

## Original Article

# Flood Risk Mapping and Evacuation Route Planning Using Network Analysis in Pasar Kliwon, Surakarta City, Indonesia

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## ABSTRACT

The Pasar Kliwon subdistrict in Surakarta is one of the areas vulnerable to flooding due to heavy rainfall, land-use changes, and inadequate drainage systems. These conditions highlight the need for flood vulnerability mapping and the planning of effective evacuation routes. This study aims to map flood vulnerability levels and determine optimal evacuation routes using a Geographic Information System (GIS) approach. Overlay and scoring methods were used to analyze vulnerability based on topographic parameters, land use, rainfall, and soil conditions, while network analysis was applied to determine evacuation routes by considering accessibility and travel time. Analysis results indicate that Pasar Kliwon Subdistrict is divided into three vulnerability levels: low (176 ha), moderate (277 ha), and high (38 ha), with the majority of high-risk areas located along the banks of the Bengawan Solo River. Additionally, 11 evacuation routes were identified, connecting 10 assembly points to 9 evacuation shelters. Evacuation routes were selected based on the shortest distance and facility capacity, with several points serving as primary evacuation hubs. This study underscores the importance of utilizing GIS to support flood disaster mitigation and the development of safe and targeted evacuation strategies in densely populated urban areas.

## KEYWORDS

Floods,  
Vulnerability  
Mapping,  
Evacuation  
Routes, GIS,  
Network Analysis

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## INTRODUCTION

Flooding is a disaster characterized by the overflow of water in open channels, causing water levels to exceed the capacity of the riverbed or flood control structures (floodgates) (Plamonia & Merapi, 2022). Indonesia is an archipelagic nation situated in the tropics with high rainfall, making it vulnerable to hydrometeorological disasters, one of which is flooding (D. Setiawan, 2021; H.

Setiawan et al., 2020). In disaster risk assessments, hydrological analysis is a critical component because high rainfall intensity generally correlates directly with the volume of water that a river basin system (RBS) can accommodate (Islami, 2022; Serastiwati et al., 2020; Sibagariang and Saputra, 2021). The city of Surakarta itself is influenced by the Bengawan Solo River Basin,

whose headwaters are located at the Gajah Mungkur Reservoir in Wonogiri, and is further supported by sub-basins that drain into that river (Candraningtyas et al., 2023; Rahmawati et al., 2019). These conditions make Pasar Kliwon District one of the areas vulnerable to flooding, especially when the river basin's storage capacity cannot keep pace with heavy rainfall (Surakarta BPBD, 2022; Pramitha et al., 2020).

Administratively, Pasar Kliwon Subdistrict consists of 10 urban villages and covers an area of 4.88 km<sup>2</sup> (Surakarta City Statistics Agency, 2024). In February, over a hundred homes in Pasar Kliwon Subdistrict were flooded by the overflowing Bengawan Solo River (NV, 2025). This subdistrict is characterized by an urban area with high population density and an inadequate drainage system. Additionally, the ongoing increase in land-use conversion has reduced the soil's ability to absorb rainwater. Generally, land-use changes not supported by effective water management systems lead to frequent flooding in metropolitan areas (Rosytha & Taufik, 2015; Wijayanti et al., 2025). This phenomenon indicates that existing disaster mitigation systems remain suboptimal in addressing flood issues in this region (Makalew & Mandang, 2020). In flood disaster mitigation efforts, mapping flood-prone areas and planning effective evacuation routes are critical aspects that require attention. Poorly planned evacuation routes can exacerbate the impact of floods on public safety, particularly for vulnerable groups such as children, the elderly, and people with disabilities (Cut Liliiza Yusra et al., 2024). Therefore, a spatial data-based approach is needed to map flood-prone areas and determine optimal evacuation routes (Rakuasa et al., 2022).

Recent research demonstrates a combined approach involving GIS-based spatial analysis, multi-criteria decision analysis (MCDA), hydrodynamic modeling, and network analysis to produce more realistic flood vulnerability maps and evacuation routes (Zhang et

al., 2025). GIS-MCDA studies have successfully mapped flood vulnerability at the urban scale by incorporating physical factors (elevation, slope, drainage), hydrology, and infrastructure exposure, thereby generating mitigation priority maps that can be used for urban planning (Allafta & Opp, 2021). For determining evacuation routes, the Network Analyst approach and time-based accessibility analysis have been used to select the fastest/safest routes to assembly points or shelters, taking into account the spatio-temporal flood conditions that affect evacuation speed (Parajuli et al., 2023). Studies on social vulnerability emphasize the need to incorporate socio-demographic indicators (children, the elderly, people with disabilities, population density, access to healthcare facilities) because vulnerable groups have different evacuation needs and risk being overlooked by general evacuation plans (Comfort, 2016).

This study aims to map flood-prone areas and determine optimal evacuation routes in Pasar Kliwon Subdistrict using Geographic Information System (GIS) methods with overlay and scoring techniques as well as Network Analysis. The innovation of this study lies in the integration of overlay and scoring methods with Network Analysis in mapping flood-prone areas and determining evacuation routes in Pasar Kliwon Subdistrict. The overlay and scoring methods were used to identify flood-prone areas based on geospatial parameters such as elevation, land use, rainfall, and drainage conditions (Fauzi, 2022). Meanwhile, Network Analysis was used to determine optimal evacuation routes by considering factors such as accessibility, road conditions, and travel time across various flood scenarios. With this method, analysis of various parameters can be conducted more accurately. The results of this study are expected to serve as a reference for local governments and relevant agencies in formulating disaster mitigation policies and planning more optimal evacuation routes (Wagistina et al., 2022).

