Mapping of Flood Disaster Risk Areas Based on Geographic Information Systems in the City of Medan

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Abstract. The problem of flood disasters in the city of Medan is very clear, so information is needed about areas that are vulnerable to flooding. The aim of this research is to determine the risk area for flood disasters using the Geographic Information System in the Medan City area. This research uses spatial analysis of overlay, scoring and weighting of several parameters including rainfall, land elevation, slope slope, soil type, land cover and river network density. The results of this research show that most areas of Medan City are in the very vulnerable and flood-prone category, with a total flood risk area reaching 29,967.14 Ha. areas that are safe from the risk of flooding covering an area of 2458.42 ha, areas that are not prone to the risk of flooding covering an area of 439.78 ha, areas with a risk level that is prone to flooding covering an area of 12213.13 ha and areas with a risk level that is very prone to flooding covering an area of 15455.81 ha . With the total area area, this map reveals that most of the areas in Medan City are in the very flood-prone category (58.24%), followed by areas at risk of being flood-prone (46.06%). Only around 10.92% of the total area is classified as safe or not prone to flood risk.

Keywords : Mapping, Flood Risk, Geographic Information Systems

1 Introduction

A disaster is a phenomenon or event that causes significant losses to the community due to its destructive nature, resulting in damage and requiring a long recovery process afterward [1]. According to BNPB (2007) in [2] a disaster is an event or series of events that threatens and disrupts the lives and livelihoods of communities. Generally, disasters can be caused by natural, non-natural, and human factors. The impacts of disasters include loss of human life, environmental damage, property loss, and psychological effects.

One of the natural disasters that has frequently occurred in Indonesia recently is flooding, especially during the rainy season [3]. Flooding is when water levels rise and overflow from rivers, lakes, or seas onto lower-lying areas, such as residential areas, roads, and agricultural lands. [4]. Flooding can be caused by natural situations and phenomena (such as topography

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and rainfall), as well as the geographical conditions of an area, which impact land use and spatial planning in the region [3]. In addition, flooding often occurs due to human activities, such as construction in flood-prone areas and improper waste disposal that blocks water flow [4].

The city of Medan, located in Indonesia, is the second largest city in the country and faces flooding nearly every year. While the extent of flooding in Medan is not as severe as in Jakarta and its neighboring areas, it has evolved into a recurring annual disaster. This persistent flooding issue is closely related to the city's geographical features, as Medan is intersected by several large and small rivers, as well as various tributaries. Major rivers that flow through Medan include the Belawan River, Deli River, Percut River, and Serdang River, while smaller rivers include the Batuan River, Badera River, and Kera River [5]. Flooding in the city of Medan has recently submerged several districts within the city over the past few months.

The city of Medan is prone to flooding due to its flat topography in certain areas, which were originally designated as water absorption zones but have since been converted into residential and industrial areas [6]. Besides that, the construction of high-rise buildings, residential complexes, and commercial areas that are not environmentally friendly has led to a lack of water absorption areas. Moreover, there is a significant amount of waste discarded indiscriminately in drainage channels, which obstructs water flow during rain. This accumulation of waste increases the potential for flooding due to standing water.

Flood disasters in each region have different characteristics, therefore decision-making in each region will be different [7]. Currently, the issue of flooding in the city of Medan is very apparent, highlighting the need for information on flood-prone areas. One approach to address this is the creation of flood hazard maps using Geographic Information Systems (GIS) to minimize flooding in Medan. Mapping flood-prone areas is essential for identifying and analyzing flood issues using GIS, which enables more targeted flood management and mitigation efforts [8].

The utilization of Geographic Information Systems (GIS) is very important because GIS applications can explain and present objects of flood-prone areas from the real world into digital form, so that flood-prone areas can be mapped and can be used as a supporting alternative for non-structural flood control [9]. Furthermore, Geographic Information Systems (GIS) techniques can provide crucial information for early warning and emergency response during disasters. By using these techniques, comprehensive geographic information is generated, which supports informed decision-making in disaster response. This enhances community protection, reduces property damage, improves disaster monitoring, and facilitates the assessment of damage and losses caused by disasters [10].

