Journal of Geospatial Science and Analytics 1 (3): 215-224 (2025)

Journal of Geospatial Science and Analytics

Journal homepage:
https://ejournal.foundae.com/index.php/jgsa/index
e-ISSN: 3090-8086 | p-ISSN: 3090-532X

Geographic information system-based mapping of flood-prone areas and evacuation routes in Cilandak Sub-district, South Jakarta City

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Article Info

Article history:

Received: Dec 29, 2024
Revised: Feb 03, 2025
Accepted: Aug 28, 2025

Keywords:

Disaster
Evacuation
Flood
Geographic Information System
Mapping

DOI:
10.58524/jgsa.v1i3.6

Abstract

Disaster is a series of events that have a direct impact in the form of threats to people's lives caused by either natural or non-natural factors so that the direct impacts caused are environmental damage, property losses, psychological impacts and loss of life. The research method used in this study is a qualitative method. Data processing is carried out using Geographic Information System software, namely QGIS version 3.16. With the development of mapping technology, especially in GIS, flood area mapping can be done to determine the final evacuation. The purpose of this study was to determine the level of flood vulnerability based on Geographic Information Systems (GIS) in Cilandak District, South Jakarta City and to determine the direction of temporary evacuation sites for flood disasters in Cilandak District, South Jakarta City. The location used was Kelapa Gading District, North Jakarta City. In this study, the data used were infrastructure data (buildings and roads) and population data. Building data in Kelapa Gading District has 77 buildings with a total affected area of 11,2045 ha. Meanwhile, the roads have a length of 65,385 km. Population data used for analysis is displayed in pixels and divided into five classes from a total population of 27,006 people. From the data on the distribution of buildings and buildings, it is then processed to create an Evacuation Route Map using the network analysis method.

To cite this article: Marta, D. J., Astuti, N. I., & Sutarga, K. (2025). Geographic information system-based mapping of flood-prone areas and evacuation routes in Cilandak Sub-district, South Jakarta City. *Journal of Geospatial Science and Analytics,* 1(3), 215–224.

INTRODUCTION

A disaster is an event that causes significant losses to society, both materially and psychologically, and requires a long recovery process (Sugiantoro & Purnomo, 2010). According to Law No. 24 of 2007 concerning Disaster Management, a disaster is a series of events that directly threaten human lives, caused by natural or non-natural factors, resulting in

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environmental damage, loss of property, psychological impacts, and fatalities. One of the most common natural disasters in Indonesia is flooding, which occurs when water from rivers or drainage systems exceeds their capacity, inundating lower areas. Flooding can be caused by natural factors such as high rainfall intensity, lowland topography, and sedimentation in river channels, as well as human activities like poor land management, reduced green spaces, and inadequate drainage systems.

Flood disasters are a recurring problem in urban areas with high population density, such as Jakarta. The flood at the beginning of 2020, which recorded extreme rainfall of 377 mm (BMKG, 2020), resulted in 24 fatalities, displaced over 31,000 residents, and caused power outages in 724 areas. Traffic was paralyzed, and many vehicles were submerged or swept away. This event highlights Jakarta's vulnerability to floods, exacerbated by land subsidence, rising sea levels, and its geographical condition, with areas as low as 0–1 meter above sea level. In South Jakarta, floods are frequent due to river overflows and tidal flooding, with BPBD reporting daily incidents during the rainy season. These floods negatively impact communities, causing both physical damage and psychological distress.

Flood vulnerability is influenced by meteorological factors such as rainfall and watershed characteristics, including land slope, elevation, soil texture, and land use (Suherlan, 2001). Misunderstandings often arise between floods and inundations, where inundations are temporary accumulations of rainwater, while floods involve large water volumes with longer durations and greater depths (Syahril, 2009). Understanding the causes and mechanisms of flooding is crucial for effective disaster management, enabling the development of appropriate mitigation strategies.

Efforts to reduce flood impacts can include public education, disaster simulations, and leveraging technology for planning. Geographic Information Systems (GIS) play a crucial role in flood risk management by integrating spatial data to identify vulnerable areas and design evacuation routes. GIS enables the visualization of flood-prone zones through maps, overlaying parameters like land elevation, land use, and rainfall patterns for accurate analysis. According to Adam & Ricky (2012), GIS functions as a computer system to build, store, manage, and display geospatial information relevant to regional planning. Quantum GIS (QGIS), an open-source platform, facilitates this process by supporting various geospatial data formats, offering tools for data processing, visualization, and map-making.