## METHOD

### Research Location

This study was conducted in Pasar Kliwon Subdistrict, Surakarta City, Central Java Province. Calculations using GIS software indicate that the subdistrict covers an area of approximately 491 hectares. Meanwhile, data recorded in an official publication by the Central Statistics Agency of Surakarta City provides a different figure, stating that the subdistrict covers an area of 4.88 km<sup>2</sup> or the equivalent of 488 hectares (BPS Kota

Surakarta, 2024). In this study, the area used is based on the GIS calculation results. The selection of Pasar Kliwon Subdistrict as the study location was based on its geographical characteristics, which include a relatively high level of flood vulnerability. Geographically, this subdistrict is situated along the Bengawan Solo River, which frequently overflows during heavy rainfall, thereby posing a risk of flooding in the surrounding residential areas.

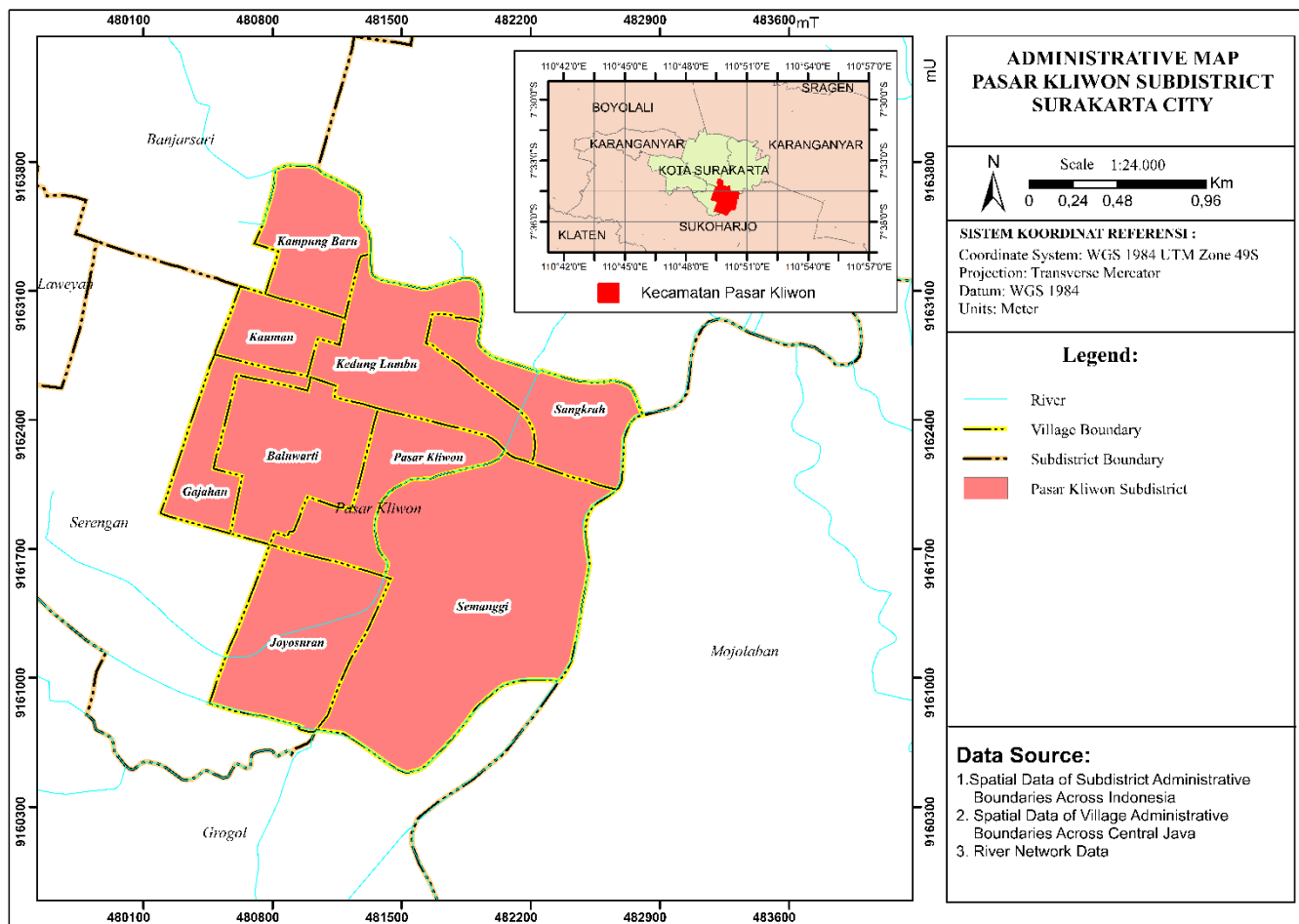


Figure 1. Map of the Pasar Kliwon District Administration

**Research Approach**

The approach used was a quantitative descriptive method with spatial analysis based on Geographic Information Systems (GIS) using ArcGIS software. The quantitative focus was used to analyze flood vulnerability levels and determine evacuation points, while the spatial analysis was used to map flood-prone areas and evacuation routes in

Pasar Kliwon Subdistrict, Surakarta City.

