P-ISSN: 2798-1134 | E-ISSN: 2797-3549 | DOI: 10.52562/injoes.2026.1607

Indonesian Journal of Earth Sciences

http://journal.moripublishing.com/index.php/injoes

| Research Article |

Integration of Geographic Information Systems in Determining Flood Risk Evacuation Routes in Medan City

Muhammad Farouq Ghazali Matondang[1]*, Meilinda Suriani Harefa[1], Rohani[1], Eni Yuniastuti[2], Mulhady Putra[1], Rozi Mahmuda[1], Tengku Abdillah Azis[1]

[1]Department of Geography Education, Faculty of Social Science, Universitas Negeri Medan, Medan, Indonesia
[2]Department of Geography Information System, Faculty of Social Science, universitas Negeri Medan, Medan, Indonesia
**Correspondence: farouqmatondang@unimed.ac.id*

Received: 19 May 2025 / Accepted: 21 June 2026 / Published: 29 June 2026

Abstract: This study aims to map flood risk evacuation routes in Medan City using the Network Analysis method based on Geographic Information Systems (GIS). Medan City is a flood-prone area due to rapid urbanization, inadequate drainage systems, and land use changes. The data used include the 2024 flood risk map, road network, and evacuation shelter locations. The evacuation route analysis was conducted using ArcGIS 10.8 software with the Network Analyst feature to determine optimal evacuation routes that avoid flood-prone areas and facilitate evacuation to safe locations. The results show ten main evacuation routes covering various districts in Medan City. These routes were designed based on accurate spatial data considering road conditions and flood risk zones. This evacuation route mapping is expected to serve as an important reference for local government and related agencies in planning flood disaster mitigation strategies and enhancing community safety. The GIS and Network Analysis approach proves effective as a planning tool for disaster evacuation by comprehensively considering geographical variables and transportation networks.

Keywords: Flood Evacuation Routes, Network Analysis, Medan City

INTRODUCTION

Disasters have consequences that affect both humans and the environment. Vulnerability to disasters often arises from inadequate disaster management, environmental impacts, or human factors. Natural disasters occur repeatedly and claim many lives. When the capacity of a community is lower than the scale of the threat it faces, a disaster event occurs (Ulum, 2013).

Medan City is one of the regions categorized as vulnerable to flood disasters (Anggraini et al., 2021). This condition is exacerbated by a high rate of urbanization, insufficient drainage capacity, and uncontrolled land use changes (Pasaribu, 2021). According to the Regional Disaster Management Agency (BPBD) of North Sumatra, several areas in Medan are classified as flood-prone zones, especially during the rainy season or when there is extremely high rainfall (Badan Penanggulangan Bencana Daerah Kota Medan, 2012). Flooding in Medan not only causes material and economic losses but also poses risks to human safety and disrupts daily community activities (Silalahi et al., 2021). Therefore, planned mitigation efforts are needed, one of which is through the mapping of effective and efficient evacuation routes (Yusra et al., 2024).

Geographic Information Systems (GIS) play an important role in spatial data analysis and mapping (Fischer & Nijkamp, 1992). Through remote sensing and GIS applications, evacuation routes can be designed, flood-affected areas can be mapped, and vulnerabilities in different zones can be evaluated. Furthermore, GIS using a spatial multi-criteria analysis approach is highly beneficial in supporting the identification of basic leadership procedures through the use of geo-referenced information (Febrina et al., 2020).

All international tsunami risk management agencies agree that well-organized evacuation planning can significantly reduce risk and save coastal communities' lives (Scheer et al., 2011). Systematic evacuation planning enables the installation of proper signage, such as hazard zone markers, safe locations, and evacuation routes (Dall'Osso & Dominey-Howes, 2010), while also supporting efforts to

increase public awareness. This contributes to strengthening community reflex responses and resilience against disaster threats.

In the context of disaster mitigation, evacuation routes play a strategic role in ensuring that residents can be evacuated quickly and safely to designated shelters. The process of mapping evacuation routes requires a spatial data-based approach integrated with modern technologies such as Geographic Information Systems (GIS) (Sahetapy et al., 2016).

In this study, flood risk maps, road networks, and shelter locations were evaluated using ArcGIS software. Route analysis was conducted to map evacuation paths that avoid flood-prone areas.

