study area shows varying precipitation levels across Blimbing, Lowokwaru, and Sukun Districts. The rainfall layer was reclassified into flood-susceptibility classes according to the criteria outlined in the Materials and Methods section.

**Fig 3.** Spatial Distribution of Rainfall

The analysis indicates that areas with higher rainfall intensity generally exhibit greater flood susceptibility due to increased runoff volume during heavy rainfall events. Nevertheless, rainfall alone does not determine flood occurrence because inundation is also influenced by land use, topography, and soil characteristics. Similar findings have been reported in previous GIS-based flood hazard studies, which emphasise that rainfall should be analysed alongside other environmental parameters to obtain a comprehensive assessment of flood susceptibility [3], [8], [9].

3.2. Land Use Analysis

Land use significantly affects infiltration capacity and runoff generation. Urbanised areas dominated by residential areas, commercial buildings, and transportation infrastructure generally produce higher runoff due to extensive impervious surfaces. In contrast, agricultural land and vegetated areas retain greater infiltration capacity and therefore contribute less to flood generation.

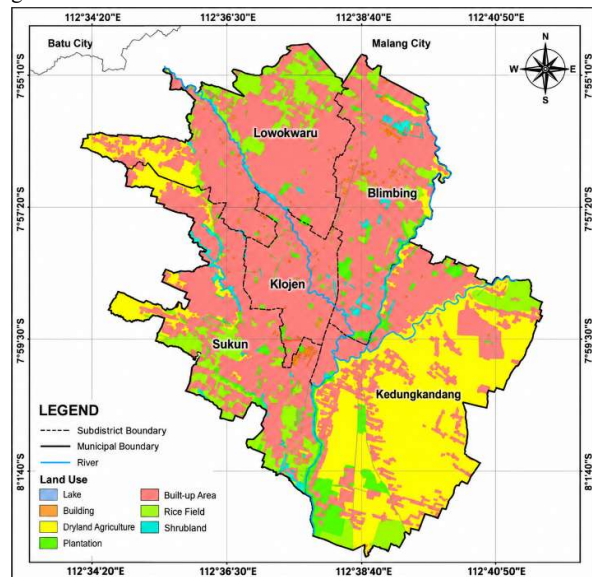


Fig 4. Land Use Map

The spatial analysis shows that residential areas occupy the largest proportion of the study area, indicating extensive urban development. The dominance of built-up land reduces natural infiltration and increases runoff accumulation during rainfall events. Consequently, these areas exhibit higher flood susceptibility than vegetated land covers. This observation is consistent with previous studies reporting that rapid urbanization is a major contributor to increasing flood hazards in urban environments [8]–[10].

3.3. Slope Analysis

Slope controls the movement and accumulation of surface runoff. Gentle slopes generally retain water longer, increasing the likelihood of inundation, whereas steeper terrain promotes faster runoff and shorter water retention times.

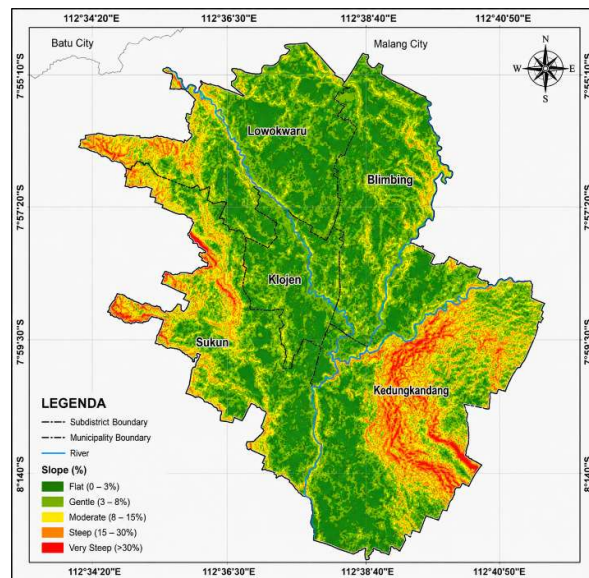


Fig. 5. Slope Classification Map

The slope analysis indicates that a considerable portion of the study area consists of relatively flat terrain. These areas exhibit greater flood susceptibility because water tends to accumulate rather than flow rapidly downstream. The relationship between gentle topography and flood occurrence has also been reported in previous hydrological studies, confirming that slope is an important parameter in flood hazard assessment [6], [9]