**Data Collection Tools**

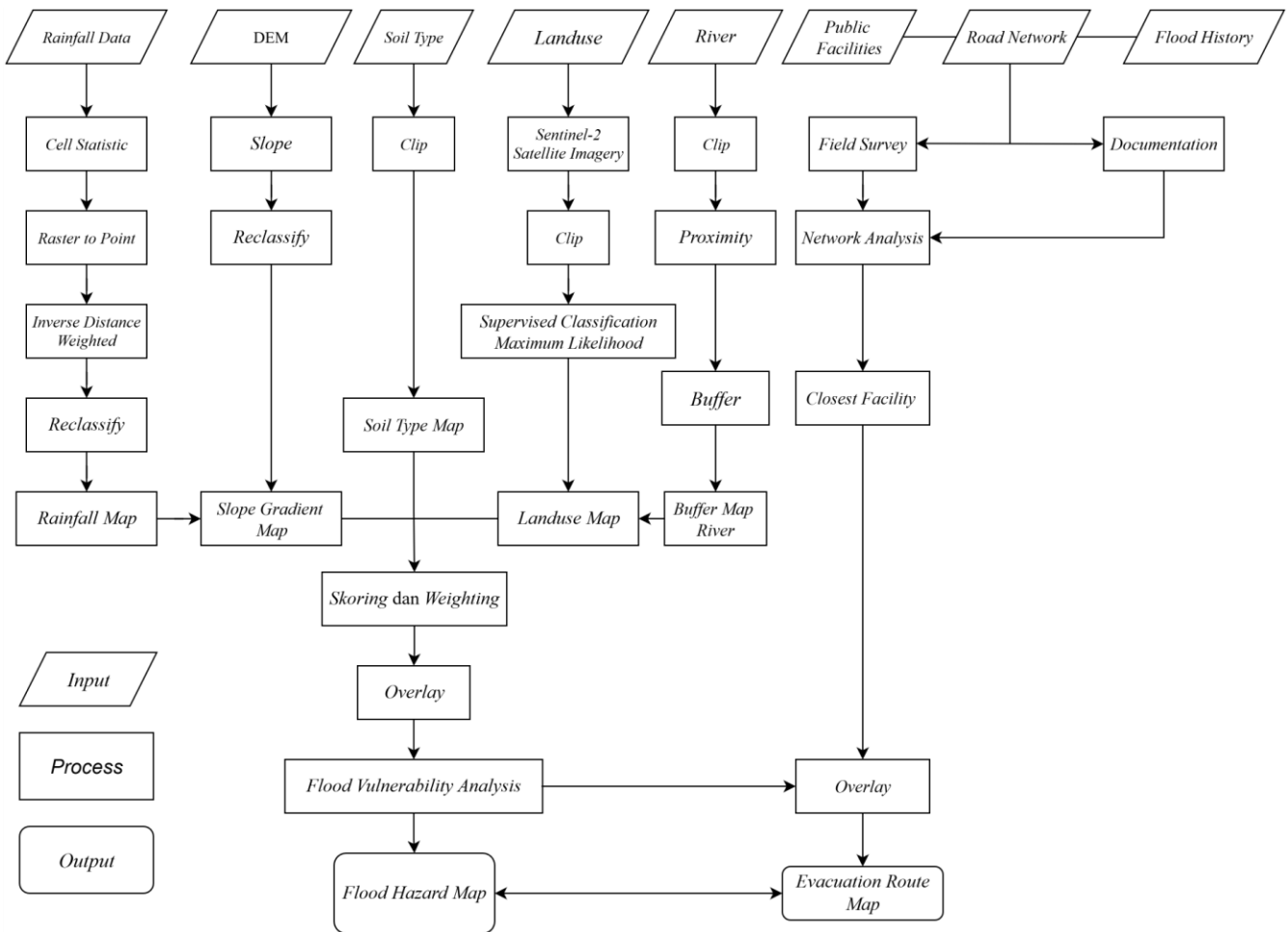
This study utilizes various types of spatial and non-spatial data sourced from relevant agencies. These data play a crucial role in the process of analyzing flood vulnerability levels and determining evacuation routes in Pasar Kliwon Subdistrict. Details regarding the data sources and materials used in this study can be found in Table 1.

Table 1. Materials and Data Sources

No	Data	Data Types	Sources:	Data Access
1	Topographic Map / DEM	Sekunder	DEMNAS	<a href="https://tanahair.indonesia.go.id/portal-web/unduh">https://tanahair.indonesia.go.id/portal-web/unduh</a>
2	2025 Rainfall Data	Sekunder	CHIRPS	<a href="https://www.chc.ucsb.edu/data/chirps">https://www.chc.ucsb.edu/data/chirps</a>
3	2025 Land Use Map	Sekunder	Sentinel-2 Satellite Imagery (Google Earth Engine)	<a href="https://earthengine.google.com/">https://earthengine.google.com/</a>
4	Soil Type Map	Sekunder	DPUPR, BIG	<a href="https://geoportal.big.go.id/">https://geoportal.big.go.id/</a>

No	Data	Data Types	Sources:	Data Access
5	Road and Transportation Map	Sekunder	OpenStreetMap / BIG	<a href="https://www.openstreetmap.org/">https://www.openstreetmap.org/</a>
6	Administrative Map of Pasar Kliwon Subdistrict	Sekunder	BPS / BIG	<a href="https://geoportal.big.go.id/">https://geoportal.big.go.id/</a>
7	Historical Flood Event Data	Sekunder	BPBD Surakarta / Local Media	<a href="https://bpbd.surakarta.go.id/portal/layanan">https://bpbd.surakarta.go.id/portal/layanan</a>
8	Location Coordinate Data (GPS)	sekunder	Google Earth Pro	Aplikasi <i>Google Earth Pro</i>