Network Analyst is a feature in GIS used to analyze road or transportation networks. According to research by Purwati (2024), this method can help determine optimal evacuation routes by considering variables such as road networks and their hierarchy. The road network data used must first be processed into a network dataset format so that relevant parameters can be adjusted to suit the analysis needs.

By utilizing GIS technology, this study is expected to make a tangible contribution to flood risk mitigation efforts in Medan City. The resulting evacuation route maps can serve as a reference for local governments and relevant agencies in planning flood disaster management strategies.

METHOD

This study was conducted across the entire city of Medan, North Sumatra, in November 2024. It employed a quantitative-spatial approach, with Geographic Information System (GIS)-based modeling and analysis as the core methodology. Preprocessing of spatial data involved validation of the 2024 flood risk map and road network layers to ensure data accuracy, consistent resolution, and completeness.

The hardware used in this study included a laptop/computer, and the primary software tools were ArcGIS version 10.8 and Microsoft Word. ArcGIS 10.8 was specifically selected for its compatibility with the advanced Network Analyst extension and its robust support for building geodatabases, which was essential for this study.

The main data components used in the analysis included:

1. The administrative map of Medan City,
2. The validated 2024 flood risk map of Medan City,
3. A shapefile (shp) of Medan City's road network.

Flood risk zones were classified into three levels: low, medium, and high, based on variables such as inundation depth, historical flood frequency, and proximity to rivers or drainage infrastructure. This classification was critical for designing evacuation routes that deliberately avoid high-risk areas.

The Network Analyst tool in ArcGIS was used for spatial analysis to determine optimized evacuation routes toward predefined shelter locations. The Route Analyst function was applied to visualize alternative evacuation paths under flood conditions in Medan. Route calculations considered travel radius and shortest travel time, with road hierarchy (arterial, collector, and local roads) incorporated as impedance factors to simulate real-world road priorities during emergencies.

According to Rahmadini (2020), evacuation route network analysis involves two key steps: geodatabase preparation and route analysis. A similar process is described by Sahetapy et al. (2016) and elaborated in practice by Dirgantara & Zalmita (2023), as follows:

1. Geodatabase Construction: Shapefile data, in its default form, cannot be used directly for network analysis. Therefore, all shapefiles were converted into geodatabase format. A network dataset was then created, which included definitions of road types, travel cost (impedance), and connectivity parameters.
2. Route Analysis: Using the prepared dataset, ArcGIS calculated the optimal evacuation routes by considering criteria such as shortest distance, lowest travel time, and minimal exposure to flood-prone segments. The results included multiple route options between starting points and destination shelters, all within pre-defined spatial constraints.

The data collection techniques included:

- Literature review, to understand theoretical frameworks and criteria for shelter site selection as well as the use of GIS in disaster risk reduction.
- Documentation method, to obtain validated secondary spatial data such as maps and shapefiles from Indonesia Geospasial, published studies, and official databases.

The overall research workflow consisted of the following stages:

1. Flood Risk Analysis: Analyze the 2024 flood risk map of Medan to identify and classify vulnerable zones.

2. Shelter Identification: Determine shelter locations based on safety and accessibility criteria.
3. Route Modeling: Apply the Network Analyst tool to generate optimized evacuation routes that avoid medium- and high-risk zones.