By carrying out flood vulnerability mapping in Medan City, the goal is to achieve more organized, coordinated, and sustainable urban development, which will ultimately help in reducing the impact of flooding on both the community and the environment. Thus, this study aims to evaluate flood disaster risk areas in Medan using Geographic Information Systems (GIS).

2 Research Methods

This study takes place in Medan City, which is located in North Sumatra Province, Indonesia. Medan is positioned between the latitudes of 3°30' and 3°43' S, and the longitudes of 98°35' and 98°44' E.The research utilizes spatial overlay analysis, scoring, and weighting techniques across various parameters, such as rainfall, land elevation, slope gradient, soil type, land cover, and river network density.

The data used in this study are rainfall data, slope, land elevation, land use, soil type, and river buffer from several sources, such as the Badan Informasi Geospasial (BIG) and National DEM Data.

Table 1. Research Data

No	Data Type	Year	Source
1	Slope	2022	Digital Elevation, National DEM Model,
2	Area Elevation	2022	Badan Informasi Geospasial
3	Administrative Boundary	2022	
4	Road Network	2022	Badan Informasi Geospasial Google Earth
5	River Network	2022	and Open Street Map
6	Land Use	2022	
7	Rainfall	2022	Centre for Hydrometeorologi, and Remote Sensing (CHRS)
8	Surface Runoff	2022	Land Use Map

Source : Author's Analysis 2024

The object of this research is the flood disaster that occurred in Medan City. The research subject is a map obtained from the relevant agencies in Medan City. The type of research used is descriptive quantitative. Quantitative descriptive data are numbers obtained from the calculation process.

Table 2. Rainfall

Rainfall (mm)	**Score**	**Weight**	**Description**
0-500	1		Very Low
500-1000	2		Low
1000-1500	3	5	Medium
1500-2000	4		High
>2000	5		Very High

Table 3. Surface Runoff

Coefficient	**Score**	**Weight**	**Description**
0,30-0,95	1		Built-up Land
0,20-0,40	2		Agricultural Land
0,10-0,30	3	4	Shrubland
0,15-0,25	4		Plantation
0,02-0,10	5		Plantation Forest

Table 4. Distance to River

Distance to River	**Score**	**Weight**	**Description**

0-50	1		Very Near
50-100	2		Near
100-250	3	5	Medium
250-500	4		Far
>500	5		Very Far

Table 5. Height of Place

Elevation	Score	Weight	Description
>1.000 masl	1		Very High
750-1.000 masl	2		Quite High
500-750 masl	3	5	High
250-500 masl	4		Ramps
0-250 masl	5		Flat

Table 6. Soil Type

Soil Type	Score	Weight	Description
Litosol, Organosol, Rendzina, Regosol	1		Low
Vertisol, Andosol, Grumusol, Laterit, Podsol, Podsolik	2		Moderate
Kambisol, Mediteran, Brown Forest Soil, Non Calcic Brown	3	5	High
Latosol	4		Veri High
Aluvial, Glei, Planosol, Hidromorf, Groundwater Laterit	5		Extremely High

Table 7. Slope

Slope	Score	Weight	Description
>40%	1		Very Steep
25 – 40 %	2		Steep
15 – 25%	3	5	Moderately Steep
8 – 15%	4		Ramps
0 – 8%	5		Flat

After each parameter is assigned scores or values and weights according to the reference table, the next step is to perform an overlay of all parameter maps and then calculate the vulnerability index using the following arithmetic formula:

$$FV = (10 \times SL) + (25 \times LU) + (15 \times RF) + (10 \times ST) + (20 \times E) + (20 \times RB)$$

Keterangan :

SL : Slope

LU : Land Use

RF : Rainfall

ST : Soil Type

E : Elevation

RB : River Buffer

Weighting is the assignment of weights on digital maps to each parameter that affects flooding. The greater the influence of the parameter on flood events, the higher the weight given [11]. Then the determination of flood-prone areas is carried out by analyzing the results of the entire parameter count to be classified. In this research, the classification of flood-prone areas is divided into three classes. The classification results are given a score which is then divided into 3 landslide vulnerability classes, namely low, medium and high. The flood vulnerability class is determined based on the sum of the final score.