**Research Procedures**



**Figure 2.** Research Flowchart

**Data Analysis**

Data analysis in this study was conducted spatially using a Geographic Information System (GIS) with ArcGIS software. Flood vulnerability levels were determined through a scoring and weighting method, which involved assigning values to each relevant parameter, summing

them using the Field Calculator feature, and then performing an overlay to generate a map of flood-prone areas. This process was further enhanced with buffering techniques based on data from Pasar Kliwon Subdistrict and community survey results. Scoring and weighting were performed after each variable was classified based on its values, with weights and scores determined using

an expert judgment approach that drew upon the views of experts as well as the results previous research (Rakuasa et al., 2022). In this study, the primary reference is drawn from the journal article by Kusumo & Nursari (2016),

which identifies six key variables in determining flood risk levels: slope gradient, land use type, rainfall intensity, soil type, elevation, and the distance of the area from the river (buffer zone).

**Table 2.** Flood Vulnerability Variables

No	Parameter Map	Classification/Classes	Skor	Bobot (%)
1	Slope Map	0–8% (Flat)	9	10
		8–15% (Gentle)	7	
		15–25% (Undulating)	5	
		25–40% (Steep)	3	
		>40% (Very Steep)	1	
2	Land Use Map	Open land, water bodies, ponds	9	25
		Settlements, rice fields	7	
		Plantations, dry fields	5	
		Mixed gardens, scrubland	3	
		Forests	1	
3	Rainfall Map	> 2500 mm	9	15
		2001 – 2500 mm	7	
		1501 – 2000 mm	5	
		1000 – 1500 mm	3	
		< 1000 mm	1	
4	Soil Type Map	Vertisol, Oxisol	9	10
		Alfisol, Ultisol, Molisol	7	
		Inceptisol	5	
		Entisol, Histosol	3	
		Spodosol, Andisol	1	
5	Elevation	0 – 20 m above sea level	9	20
		21 – 50 m above sea level	7	
		51 – 100 m above sea level	5	
		101 – 300 m above sea level	3	
		> 300 m above sea level	1	
6	River Buffer Map	0 – 25 m	9	20
		25 – 50 m	7	
		50 – 75 m	5	
		75 – 100 m	3	
		> 100 m	1	

source : (Kusumo & Nursari, 2016).

The weighting of flood-prone areas in Pasar Kliwon Subdistrict was calculated using a formula modified from the studies by (Kusumo & Nursari, 2016) and (Aziza et al., 2021) as follows:

$$KB=(10 \times KEL)+(15 \times CH)+(10 \times JT)+(20 \times KL)+(20 \times BS)$$

Notes:

KB: Flood Risk

JT: Soil Type,

KL: Slope Gradient,

CH: Rainfall,

E: Elevation,

PL: Land Use,

BS: River Buffer.

For the analysis of evacuation routes, a network analysis approach was used that leverages topological principles. Since road data serves as the primary element

in determining evacuation routes, topological processing was performed to ensure that all road segments are interconnected and that there are no errors at their intersections. The determination of evacuation assembly point locations refers to the Guidelines for the

Development of Early Warning and Evacuation Systems for Flash Floods published by the Ministry of Public Works in 2012, taking into account buildings or infrastructure that can be utilized as temporary evacuation sites.