In the context of flood mitigation in Cilandak District, GIS can analyze factors such as rainfall intensity, soil capacity, and topography to predict flood-prone areas effectively (Aronoff, 1989). This technology helps identify high-risk zones, model potential flood scenarios, and plan evacuation routes to minimize risks. By providing accurate, real-time data, GIS supports both government agencies and communities in making informed decisions during disasters.

In conclusion, flood hazard mapping and GIS-based disaster management are essential to enhance community resilience and support government policies in flood-prone areas. Utilizing GIS technology allows for more targeted and efficient mitigation strategies, such as identifying safe evacuation routes, optimizing emergency response resources, and increasing public awareness through education programs. This approach not only reduces the risks and impacts of flooding but also strengthens overall disaster preparedness in vulnerable urban areas like South Jakarta.

Several previous studies have demonstrated the effectiveness of GIS in disaster mitigation. Corry, et al (2022) in their study showed how GIS was used to effectively identify landslide-prone areas. Furthermore, Agus, et al (2020) highlighted the importance of GIS in flood disaster education and preparedness. In addition, Sularno, et al (2020) also in their research integrated GIS with mobile technology to improve disaster response. Another case conducted by Rianto & Mardwi (2018) when compared to the research conducted by researchers in terms of making a significant contribution in understanding spatial data-based evacuation planning. However, these previous studies generally focused only on risk mapping or disaster education, without integrating a comprehensive flood vulnerability analysis with the determination of final evacuation locations in densely populated urban areas such as Cilandak District.

Therefore, the research gap addressed in this study is the lack of an integrated GIS-based approach that not only maps flood vulnerability but also identifies optimal and strategic final evacuation locations in dense urban environments. This study aims to analyze the level of flood vulnerability using GIS in Cilandak District, South Jakarta, and to determine the most optimal final evacuation locations based on the integration of the latest spatial data. The findings of this research are expected to make a significant contribution to strengthening flood risk mitigation and enhancing evacuation planning that is more responsive and evidence-based in disaster-prone urban areas.

METHOD

The research method used in this study is a qualitative method. Data processing is carried out using Geographic Information System software, namely QGIS version 3.16. The data used for this study are population data in the form of population in raster form, building data in the form of area vector data, administrative boundaries of the region which are also in the form of area vectors and road data in the form of line vector data. The explanation of the data processing stages is explained in more detail in the following presentation.

a. Raster extraction analysis process

Flood disasters can be detected using remote sensing technology and Geographic Information Systems. The data used is spatial data in raster or vector format. Raster data extraction is an activity where existing raster data is extracted to obtain information about flooding in the study area. The raster data extracted is the population raster data of Java Island. The extraction process begins by cutting the population raster data according to the study area, namely Kelapa Gading District, North Jakarta. Cutting is done using the clip raster by mask tool which will cut the population raster data of one Java Island, to only Kelapa Gading District. The next stage is to classify population density based on pixel values in raster data. Population density is obtained using the formula:

$$Population\ Density = \frac{Population\ Per\ Pixel}{Pixel\ Grid\ Area} \quad (1)$$

The calculation results are then classified into 5 population density classes. These results are then further analyzed using the union tool where the population raster data is then adjusted to the study area, namely Kelapa Gading District. The results obtained from raster extraction are in the form of fractions so that rounding is necessary using the round tool. The density value of each pixel is grouped into 5 classes with the same value.

b. Process of analysis of affected areas

The analysis of the affected areas was carried out using building and infrastructure data and population data in the study area. The analysis process that was carried out began by cutting each data according to the study area. This cutting process was carried out using the clip vector tool for vector data and the clip by mask tool to cut raster data. After the data was cut according to the study area, the data was then overlapped to see and analyze the affected areas. Analysis of the area that impacted starting from the analysis of the area affected. The area affected is taken from the results of the intersect of building data that has been calculated and flood modeling.