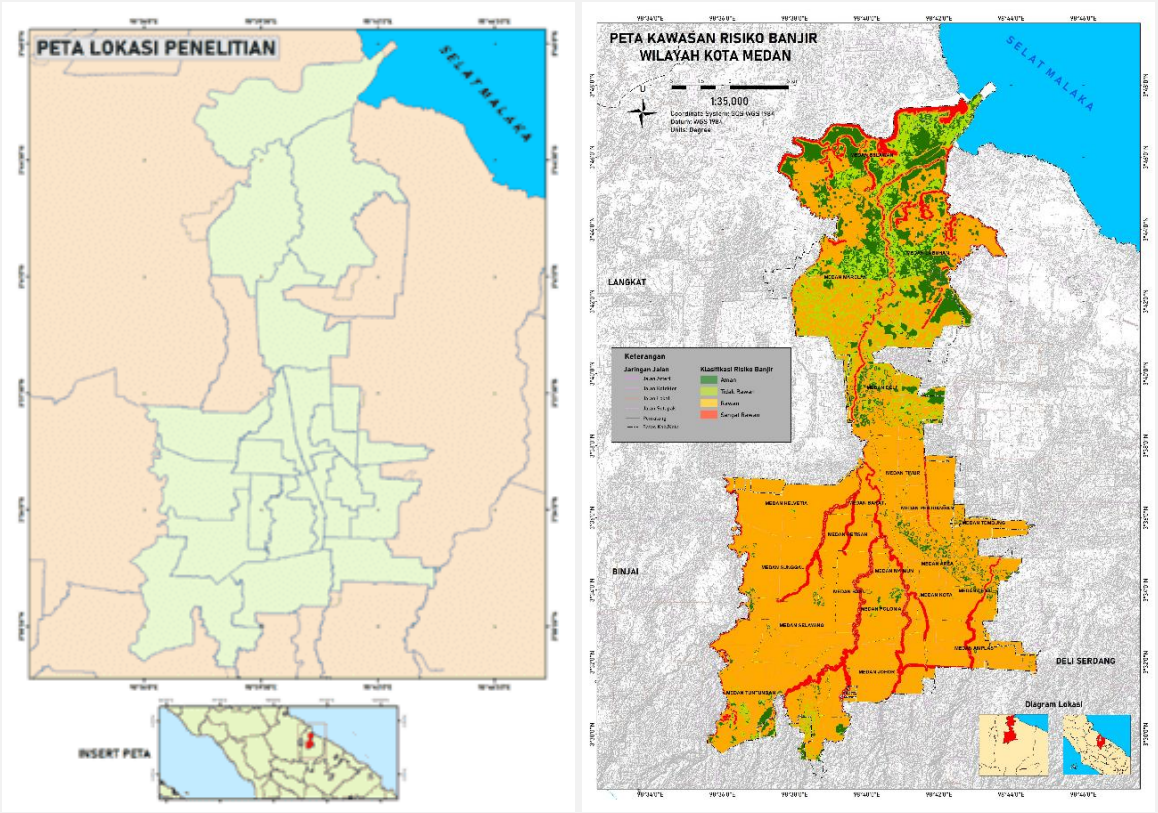

Figure 1. (a) Research location in 2024, and (b) Flood Risk Map of Medan City Region 2024.

RESULTS & DISCUSSION

Flooding is a natural phenomenon where water accumulates excessively on the ground surface, surpassing the capacity of absorption or evaporation, and causing serious impacts on surrounding communities and infrastructure. Based on the analysis of the 2024 flood risk map (Figure 1), it can be concluded that Medan City is highly prone to flooding, with an affected area reaching approximately 15,455.81 hectares.

Evacuation routes are defined as alternative pathways designed to guide the public to safe zones during disasters, particularly flood events. In this study, flood evacuation routes in Medan were developed using Geographic Information System (GIS) technology combined with Network Analyst tools in ArcGIS 10.8, which allowed optimal route calculations that consider road hierarchy, accessibility, and flood exposure.

Using the Network Analysis method, a total of ten (10) evacuation routes were identified throughout Medan City. These routes were selected based on spatial proximity to flood-prone areas, accessibility to shelters, and avoidance of high-risk zones. Each route includes designated evacuation points distributed across various districts. Below is a summary of each route:

1. The first route has the most points, with 65 evacuation route locations along the districts starting from the main point in Medan Amplas, then continuing through Medan Johor, Medan Polonia, Medan Maimun, Medan Barat, Medan Perjuangan, and ending in Medan Tembung. Here's the image:

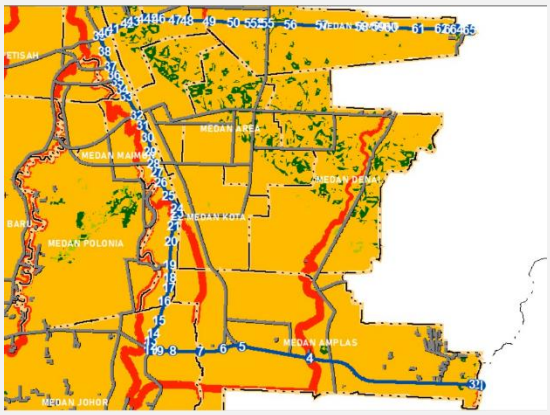

Figure 2. First Route

2. The second route has fifteen evacuation route points located in several areas of Medan City. The main point is in Medan Tuntungan District, then it continues through Medan Johor, Medan Baru, Medan Petisah, Medan Barat, Medan Maimun, Medan Polonia, and returns to Medan Johor. Part of Route 2 overlaps with Route 1. Here's the image:

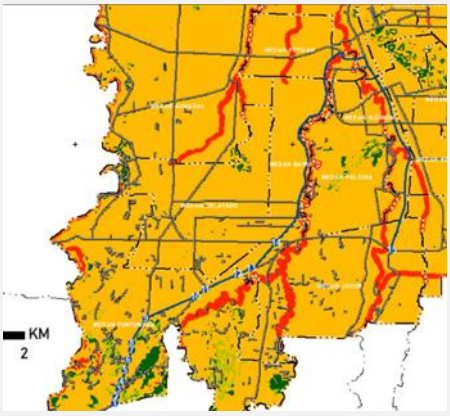

Figure 3. Second Route

3. The third route has five evacuation route points, starting from Medan Helvetia, continuing through Medan Petisah and Medan Barat, and ending in Medan Perjuangan. Here's the image:

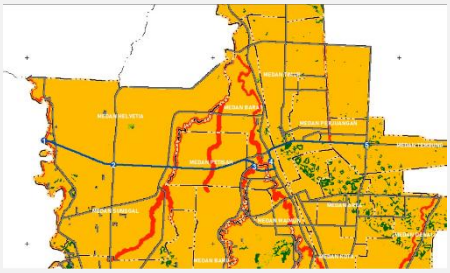

Figure 4. Third Route

4. The fourth route has eleven evacuation route points located in several areas of Medan City. These include 3 points in Medan Helvetia, 3 points in Medan Sunggal, 2 points in Medan Selayang, and the final point in Medan Johor.

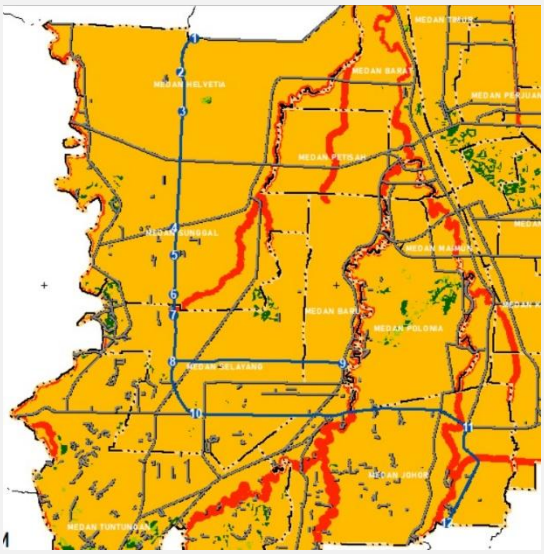

Figure 5. Fourth Route

5. The fifth route has 17 evacuation route points, all of which are located within the Medan Belawan district. Here's the image:

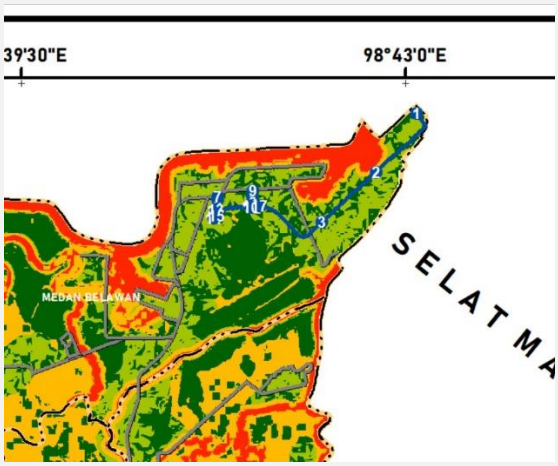

Figure 6. Fifth Route

6. The sixth route has 35 evacuation route points spread across the areas of Medan Belawan, Medan Labuhan, and Medan Deli. Here's the image:

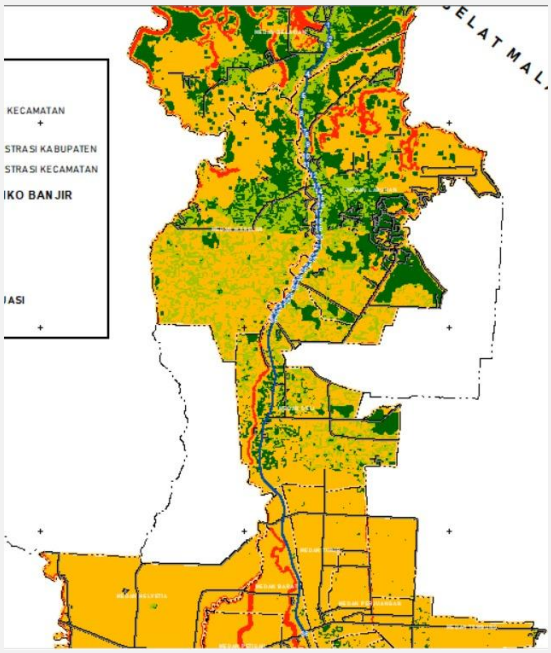

Figure 7. Sixth Route

7. The seventh route has 14 evacuation route points, all of which are located within the Medan Belawan District. Here's the image:

Figure 8. Seventh Route

8. The eighth route has 15 evacuation route points located in Medan City, with the main point in Medan Perjuangan District and also in Medan Tembung. This route passes through Medan Timur District, but there are no route points in that district. Here's the image:

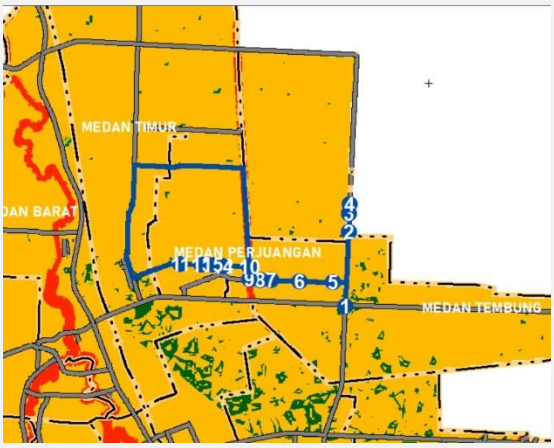

Figure 9. Eighth Route

9. The ninth route has eleven evacuation route points located in Medan City, starting from the first point in Medan Johor, continuing to Medan Tuntungan, and then returning to Medan Johor. Here's the image:

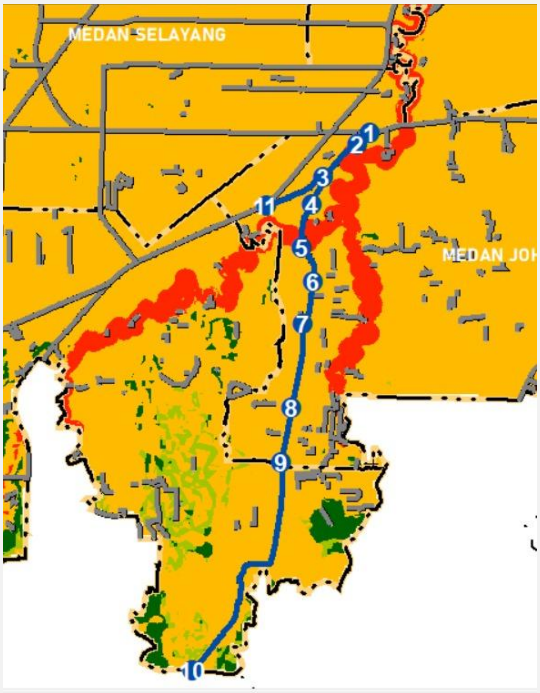

Figure 10. Ninth Route

10. The tenth route has eight route points, starting from Medan Sunggal, passing through Medan Helvetia, and ending in Medan Barat. Here's the image:

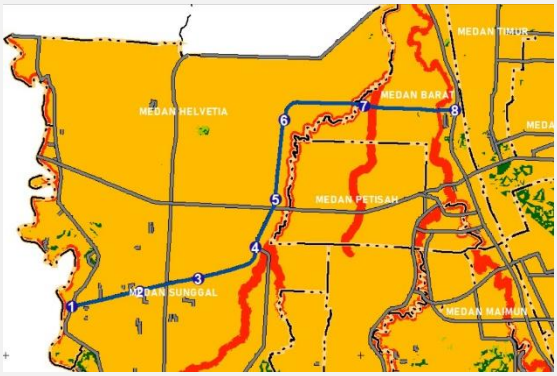

Figure 11. Tenth Route

Here are the results of the flood risk evacuation route mapping in Medan City, as shown below:

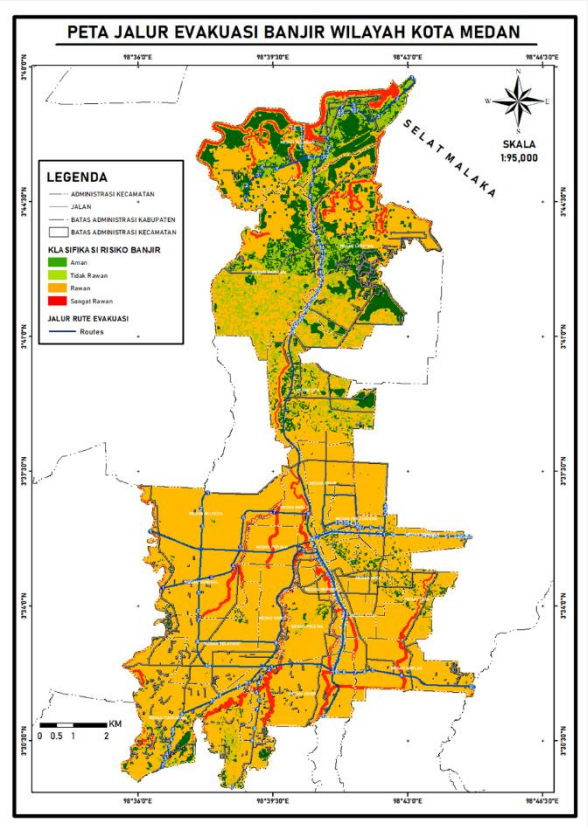

Figure 12. Flood Evacuation Route Map of Medan City Area

Figure 12 displays the result of flood evacuation route mapping in Medan City based on spatial analysis using GIS. The mapping process considered flood-prone locations and the accessibility to safe evacuation points. Each evacuation route shown on the map is the result of Network Analyst calculations, which account for factors such as road conditions, flood risk levels, and proximity to residential areas. Through this mapping, a clear visual overview of evacuation route distribution across various districts is provided, facilitating better planning and decision-making in response to potential flood disasters.

After mapping the flood evacuation routes across the entire Medan City area, the next step is to measure the length of each evacuation route. The length of a route reflects the extent of its coverage in connecting flood-prone areas to safe zones or evacuation shelters. This measurement is essential to assess the effectiveness of the designed routes, as well as to serve as a basis for making logistical decisions and

providing supporting facilities along the evacuation paths. Additionally, comparing route lengths can help identify areas that may require additional access or reinforcement of evacuation infrastructure.

Table 1. Length of Each Flood Evacuation Route

Routes	Route length (Km)
Route 1	21.248301
Route 2	21.120217
Route 3	12.641165
Route 4	20.852767
Route 5	5.567409
Route 6	20.924837
Route 7	8.440056
Route 8	8.84547
Route 9	6.620684
Route 10	9.434835

Table 1 provides a detailed summary of the total length (in kilometers) for each flood evacuation route identified in Medan City. The length of these routes varies depending on the geographical coverage, road network structure, and distribution of evacuation points across subdistricts.

1. Route 1 is the longest evacuation route, covering approximately 21.25 km, which corresponds to its extensive coverage across multiple subdistricts from Medan Amplas to Medan Tembung.
2. Route 5, on the other hand, is the shortest, with only 5.57 km, as it is concentrated entirely within the Medan Belawan district.
3. Other routes, such as Route 2 and Route 6, also cover over 20 km, indicating a broad spatial scope that includes several flood-prone areas.
4. Meanwhile, mid-range routes like Route 4, Route 8, and Route 10 offer moderately long pathways that connect key neighborhoods to designated evacuation zones.

The information in this table is essential for evaluating the relative accessibility and logistical planning needs for each route. It also assists disaster management agencies in identifying which routes may require priority in terms of infrastructure maintenance, signage, and resource allocation to ensure effective flood evacuation.