## RESULTS AND DISCUSSION

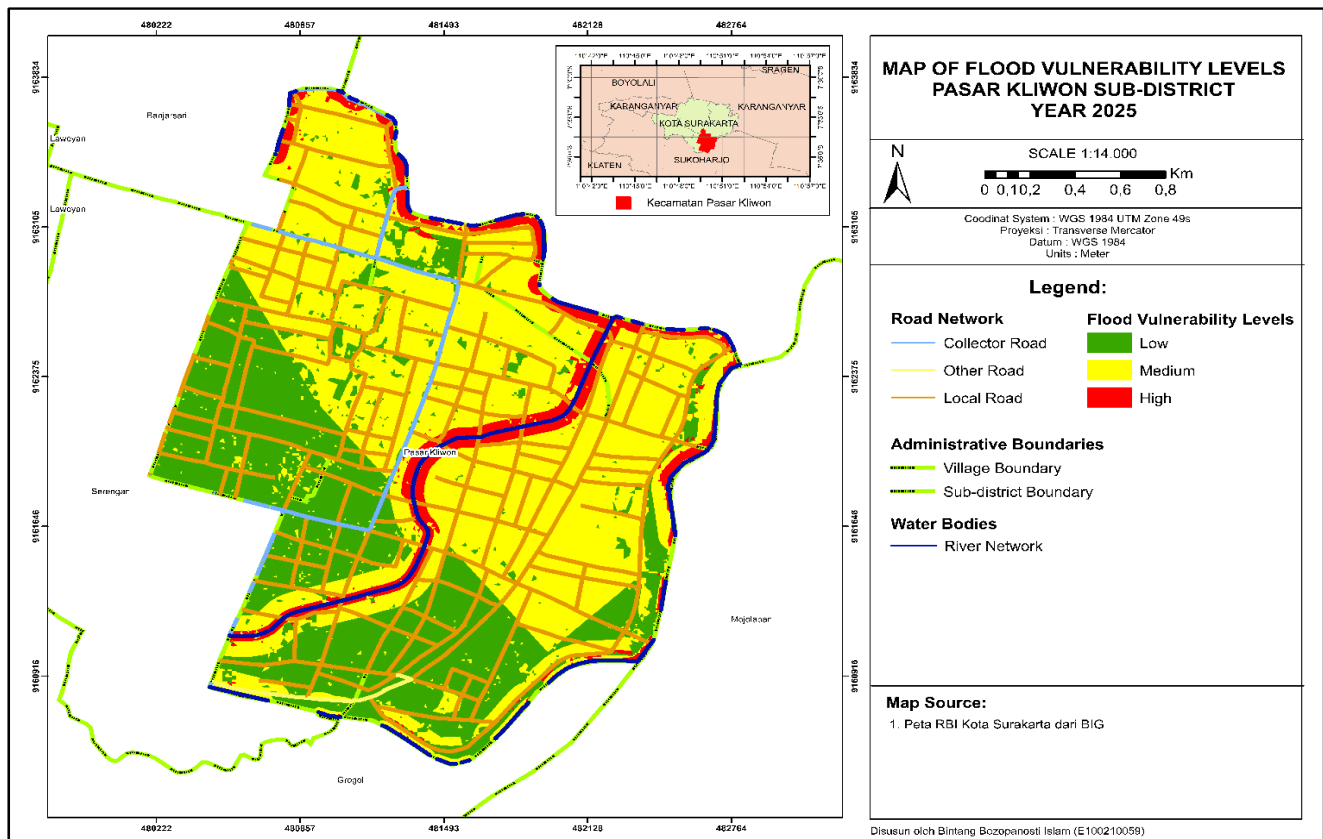
The Pasar Kliwon subdistrict has a relatively uniform topography with varied land-use patterns, which affects the level of flood risk in each of its areas. Based on physical geography studies, flood risk levels are influenced by several factors, including slope gradient, elevation, soil type, land use patterns, rainfall intensity, and the area's proximity to river channels (Rachmat & Pamungkas, 2014). Through an analysis of these factors, areas in Pasar Kliwon Subdistrict can be classified into three flood vulnerability categories: low, moderate, and high. In identifying flood vulnerability in Pasar Kliwon Subdistrict, the results of the scoring and weighting of each variable are as follows.

Based on the table, the flood risk level in Pasar Kliwon Subdistrict can be categorized into three classes: low, moderate, and high. The area of each zone varies,

with the low-risk zone covering 176 hectares, the moderate-risk zone spanning 277 hectares, and the high-risk zone reaching 38 hectares, which is generally located along the Bengawan Solo River. In total, the area identified in this analysis is 491 hectares. The flood risk map for Pasar Kliwon Subdistrict can be seen in the figure as follows.

**Table 3.** Results of the Flood Vulnerability Analysis

Level:	SKOR	Area (Ha)
Low	572	176
Medium	1030	277
High	1004	38
<b>TOTAL</b>	<b>2606</b>	<b>491</b>






**Figure 4.** Flood Risk Map

Based on historical data from the BPBD (BPBD, 2022), Pasar Kliwon is one of the areas in Surakarta City that is consistently affected by flooding due to heavy rainfall, the overflowing of the Bengawan Solo River, collapsed embankments, and high residential density. These incidents have resulted in flooded homes, resident evacuations, and displacement, although few fatalities have been reported (Bantara, 2025). The following table details flood incidents. The determination of evacuation points in Pasar Kliwon subdistrict is conducted through a scoring analysis of facility availability. Only facilities meeting eligibility criteria may be designated as evacuation points. Based on the attached data on public

facilities (fasum), 11 facilities were identified as suitable for use as evacuation points in Pasar Kliwon Subdistrict. These facilities represent two main types: schools and places of worship. From the classification results, only one school met the criteria: State Vocational High School 1 Surakarta.

In the place of worship category, the majority are mosques, including the Martorahardjan Mosque, Baitul Hikmah Mosque, Ciptosari An-Nurr Mosque, Jami' Assagaf Mosque, Al-Hidayah Mosque, Siti Maryam Mosque, and Muslimin Mosque. In addition to mosques, there is also a Christian place of worship, namely GKI Sangkrah Surakarta.

**Table 4.** Flood Incidence Rates in Surakarta

No	Level:	Flood Incident	Location	Day/Date
1	High		Sangkrah Village	Monday, 24-02-2025
2	Medium		Maja Village	Monday, 24-02-2025
3	Low		Joyosuran Subdistrict	Thrusday, 26-02-2025