3.4. Soil Type Analysis

Soil permeability strongly influences infiltration and runoff generation. Soil types with low permeability reduce infiltration capacity, resulting in greater surface runoff during rainfall events

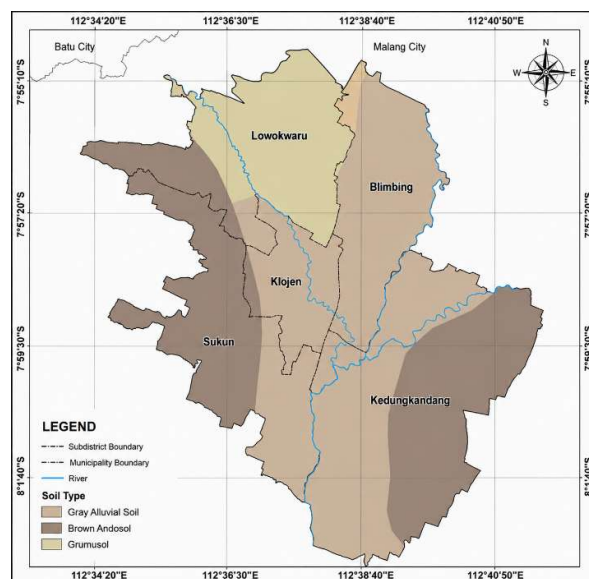


Fig 6. Soil Type Map

The dominant soil types in the study area exhibit different infiltration characteristics, resulting in varying levels of flood susceptibility. Areas with relatively low-permeability soils tend to experience greater runoff accumulation and therefore have higher flood susceptibility scores. These findings support previous research highlighting soil characteristics as one of the principal environmental variables in flood hazard mapping [6], [8].

3.5. Flood Hazard Mapping

Flood hazard mapping was produced by integrating rainfall, land use, slope, and soil type through the Weighted Overlay method in ArcGIS. The overlay analysis generated a composite Flood Hazard Index, which was subsequently classified into three hazard categories: low, moderate, and high.

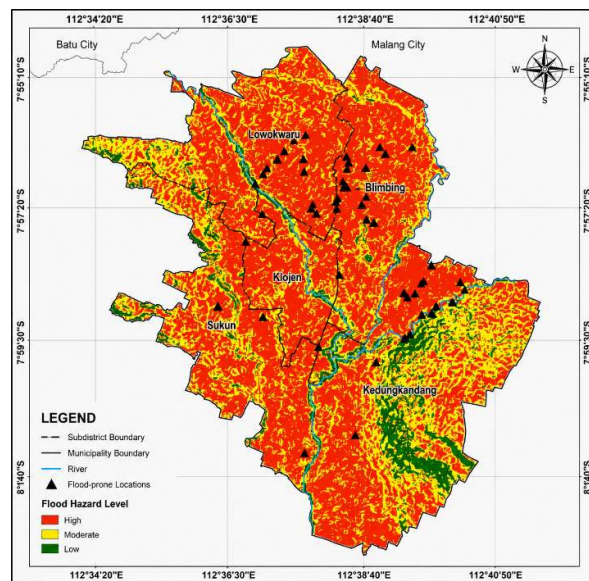


Fig 7. Flood Hazard Map

Table 6. Flood Hazard Classification

Hazard Level	Area (Ha)	Percentage (%)
Low	2114.56	19,04
Moderate	2771.33	24,96
High	6222.81	56
Total	11108.7	100

The flood hazard map indicates that high-hazard areas are primarily concentrated in densely urbanized locations characterized by intensive residential development, relatively flat topography, and limited infiltration capacity. Conversely, areas with greater vegetation cover and steeper slopes tend to fall into the low-hazard category. These findings demonstrate that flood susceptibility is governed by the combined influence of multiple environmental parameters rather than by rainfall alone. Similar conclusions have been reported in previous GIS-based flood hazard assessments employing Weighted Overlay analysis [8]–[10].