Another analysis of the affected areas is the number of affected residents and affected infrastructure in the study area. Analysis of the number of affected residents is obtained from the results of raster extraction of the number of residents which is then overlapped with flood data and administrative boundaries of Kelapa Gading District. The same thing is done on infrastructure data to see the affected infrastructure.

c. Evacuation Route

Flood disaster evacuation routes can be analyzed using remote sensing data using a geographic information system. Evacuation routes are made using several data, namely:

1) Evacuation location
Evacuation locations are related to the location of the flood. Supporting variables include topographic data, slopes, building conditions, and building functions. Evacuation locations in this study are based on building condition and building function variables. The data used in this study are based on building point data.
2) Accessibility
Accessibility is related to infrastructure in the study area. The variables used are road hierarchy, road conditions, travel time, direction of movement, and distance to the evacuation location. Accessibility in this study is based on road data in the study area.
3) Population
Population is related to the number of people in the study area. The variables used are the number of residents at the activity center, population density, and population based on age. In this study, the data used is the population density of the study area. Evacuation routes are analyzed using network analysis. The data used to create evacuation routes are building point data, population density and road. From the data, several evacuation route scenarios will be created, from which the most appropriate will be selected. The research method used is presented in the flowchart in Figure 1.

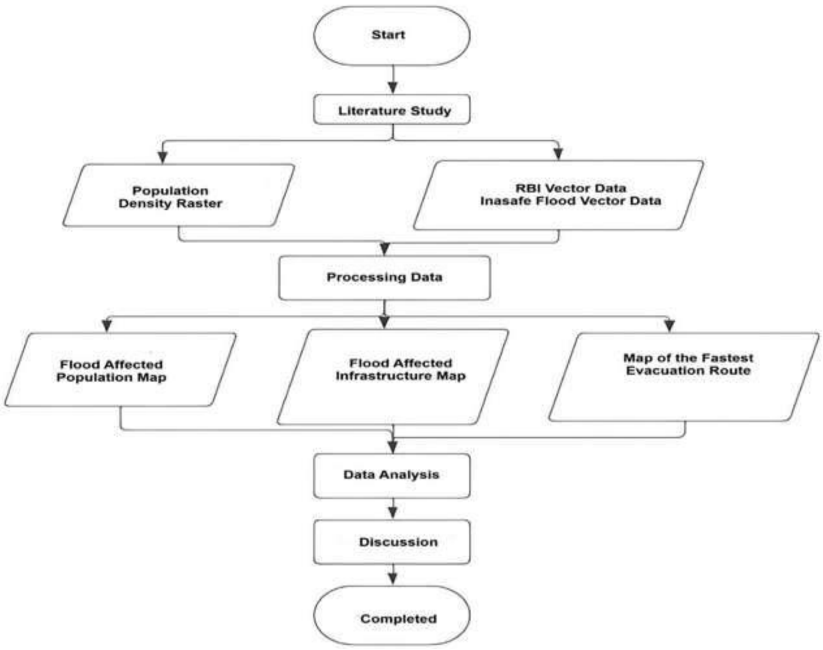

Figure 1. Workflow
Source: Processed by Researcher, 2025

RESULTS AND DISCUSSIONS

The research results were obtained from a series of research stages as stated in the research method. The results obtained were in the form of infrastructure maps, population maps, and evacuation route maps.

a. Infrastructure Map

The infrastructure map represents what infrastructure is affected by the flood disaster that hit the study area. The infrastructure map is obtained from processing road data, building area, and affected areas. Data processing is carried out by overlapping road and building data with affected areas.

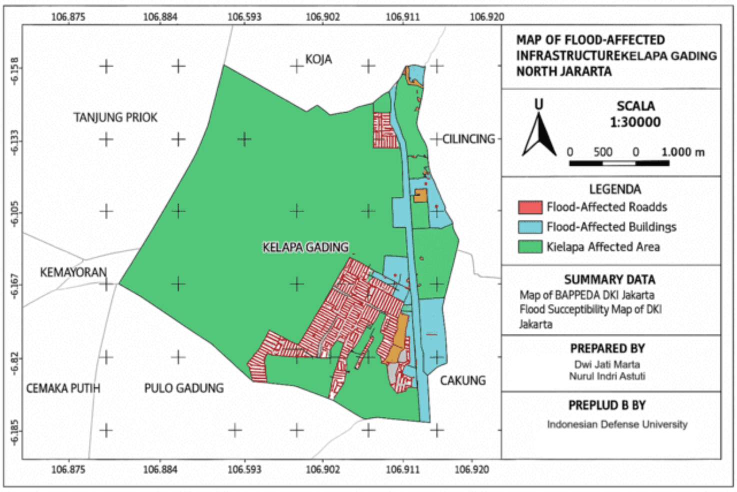

Figure 2. Flood-Affected Infrastructure Map
Source: Processed by Researcher, 2025