Source: Surakarta City Disaster Mitigation Agency

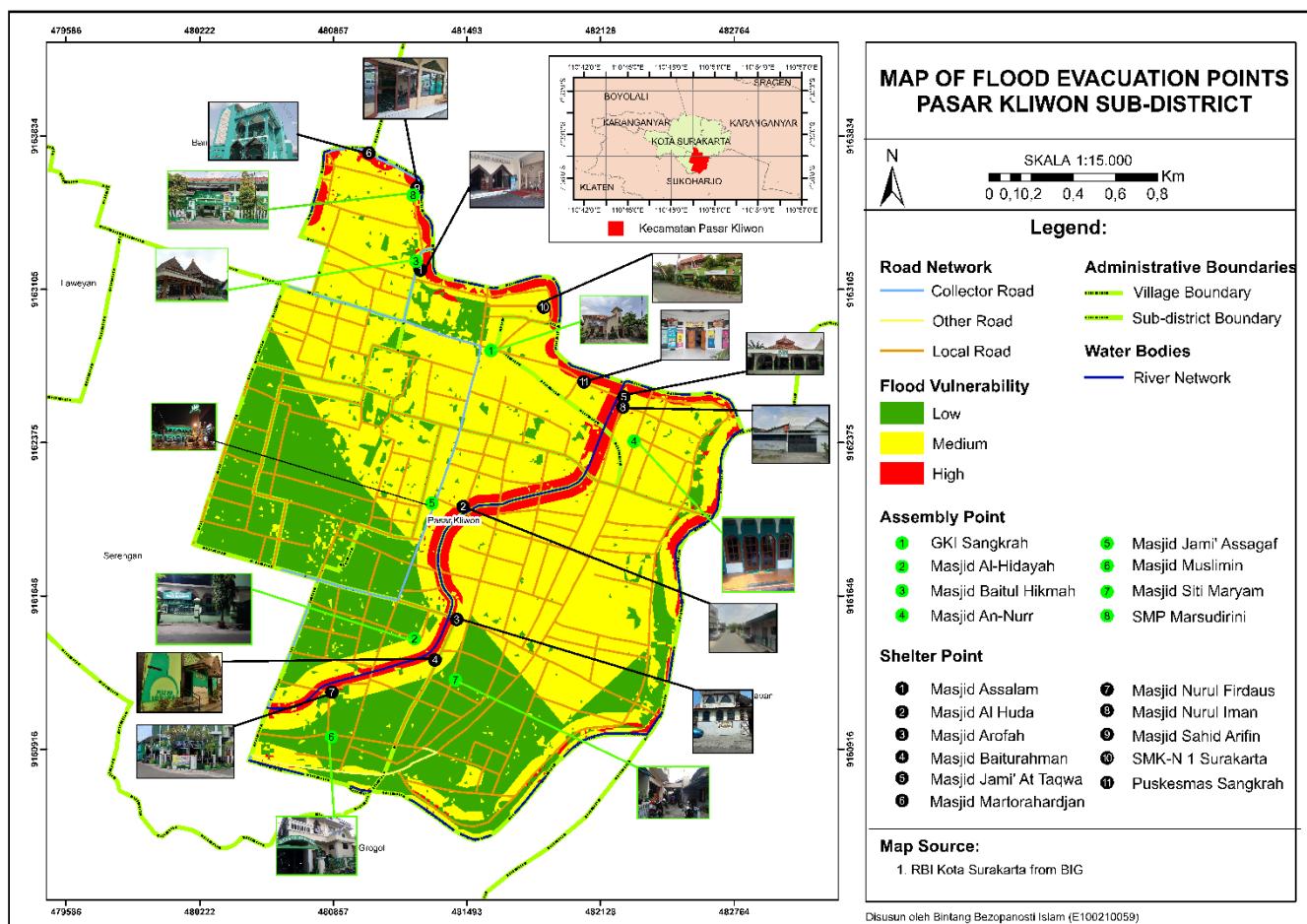


Figure 3. Flood Evacuation Points Map

Based on these results it can be concluded that places of worship, particularly mosques, are the predominant potential evacuation sites in Pasar Kliwon Subdistrict (Hotimah et al., 2024). This is because there are relatively more mosques, and they are distributed across various strategic locations. The selection of these locations aligns with geographical principles that take into account spatial aspects, social functions, and the accessibility of facilities in supporting disaster mitigation (Fauzia et al., 2021).

According to (Dirgantara & Zalmita, 2023; Makalew & Mandang, 2020), evacuation can generally be understood as the process of relocating people and/or assets from areas potentially affected by a disaster to safer areas free from threat. Meanwhile, an evacuation route is a path designed to facilitate the rapid and directed movement of the public in an effort to move away from sources of danger or conditions that threaten safety (Saptaputra et al., 2025). The determination of evacuation routes uses the "closest facility" network analysis and accessibility assessment with the assistance of ArcGIS software (Adilang et al., 2022). The

input used for network analysis consists of road data from relevant agencies, while accessibility assessments utilize data from relevant agencies and field observations aligned with the study's variables (Giyai & Pamungkas, 2022). The starting point (Assembly Point) and final point (Shelter Point) for evacuees are determined through settlement reach analysis, ensuring that the resulting evacuation routes represent the fastest and most effective access to safe locations (Aswad Janfari et al., 2024; Cristianti et al., 2024). The initial assembly point (Assembly Point) is a temporary gathering point before evacuation to a safer location. Its purpose is to facilitate an effective evacuation process. The initial assembly point (Assembly Point) is located in an area with a high flood risk level to make it easier for flood victims to reach, while the final assembly point (Assembly Point) is situated in a flood-safe area. The results of the flood evacuation route planning in Pasar Kliwon Subdistrict yielded 15 evacuation routes connecting 10 initial assembly points and 9 final shelter points.

Several international studies underscore the importance of integrating spatial methods into disaster

evacuation planning. GIS-based network analysis can generate realistic evacuation routes when considering factors such as distance, travel time, and road capacity (Parajuli et al., 2023). The spatial-temporal dimensions of flooding need to be integrated to anticipate changes in flood conditions during the evacuation process (Masoud & Aldosari, 2020). Multi-criteria decision analysis (MCDA) within GIS can improve the accuracy of determining assembly point and shelter locations by incorporating physical and social vulnerability variables (Netzel et al., 2021). The combination of hydrodynamic modeling and network analysis can provide evacuation scenarios that are more responsive to variations in rainfall intensity (Park et al., 2020). Change use land Urbanization and increasing soil impermeability affect flood flow velocity and must therefore be incorporated into evacuation route planning scenarios (Zhang et al., 2025). Finally, recent research by (Ahmad et al., 2025) indicates that

integrating machine learning with spatial data can improve the accuracy of flood pool predictions and accelerate the calculation of dynamic evacuation routes.