3.6. Flood Hazard Validation

To evaluate the reliability of the flood hazard map, the resulting flood hazard zones were compared with historical flood

reports obtained from BPBD Kota Malang. The comparison indicates that most recorded flood events occur in areas classified as high flood hazard, particularly in the districts of Blimbing, Lowokwaru, and Sukun. This consistency suggests that the Weighted Overlay approach adequately represents the spatial distribution of flood-prone areas in the study area.

Although no quantitative accuracy assessment was performed due to the limited availability of detailed flood inventory data, the comparison with historical flood records provides qualitative evidence supporting the validity of the generated flood hazard map. Future studies are recommended to incorporate field observations, flood depth measurements, and hydrodynamic simulations to improve the accuracy and validation of flood hazard assessment.

3.7. Evacuation Route Analysis

Following the identification of flood-prone areas, GIS-based Network Analysis was employed to determine optimal evacuation routes connecting vulnerable locations to designated evacuation points. The analysis considered road connectivity and travel distance to generate the shortest accessible routes.

The evacuation routes were developed using the existing road network to ensure efficient movement during flood emergencies. Route selection prioritized direct access while maintaining connectivity between residential areas and evacuation points. The generated network minimizes travel distance and provides clear directional guidance for residents. These routes support emergency response planning by improving accessibility and reducing evacuation time. The resulting maps serve as practical decision-support tools for disaster preparedness and flood risk management.