The map presented shows road infrastructure and buildings affected by the flood disaster. The eastern area of the affected area is affected infrastructure is buildings. The affected infrastructure in the western area is road infrastructure. Based on the map presented, road infrastructure is more affected by the flood disaster than buildings. There are Hamlet 14 in two sub-districts affected by flooding in Kelapa Gading District, namely in Kelapa Gading Timur and Pegangsaan Two Sub-districts, which can be seen in the table below.

Table 1. Flood Affected Areas

Sub-district	Ward	RW Affected
Kelapa Gading	Kelapa Gading East	Hamlet 06, Hamlet 07, Hamlet 08, Hamlet 09, Hamlet 10, Hamlet 17, Hamlet 19
Kelapa Gading	Pegangsaan Two	Hamlet 02, Hamlet 03, Hamlet 07, Hamlet 10, Hamlet 11, Hamlet 15, Hamlet 16

Source: Processed by Researcher, 2025

The total area affected based on building classification can be obtained from the results of mathematical calculation analysis using the area tools in calculate geometry. The calculation of the area of the affected area can be seen in the table below.

Table 2. Buildings Affected by Floods

Building Classification	Area Affected (m^2)	Number of Affected
Clinic/Doctor	361.37	1
Government	2804.35	13
Hospital	2524.4	1
Place Of Worship - Islam	2620.37	14
Police Station	573.12	1
Residential	74879.18	34
School	28282.21	13
Grand Total	112045	77

Source: Processed by Researcher, 2025

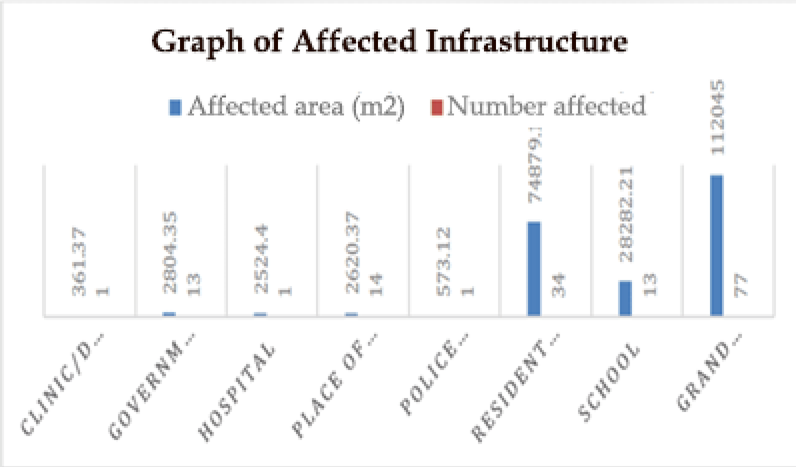

Figure 3. Flood-Affected Infrastructure Graph
Source: Processed by Researcher, 2025

From the graph, it can be seen that in Kelapa Gading District, there are a total of 77 buildings consisting of clinics, government centers, hospitals, places of worship, police posts and residential buildings with a total area affected by the flood disaster of 11.2045 hectares. The length of the affected road was obtained from Jakarta street's which was clipped in the flood-affected area to produce flood-affected roads in Kelapa Gading District. The results of the analysis are shown in Table 3.

Table 3. Classification of Flood-Affected Roads

Road Classification	Length of Affected Road (m)
Motorway Or Highway	753.59
Road, Residential, Living Street, etc	49991.7
Secondary	8633.19
Tertiary	5572.27
Grand Total	**65385.25**