CONCLUSION

We can conclude from the results of this study entitled Mapping Flood Risk Evacuation Routes in Medan City Using Network Analysis Method that Medan City is a flood-prone area due to urbanization, inadequate drainage systems, and changes in land use. The results produced 10 main evacuation routes covering various districts in Medan City. These routes are designed to avoid flood-prone areas and facilitate evacuation to safe locations. This mapping outcome is expected to serve as a reference for the government in flood risk mitigation and to enhance community safety.

REFERENCES

Anggraini, N., Pangaribuan, B., Siregar, A. P., Sintampalam, G., Muhammad, A., Damanik, M. R. S., & Rahmadi, M. T. (2021). Analisis pemetaan daerah rawan banjir di kota medan tahun 2020. *Jurnal Samudra Geografi, 4*(2), 27–33. https://doi.org/10.33059/jsg.v4i2.3851

Badan Penanggulangan Bencana Daerah Kota Medan. (2012). *Profil Badan Penanggulangan Bencana Daerah Kota Medan*. Badan Penanggulangan Bencana Daerah Kota Medan.

Dall'Osso, F., & Dominey-Howes, D. (2010). Public assessment of the usefulness of "draft" tsunami evacuation maps from Sydney, Australia – implications for the establishment of formal evacuation plans. *Natural Hazards and Earth System Sciences, 10*(8), 1739–1750. https://doi.org/10.5194/nhess-10-1739-2010

Dirgantara, I., & Zalmita, N. (2022). Pemetaan Jalur Evakuasi Bencana Banjir di Kecamatan Gunung Meriah Kabupaten Aceh Singkil menggunakan metode Network Analyst. *Jurnal Pendidikan Geosfer, 7*(2), 256-266. https://doi.org/10.24815/jpg.v7i2.28458

Febrina, R., Evan, D. K., Afriani, L., Retno, R. M. I., Susilorini, & Fitra, H. A. (2020). The analysis of Tsunami evacuation route based on geographic information system: A case study in the coast of Lampung Bay. *IOP Conference Series: Materials Science and Engineering*. https://doi.org/10.1088/1757-899X/807/1/012022

Fischer, M. M., & Nijkamp, P. (1992). Geographic information systems and spatial analysis. *The Annals of Regional Science, 26*, 3–17. https://doi.org/10.1007/BF01581477

Silalahi, M. I., Yunus, M. L., Syamsul, M., Hardianti, S., Wydyiastuti, Y. A., Paramitha, D. S., Firmansyah, H., Abudurohim, A., Gunawan, I. E., & Gumilar, A. (2021). *Kesehatan Lingkungan Suatu Pengantar*. Penerbit Insania.

Pasaribu, D. M. (2021). Tinjauan Perundangan Terhadap Kebijakan Dalam Penanggulangan Bencana Banjir Di Kota Medan. *Prosiding Mitigasi Bencana, November*, 36–42.

Purwati, E. (2024). *Pemanfaatan Sistem Informasi Geografis Untuk Menentukan Jalur Evakuasi Banjir Di Kecamatan Mustikajaya Kota Bekasi* [Undergraduate Thesis, Universitas Islam Sultan Agung Semarang].

Rahmadini, N. (2020). *Pemetaan Jalur Evakuasi Bencana Gempa Sesar Lembang* [Undergraduate Thesis, Institut Teknologi Nasional Bandung].

Sahetapy, G. B., Poli, H., & Suryono. (2016). Analisis Jalur Evakuasi Bencana Banjir Di Kota Manado. *Spasial*, *3*(2), 70–79.

Scheer, S., Gardi, A., Guillande, R., Eftichidis, G., Varela, V., Vanssay, B. de, & Colbeau-Justin, L. (2011). *Handbook of Tsunami Evacuation Planning*. Publications Office of the European Union. https://doi.org/10.2788/34292

Ulum, M. C. (2013). Governance Dan Capacity Building Dalam Manajemen Bencana Banjir Di Indonesia. *Jurnal Dialog Penanggulangan Bencana*, *4*(2), 69–76.

Yusra, C. L., Hilma Erliana, Agustian, K., Zarita, S. S., Luthfi, Mustari, A., Nuthihar, R., Chaira, Arafah, Y., & Fadhiela, K. (2024). Introduction to Evacuation Routes for Tsunami Earthquake Disaster Threats at SMKN 1 Meureubo. *Jati Emas (Jurnal Aplikasi Teknik Dan Pengabdian Masyarakat)*, *8*(3), 55–60.