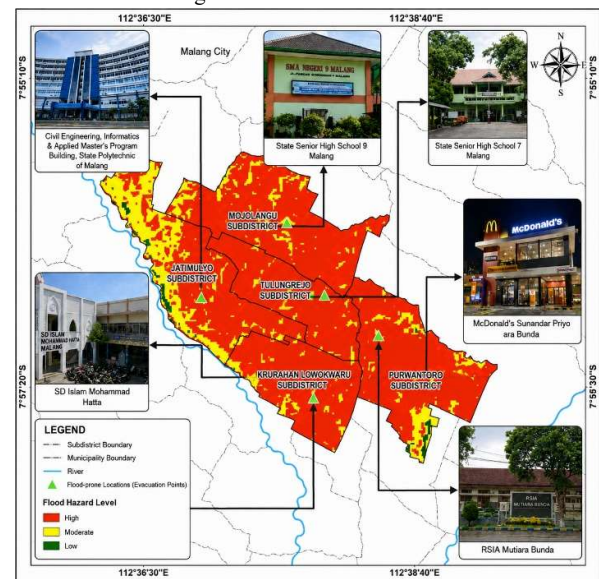


Fig.8. Evacuation Route Map

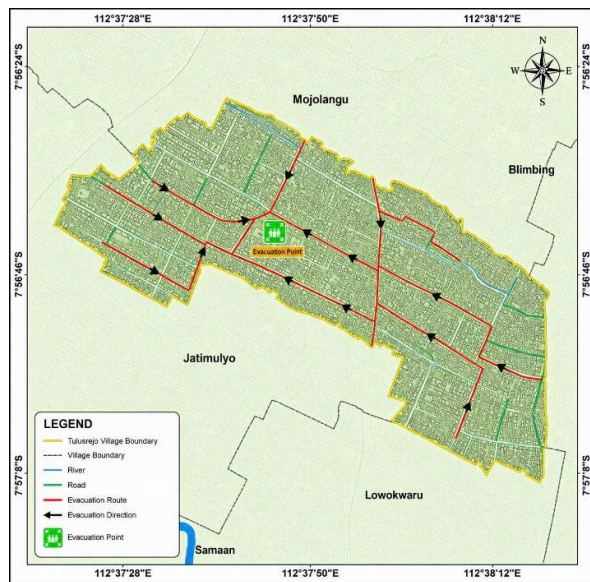


Fig.9. Flood Evacuation Route Map Tulusrejo urban village

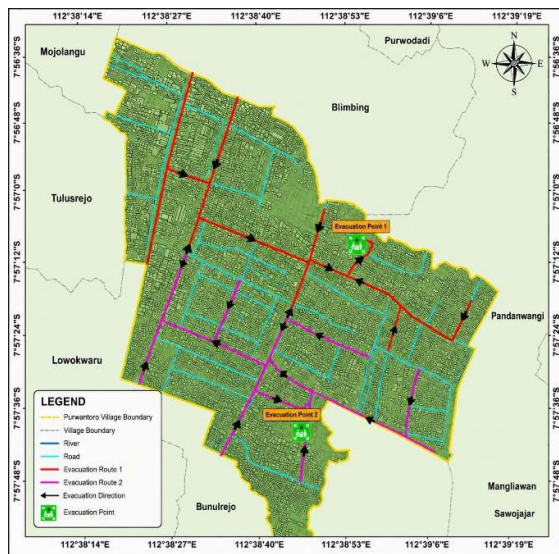


Fig.10. Flood Evacuation Route Map Purwanto urban village

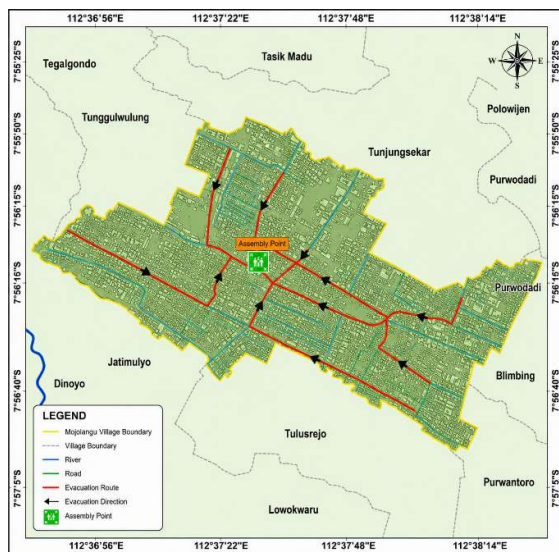


Fig.11. Flood Evacuation Route Map Mojolangu urban village

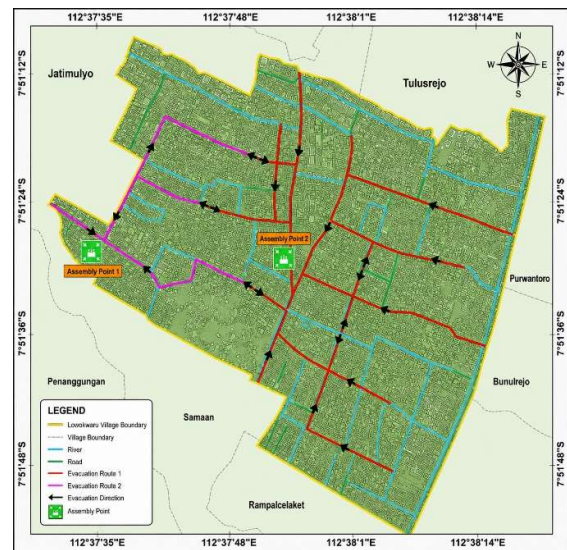


Fig.12. Flood Evacuation Route Map Lowokwaru urban village

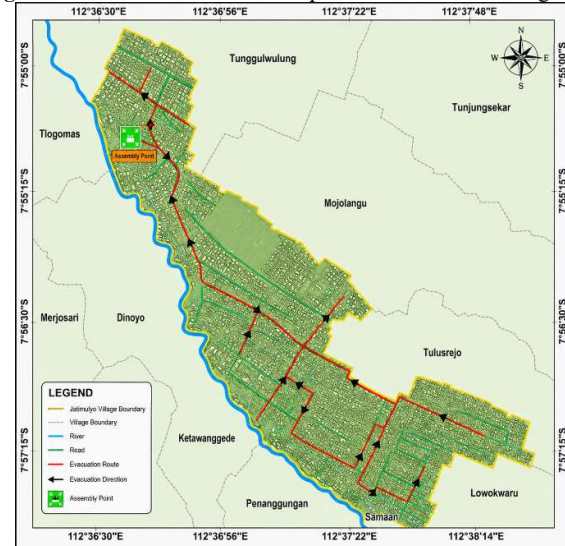


Fig.13. Flood Evacuation Route Map Jatimulyo urban village.

The resulting evacuation network provides practical guidance for emergency response by directing residents from flood-prone areas toward designated evacuation locations through efficient road corridors. Integrating flood hazard mapping with Network Analysis enhances evacuation planning by allowing route selection to consider both transportation efficiency and the spatial distribution of flood hazards. This integrated approach offers greater practical value than analyses that focus solely on hazard mapping or route optimisation [5], [7], [10].