The higher the final score obtained from the weighted overlay of parameters, the greater the flood vulnerability in the area. When classifying flood vulnerability, it is typically done by considering specific standards or criteria, such as using the interval class method or the class distance method [12]. The aim is to produce a classification that is objective and accountable

The implementation of the research refers to the flowchart that has been made so that the research runs according to the procedure. The research flowchart is illustrated in Figure 1.

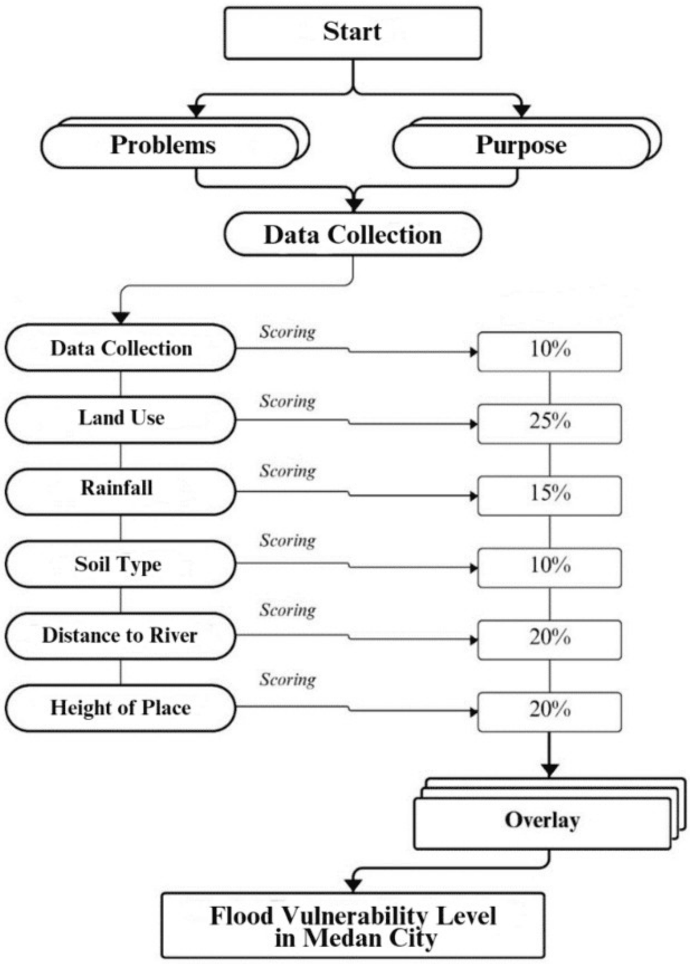

Fig. 1. Research Workflow

3 Results And Discussion

3.1 Description of Medan City Area

Medan City is the capital of North Sumatra Province, Indonesia with an area of 265.10 km2 (BPS Kota Medan, 2023). Thus, compared to other cities or regencies, Medan has a relatively small area but a relatively large population. Medan is located between 3°30' - 3°43' North Latitude and 98°35' - 98°44' East Longitude, with an elevation ranging from 2.5 to 37.5 meters above sea level.

Medan City borders the Malacca Strait and Deli Serdang Regency with the following boundaries:

1. Northern Boundary : Strait of Malacca
2. Western Boundary : Pancur Batu, Deli Tua (Deli Serdang Regency)
3. Eastern Boundary : Tanjung Morawa (Deli Serdang Regency)
4. Southern Boundary : Binjai City, Hamparan Perak (Deli Serdang Regency)

Medan City is divided into 21 sub-districts and 151 urban villages, which are further segmented into 2,001 neighborhoods. The sub-districts within Medan include Medan Tuntungan, Medan Johor, Medan Amplas, Medan Denai, Medan Area, Medan Kota, Medan Maimun, Medan Polonia, Medan Baru, Medan Selayang, Medan Sunggal, Medan Helvetia, Medan Petisah, Medan Barat, Medan Timur, Medan Perjuangan, Medan Tembung, Medan Deli, Medan Labuhan, Medan Marelan, and Medan Belawan [14].