The results of evacuation route mapping in Pasar Kliwon Subdistrict reveal 11 evacuation routes connecting assembly points (at the *shelter point*). Assembly points are generally located at facilities that are easily accessible to the public, particularly mosques, schools, community health centers, and hospitals (Pepadu et al., 2023). This selection is not without reason, as these locations are situated near densely populated residential areas, allowing residents to reach them quickly when flooding occurs. Meanwhile, evacuation centers are selected at public facilities that have greater capacity, sturdy building structures, and are located in areas safer from the risk of flooding.

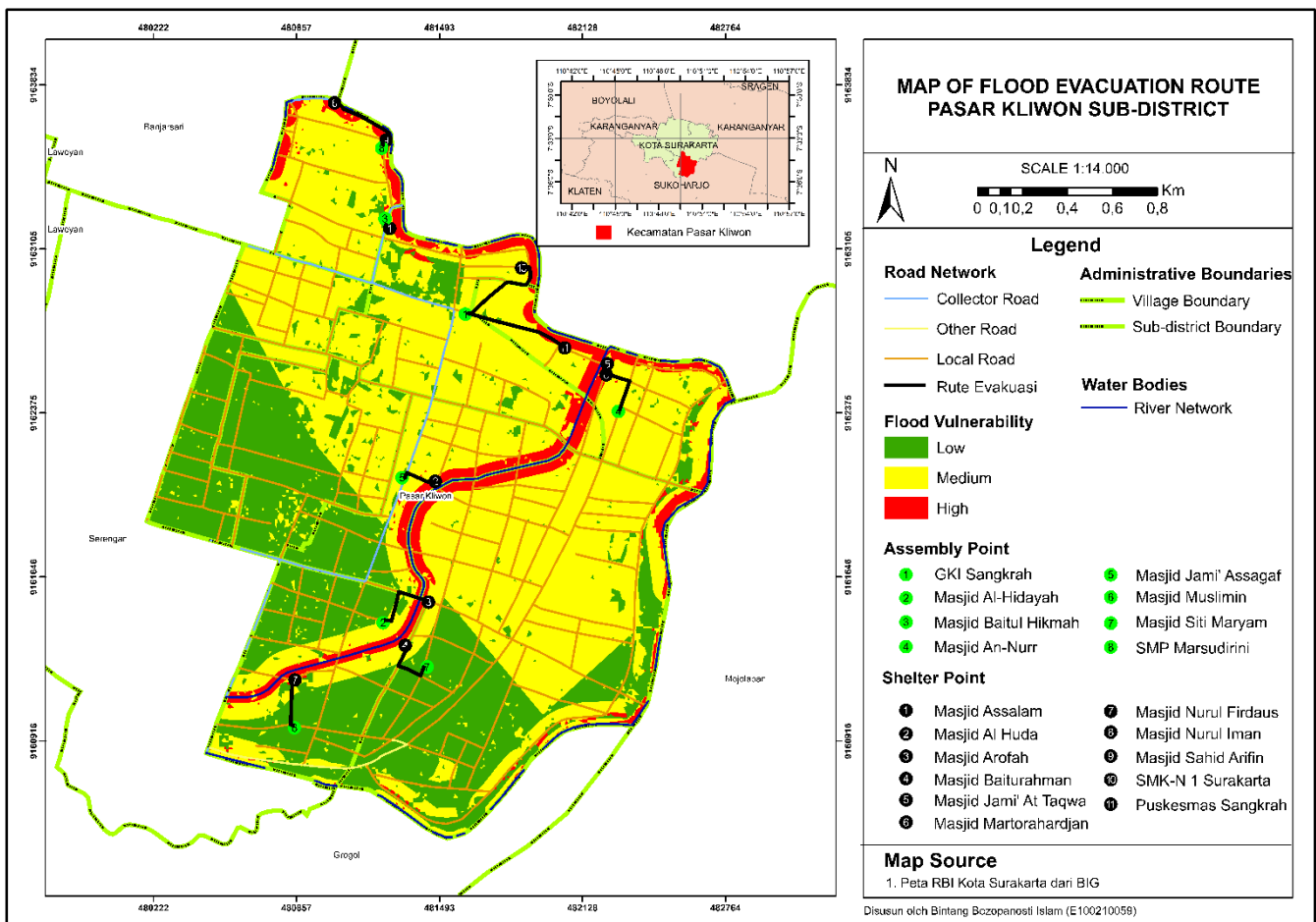


Figure 6. Evacuation Route Map

On the first and second routes, the Sahid Arifin Mosque was designated as the assembly point with two different evacuation destinations: the Martorahardjan Mosque and the Marsudirini Santa Theresia Junior High School in Surakarta. The existence of two alternative routes from the same assembly point indicates a planning effort to reduce the risk of crowd congestion and provide evacuation options based on on-site conditions. Furthermore, the third route connects Assalam Telkom Mosque in Solo with Baitul Hikmah Mosque, while the fourth route runs from State Vocational High School 1 Surakarta to GKI Sangkrah Surakarta. This demonstrates that schools not only serve as starting points for evacuation but also have direct connections to places of worship that are relatively safer. This finding aligns with the results of a study (Thapa et al., 2022) in Nepal, which showed that GIS-based alternative evacuation routes can increase community flexibility when facing flood disasters. Meanwhile, (Leal et al., 2022), who studied floods in South Texas, found that route variation is crucial to maintain road connectivity when flooding occurs urban areas.