3.8. Discussion

The results demonstrate that integrating rainfall, land use, slope, and soil type through the Weighted Overlay method provides a comprehensive representation of flood susceptibility in Malang City. Among these parameters, land use and slope exert a particularly strong influence on the spatial distribution of flood hazards, as highly urbanised, relatively flat areas consistently exhibit higher hazard levels.

Compared with previous studies that focused exclusively on flood susceptibility assessment, this research extends the application of GIS by incorporating Network Analysis to support

evacuation planning. The integrated framework enables not only the identification of flood-prone areas but also the determination of practical evacuation routes, thereby providing more comprehensive spatial information for disaster mitigation.

The findings are expected to assist local governments in prioritizing flood mitigation measures, improving emergency preparedness, and supporting evidence-based urban planning. Nevertheless, the present study is limited by the availability and spatial resolution of input datasets. Future research could integrate hydrodynamic modelling, real-time rainfall observations, and flood depth simulations to improve prediction accuracy and operational flood management.

The integration of the Weighted Overlay method and GIS-based Network Analysis proved an effective approach to supporting flood disaster mitigation at the urban scale. The Weighted Overlay technique integrates multiple environmental parameters, including rainfall, land use, slope, and soil type, into a single flood hazard index, providing a practical representation of spatial flood susceptibility. Furthermore, Network Analysis complements the hazard assessment by identifying the shortest and most accessible evacuation routes through the existing road network. Compared with more computationally intensive hydrodynamic models, this approach requires fewer input datasets, is easier to implement, and can be readily adopted by local governments for regional disaster planning and decision-making.

Despite these advantages, several limitations should be acknowledged. First, the Digital Elevation Model (DEMNAS) used in this study has a spatial resolution that may not fully capture micro-topographic variations, particularly in densely built urban environments where small differences in elevation can significantly influence local flood accumulation. Second, the road network derived from OpenStreetMap (OSM) relies on voluntary geographic information, which may contain incomplete or outdated road attributes in some areas. In addition, this study did not incorporate hydrodynamic or hydraulic modelling to simulate flood depth, flow velocity, or temporal inundation dynamics. Consequently, the generated flood hazard map represents relative flood susceptibility based on spatial environmental characteristics rather than the physical behaviour of flood events during extreme rainfall.

The findings of this study are generally consistent with previous GIS-based flood hazard assessments, which have demonstrated that urban areas characterized by extensive impervious surfaces, gentle slopes, and limited infiltration capacity are more susceptible to flooding. Similar studies have also reported that integrating spatial flood hazard mapping with network-based evacuation analysis enhances emergency preparedness by improving accessibility to safe evacuation locations. Therefore, although the present study adopts a relatively simple GIS-based approach, the proposed framework provides practical spatial information that can support disaster risk reduction and urban planning in Malang City. Future research is recommended to integrate higher-resolution elevation data, hydrodynamic modelling, real-time rainfall observations, and dynamic traffic conditions to improve the accuracy and operational applicability of flood hazard assessment and evacuation route planning.

4. CONCLUSION

This study demonstrated the application of Geographic Information Systems (GIS) for flood hazard assessment and evacuation route planning in Malang City, East Java, Indonesia. Flood hazard mapping was performed by integrating rainfall, land use, slope, and soil type through the Weighted Overlay method, while evacuation routes were determined using GIS-based Network Analysis. The results indicate that flood hazards in the study area are influenced by the combined interaction of environmental parameters rather than a single factor. Urban areas characterised by intensive land development, relatively flat terrain, and limited infiltration capacity are more susceptible to flooding. The generated flood hazard map successfully classified the study area into low-, moderate-, and high-hazard zones, providing spatial information to support flood risk assessment and disaster mitigation planning. Furthermore, the application of Network Analysis enabled the identification of optimal evacuation routes connecting flood-prone areas with designated evacuation points through the existing road network. The integration of flood hazard mapping and evacuation route analysis provides a more comprehensive approach to disaster management than conducting these analyses separately. This integrated spatial framework can assist local governments in improving emergency preparedness, optimizing evacuation planning, and supporting sustainable urban development. Future studies are recommended to incorporate additional parameters, such as drainage capacity, river discharge, and flood depth, and to use high-resolution hydrodynamic modelling to improve flood hazard prediction and evacuation planning.

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