Source: Processed by Researcher, 2025

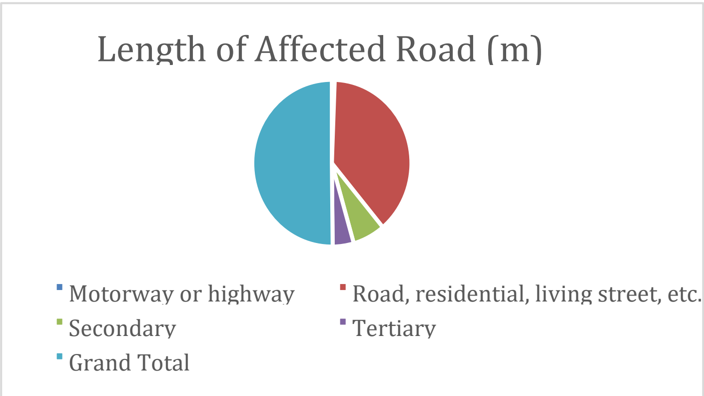

Figure 4. Flood Affected Roads
Source: Processed by Researcher, 2025

Roads affected by flooding include highways, residential roads, secondary roads and tertiary roads with a total affected road section of 65.385 km.

b. Population Map

Population maps are obtained from raster data that have population values in the study area. The raster data is then extracted and population density is calculated according to the existing raster grid. Based on this processing, population density data is obtained in the study area which is divided into five density classes.

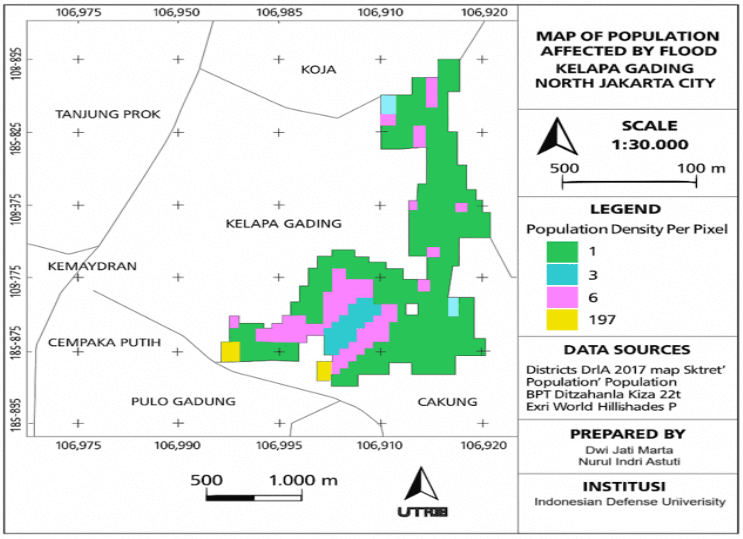

Figure 5. Map of Flood Affected Population
Source: Processed by Researcher, 2025

The map in the image above displays population density represented in the form of a pixel grid. Based on the information presented, there are 5 classes of population density in the study area. The class is presented in the form of density numbers per pixel. The most affected population density is the area with a density of 3 people per pixel. The second most affected population density is the density of 197 people per pixel. The assumption is that each pixel has more than one house. The results obtained are still fractions, so they are rounded using the round menu in the QGIS application. The results of the raster analysis are as follows.

Table 4. Population Exposed to Floods

Pixel Value	The Amount	Exposed Population
0	1201	0
3	286	858
6	12	72
7	1	7
197	119	23443
202	13	2626
Total Population Exposed		**27006**

Source: Processed by Researcher, 2025

From the results of the raster analysis, the total population exposed to flooding in Kelapa Gading District was 27,006 people.

c. Evacuation Route Map

Evacuation route map is the result of processing building, road and population density data in the study area. Processing is done using the network analysis method where road, population and building location data are used as variables.

The evacuation route map contains evacuation routes and evacuation locations. The evacuation location is the Pegangsaan Two Village Office. The selection of the Pegangsaan Two Village Office as an evacuation location is because the location is outside the flood area and the evacuation location is centralized at one point in one sub district. The evacuation route starts from the flood-affected building to the evacuation location. The evacuation route is obtained based on the fastest route to the evacuation location from the affected building.