On the fifth route, the Sangkrah Community Health Center (UPTD Puskesmas Sangkrah) is directed toward GKI Sangkrah Surakarta, indicating a concentration of the evacuation flow at a single evacuation site. The same pattern is observed on the sixth and seventh routes, where both the Nurul Iman Makmur Mosque and the Jami' At Taqwa Mosque are directed toward the Ciptosari An-Nurr Mosque. Such evacuation concentration indicates that certain shelters function as primary nodes within the evacuation network, thereby potentially accommodating a larger number of evacuees compared to other points (Shabrina & Ahmad, 2023). This is consistent with the findings of a study (Musolino et al., 2022) in Italy, which emphasized the importance of strengthening the infrastructure capacity of pedestrian pathways at main

shelters to prevent bottlenecks during disasters. This situation must be anticipated through effective evacuation management to avoid excessive crowding. A study (Safizadeh et al., 2022) in Penang, Malaysia, confirms that the distribution of evacuation routes must account for spatial capacity limitations in densely populated or historic areas to ensure the evacuation process remains effective.

The following routes demonstrate a pattern of one assembly point connected to one evacuation site. For example, on the eighth route, Masjid Al Huda is directed to Masjid Jami' Assagaf; on the ninth route, Masjid Arofah leads to Masjid Al-Hidayah; on the tenth route, Masjid Baiturahman leads to Masjid Siti Maryam; and on the eleventh route, Masjid Nurul Firdaus leads to Masjid Muslimin. These direct connections illustrate a more even distribution of evacuees, ensuring the community is not concentrated in a single shelter. This pattern aligns with research (Gu et al., 2025) that developed a bi-criteria framework for evacuation planning in China, where evacuation routes are selected not only based on travel time but also on the equitable distribution of evacuee loads.

Overall, the formed evacuation routes consider aspects of spatial proximity, road network accessibility, and the safety of evacuation sites from flood risks. Several evacuation points, such as GKI Sangkrah Surakarta and Masjid Ciptosari An-Nurr, serve as destinations for more than one assembly point, making their role crucial in the evacuation system. Meanwhile, routes connecting a single assembly point to a single shelter point provide a more targeted distribution pattern and help balance the flow of evacuees. Thus, this evacuation route structure reflects a disaster mitigation strategy focused on route efficiency, shelter capacity, and the safety of flood-affected communities.

## CONCLUSION

Based on the results of the analysis conducted and a review of the literature, this study successfully identified the flood vulnerability levels in Pasar Kliwon Subdistrict by classifying them into three categories: low, moderate, and high. The analysis results show that areas with high vulnerability cover approximately 38 hectares, moderate vulnerability covers 277 hectares, and low vulnerability spans 176 hectares. The areas most vulnerable to flooding are generally located along the banks of the

Bengawan Solo River, influenced by geomorphological conditions, topography, and land-use changes. Additionally, this study mapped evacuation routes using network analysis and identified 11 evacuation routes connecting 10 assembly points with 9 evacuation shelters. The evacuation network pattern reveals variations in route length and travel time, ranging from the longest route exceeding one kilometer to the shortest route under 200 meters. These results indicate that the

determination of evacuation routes must not only consider distance but also account for accessibility, facility capacity, and the safety of the destination. Overall, this study confirms that the use of GIS can support more effective flood disaster mitigation planning, both through vulnerability mapping and targeted evacuation route planning in densely populated urban areas.

This study has several limitations that should be noted. The data used was largely sourced from relevant agencies and field observations, so the accuracy of the information remains limited, particularly regarding drainage maps and land-use data that are not fully up-to-date. The evacuation route analysis conducted using network analysis in ArcGIS software is indeed capable of illustrating spatial accessibility; however, it does not yet account for the actual capacity of each shelter point or the dynamic conditions that may occur during a flood, such as flow velocity, water depth, and road obstructions. Additionally, socioeconomic factors of the community, including the vulnerability levels of at-risk groups such as children, the elderly, and people with disabilities, have not been deeply integrated into the determination of assembly points or evacuation routes. The scope of the study is also limited to the Pasar Kliwon subdistrict, so the results cannot yet be generalized to other urban areas in Surakarta or regions with different characteristics.

Given these limitations, future research is recommended to update and enrich the spatial database by utilizing high-resolution satellite imagery, flood hydrodynamic data, and real-time sensors to improve the accuracy of vulnerability modeling. Integrating shelter

capacity and evacuation management is also crucial to ensure that the resulting evacuation routes are more realistic and aligned with the locations' capacity. Additionally, socioeconomic aspects and community vulnerability levels must be considered, for example, by using a social vulnerability index to create more inclusive evacuation routes. Future research is also advised to develop dynamic evacuation models capable of adjusting routes based on evolving flood conditions on the ground. Finally, applying this method to other regions with different physical and social characteristics could serve as a comparative study to test the effectiveness and flexibility of the network analysis approach in flood disaster evacuation planning.

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**Conflict of interest** The author has no competing interests to declare that are relevant to the content of this article.

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