In addition, Medan City is also flowed by several rivers, namely Badera River, Belawan River, White River, Sikambing River, Deli River, Babura River, Kera River, Sulang-Saling River and Tuntungan River. Some areas of Medan City are also very close to the sea area, namely the West Coast of Belawan and areas classified as highlands, namely Karo Regency.

3.2 Description of Flood Risk Area Map of Medan City

The goal of mapping flood disaster risk areas in Medan City is to classify regions based on their flood risk levels, ranging from safe and low risk to prone and highly prone. This is done through spatial analysis using Geographic Information Systems (GIS) with ArcGIS software. The resulting map is printed on A0-sized paper with a scale of 1:50,000.

The map shows the administrative divisions of Medan City, including its 21 sub-districts. It also includes additional information such as administrative boundaries for districts and sub-districts, road networks, rivers within Medan, map scale, cardinal directions, coordinate systems, and location diagrams.

The data shown on this map represents flood risk areas in Medan, sourced from analysis conducted between April and May 2024. The flood risk area data is derived from processing various risk parameters, including rainfall, slope gradient, land elevation, land use, soil type, and river buffers from sources such as the Geospatial Information Agency (BIG) and National DEM data. This data was processed using overlay and scoring methods to produce the flood risk map as shown in (Figure 2).

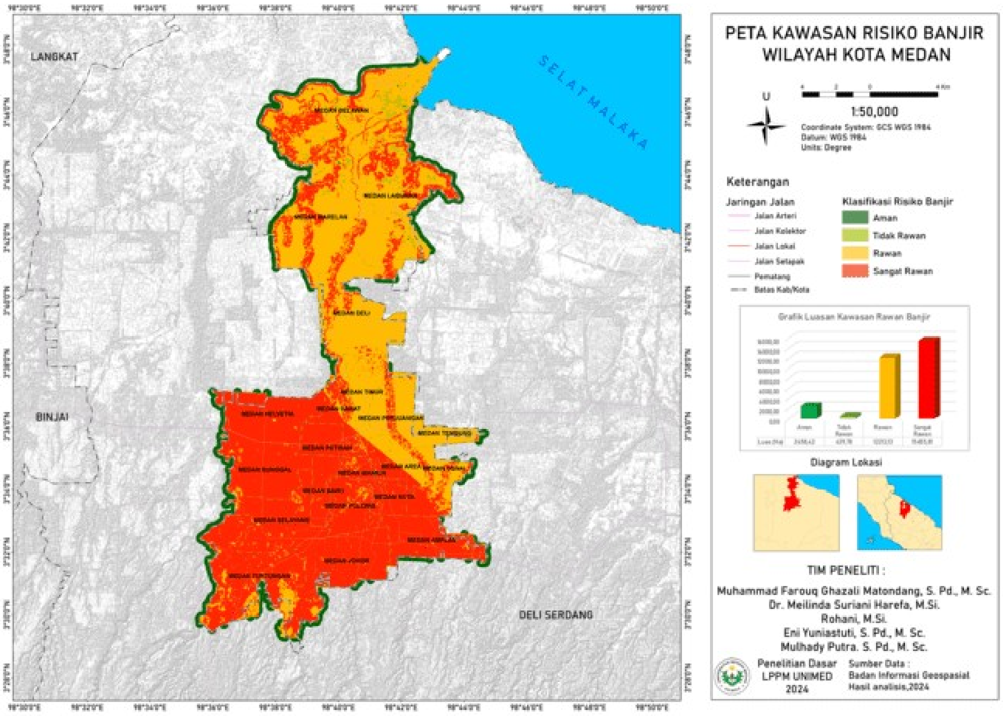

Fig. 2. Flood Risk Area Map of Medan City

From the results of the analysis that has been carried out, it produces a percentage and area of flood risk areas. Based on previous data processing in (Figure 2) there are 4 color classifications used to distinguish the level of flood risk as follows:

1. Dark green indicates areas that are safe from flood risk, with an area of 2,458.42 hectares.
2. Light green shows areas that are not prone to flood risk, with an area of 439.78 hectares.
3. Yellow denotes areas with a high risk of flooding, covering an area of 12,213.13 hectares.
4. Red represents areas with a very high risk of flooding, with an area of 15,455.81 hectares.

Based on the analysis results, it is known that each sub-district in Medan City is identified with varying levels of flood risk. To obtain the percentage of each category based on the above data, the total area of each category is calculated. The total area of Medan City is known to be 26,510 hectares. Therefore, the percentage for each flood risk category is calculated using the following formula:

Percentage = (Area of category / Total area) × 100

After that, the percentage of each category is calculated as follows:

1. Safe Percentage = (2458,42 / 26.510) × 100 = 9,26%
2. Not Prone Percentage = (439,78 / 26.510) × 100 = 1,66%
3. Prone Percentage = (12213.13 / 26.510) × 100 = 46,06%
4. Very Prone Percentage = (15455.81 / 26.510) × 100 = 58,24%

Based on the calculations, it can be concluded that most of Medan City is categorized as "very prone" to flooding, accounting for 58.24%. This high-risk classification covers significant portions of the sub-districts including Medan Helvetia, Medan Petisah, Medan Maimun, Medan Baru, Medan Sunggal, Medan Polonia, Medan Kota, Medan Amplas, Medan Johor, Medan Tuntungan, and Medan Selayang. This is further supported by data from BPBD (2020) in [15] which reports that during 2019, there were 3,247 victims from 25 flood incidents in the sub-districts of Medan Johor (five times), Medan Maimun (five times), Medan Polonia (five times), Medan Baru (five times), and Medan Selayang (five times).

This is followed by areas with a high flood risk (46.06%), which include parts of Medan City such as the sub-districts of Medan Belawan, Medan Labuhan, Medan Marelan, Medan Deli, Medan Timur, Medan Perjuangan, Medan Tembung, Medan Denai, and Medan Area. Only about 10.92% of the total area of Medan City is classified as safe or not prone to flood risk.

This indicates the need for more serious attention and mitigation measures to address flood risks in the area. The analysis suggests that both the government and the community need to pay closer attention to the recurring flood issues in Medan City. One approach to flood disaster risk reduction in this study is space-based risk management. Additionally, flood risk reduction in Medan City should also consider spatial planning, land use management, and regulation of land use.

Spatial planning is mapping areas that are low risk and do not have historical disasters to be used as relocation sites for communities located in land use utilization areas that deviate or are not in accordance with spatial patterns such as settlements on riverbanks and coastal borders [16]. Then, spatial utilization is carried out by controlling settlements located in the river boundaries surrounding Medan City. With accurate mapping and in-depth analysis, it is expected that effective mitigation measures can be taken to reduce the impact of flood disasters in Medan City.

4 Conclusions

From the findings of this study, it can be inferred that flood risk mapping for Medan City reveals that a significant portion of the area falls into the very high risk and high risk categories, totaling 29,967.14 hectares. The analysis shows that areas considered safe from flood risk amount to 2,458.42 hectares, regions with low flood risk are 439.78 hectares, those at high flood risk cover 12,213.13 hectares, and areas with very high flood risk span 15,455.81 hectares. Consequently, the map indicates that most of Medan City is categorized as very high risk (58.24%), with areas at high flood risk following at 46.06%. Only approximately 10.92%

of the total area is deemed safe or not prone to flood risk. This underscores the urgent need for more focused attention and effective measures to mitigate flood risks in the area.

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