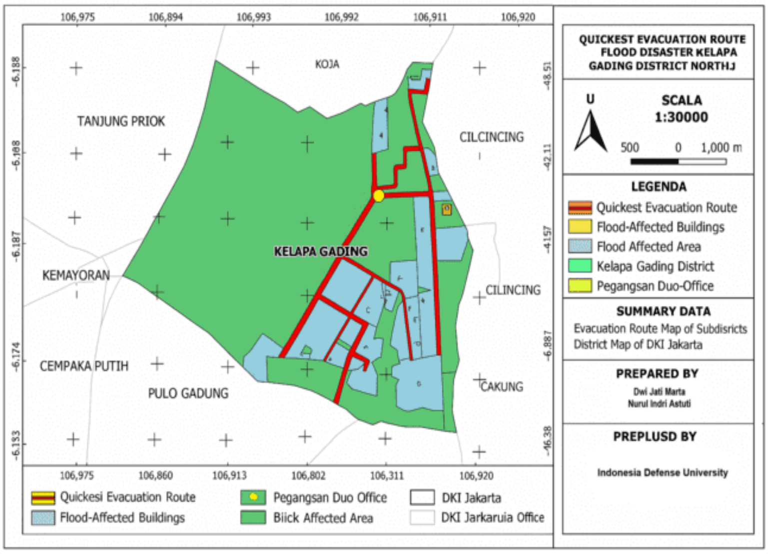

Figure 6. Fastest Evacuation Route Map
Source: Processed by Researcher, 2025

Based on the results of the analysis and discussion, this research shows a number of new findings that distinguish it from previous studies. When compared to Corry, et al's (2022) study that focused on GIS-based mitigation of landslide-prone areas in Bumiaji Sub-district, this study presents a more comprehensive approach by integrating flood-prone area mapping and evacuation routes in one analytical framework. This approach not only identifies risk areas, but also designs effective evacuation routes, an aspect that has not been accommodated yet.

The research by Agus, et al (2020) focuses on flood disaster education and mitigation using GIS to improve community preparedness. Although relevant, the research did not specifically analyze strategic evacuation routes. In comparison, this research serves not only as an educational tool, but also as a basis for planning evacuation routes that consider the dynamic geographical and infrastructure conditions in South Jakarta.

Meanwhile, Sularno, et al's (2020) research focused on Android-based mapping of tsunami evacuation routes in Padang City. While an application-based approach provides benefits in terms of information accessibility, this research is limited to one type of disaster and does not take into account the complexity of flooding in dense urban areas. This research fills the gap with a GIS-based approach that is not only compatible with various spatial data formats, but also able to integrate various environmental and infrastructure variables for more effective flood evacuation planning.

Furthermore, Rianto & Mardwi's (2018) research identifying flood-prone zones and evacuation routes in Genuk Sub-district, Semarang City, provides an important foundation in the use of GIS for flood disasters. However, the study was still limited to identifying vulnerable zones without considering dynamic spatial changes and rapid urbanization factors. This research offers a novelty by considering these factors, especially in South Jakarta, which faces complex challenges related to land subsidence, land use change, and increased rainfall intensity due to climate change.

Thus, the novelty of this research lies in the comprehensive approach that combines flood vulnerability analysis with GIS-based evacuation route mapping and final evacuation site determination in an integrated manner. Unlike previous studies that focused more on general disaster mitigation aspects, disaster education, or evacuation route mapping without considering full integration with spatial analysis of flood vulnerability in dense urban areas, this study develops a more specific and applicable model. This research also utilizes GIS technology with the latest relevant spatial data to identify strategic evacuation points, which is expected to improve the effectiveness of disaster response and reduce the risks faced by the community in Cilandak Sub-district, South Jakarta City.

CONCLUSION

This study reveals that flood disasters in Kelapa Gading Sub-district significantly impact infrastructure, population, and evacuation routes. The analysis highlights that 77 buildings covering 11.2045 hectares and 65.385 km of roads are affected, with damage concentrated on residential roads and public facilities such as hospitals, schools, and places of worship. Additionally, flooding has affected 27,006 people, with the densest areas housing 23,443 individuals. The strategic selection of Pegangsaan Two Urban Village Office as an evacuation point, combined with network analysis for optimal evacuation routes, proves effective in reducing evacuation time and risk. These findings emphasize the need for improved infrastructure resilience, efficient emergency services, and comprehensive disaster preparedness strategies to mitigate future flood impacts.

Future research should explore the integration of advanced technologies, such as real-time GIS-based flood monitoring systems, to enhance disaster response effectiveness. Additionally, studies could focus on developing multi-criteria evacuation models that consider not only the shortest routes but also factors like road conditions, population vulnerability and dynamic flood patterns. Investigating the effectiveness of decentralized evacuation points in densely populated areas and assessing community-based disaster risk reduction programs will provide valuable insights for improving flood mitigation and emergency response strategies in flood-prone urban environments.

AUTHOR CONTRIBUTIONS

Each author of this article played an important role in the process of method conceptualization, simulation, and article writing.

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