

Implementing Sustainable Drainage Systems for Urban Flood Resilience in Medan

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Abstract. This research is motivated by the significant impact of flood disasters, both in terms of material and non-material losses, as well as the difficulty in determining priority scales for flood management in the city of Medan. The drainage system no longer functions as intended, either due to its capacity being smaller than the existing discharge, lack of maintenance, or drainage and disposal systems that no longer align with environmental conditions, among other factors. These issues result in recurring annual flooding. The objective of this research is to implement a drainage system for flood disaster risk mitigation in a case study of the Medan city area, including mapping flood vulnerability and susceptibility indices through drainage system design, and providing guidelines for drainage system design in Medan. The research methodology involves collecting both primary and secondary data. A flood risk index map is compiled based on vulnerability, susceptibility, and capacity indices in the study area. The development of these indices for the drainage areas in Medan city is conducted using parameter weighting with the support of Geographic Information System (GIS) technology, rainfall data from BMKG (Meteorology, Climatology, and Geophysical Agency), land use data, and more. Furthermore, periodic flood discharge is calculated using the Rational Method. The research method used is research and development (R&D).

Keywords: Drainage System, Flood Disaster, GIS, Medan City

1. Introduction

1.1. Background

Medan is one of the major cities in Indonesia that frequently experiences flooding, especially during the rainy season. The main causes of flooding in Medan are high rainfall intensity and an inadequate drainage system. The inability of the drainage system to accommodate rainwater is considered the primary factor behind the recurrent floods. As a result, thousands of people have been affected, residential homes have been submerged, and several residents have tragically lost their lives after being swept away by the floodwaters. [2] Meteorological data related to rainfall patterns that influence flooding in Medan can be utilized for further analysis. The occurrence of evenly distributed, high-intensity, and prolonged rainfall across several areas of the city has led to severe flooding and landslides, forcing many residents to evacuate to safer locations [1]. Responding to the definition of disaster, it is concluded that most disaster

definitions reflect the following characteristics: disruption to normal life, effects on humans, such as becoming victims, injuries/disabilities, health problems, effects on social structures and community needs [4].

The title of this research is “Implementing Sustainable Drainage Systems for Urban Flood Resilience In Medan.” This study aims to support flood risk mitigation by reducing the potential for waterlogging and inundation in urban areas, particularly in Medan. With effective flood mitigation, previously flood-prone land can be repurposed for other uses such as recreational spaces or road infrastructure. The main problems addressed in this research include the absence of a proper drainage system design, the urgent need for drainage planning and implementation in Medan, and the lack of comprehensive management and coordination among responsible institutions. Moreover, the study highlights the need for greater community involvement in drainage management, along with addressing limitations in funding and regulatory frameworks.[5]. Literature studies were conducted by reviewing the contents of literature related to the research theme, including books, research results, spatial planning documents, and articles on the internet and mass media [6]. Many factors contribute to flooding. However, generally speaking, flooding can be classified into two categories: naturally occurring floods and human-caused floods [3]

1.2. Research Problems

- How can flood disaster risk reduction be effectively mitigated in urban areas of Medan?
- How can public awareness be improved to encourage community participation in maintaining the cleanliness of drainage channels?
- How can flood hazard and vulnerability mapping be conducted through the implementation of an effective drainage system?

1.3. Research Novelty and Technological Innovation

The novelty of this research lies in the application of Building Information Modeling (BIM) to design and simulate a more accurate and effective urban drainage system. This approach incorporates key variables such as topography, rainfall intensity, and drainage capacity, allowing for a more data-driven and spatially informed planning process. In addition, the research introduces the integration of Big Data and Artificial Intelligence (AI) technologies to analyze weather patterns, rainfall distribution, and water flow. This enables flood risk prediction across various urban zones with improved precision. By leveraging advanced data analytics, the system can dynamically provide more accurate flood forecasts and offer real-time recommendations for drainage management and disaster mitigation.

This technological breakthrough is highly urgent, considering the extensive damage urban flooding can cause including destruction of transportation infrastructure (roads, bridges, railways, airports), residential areas, schools, places of worship, disruptions to local economies and public health, and damage to agricultural facilities.

The research also contributes to the advancement of science, technology, and innovation. Key strengths of this study include:

1. Addressing the limited availability of effective drainage systems for flood control in Medan.
2. Enabling faster access to information related to management, coordination among responsible institutions, community involvement, and identifying gaps in funding and regulatory frameworks.

3. Providing a mapping framework for flood vulnerability, hazard, and adaptive capacity through the design and modeling of an urban drainage system specific to Medan. Ultimately, this research is conducted as part of a broader effort to mitigate and reduce the risks of flood disasters, which pose a significant threat to urban populations.

2. Methodology

2.1. Initial Survey and Analysis

Survey of Existing Drainage Conditions in Medan City was conducted at several flood-prone locations, involving interviews with the Department of Public Works (Dinas PU) and the Regional Disaster Management Agency (BPBD), as well as photographic documentation of drainage channels. The study employed a combined approach, integrating geospatial data analysis, hydrological simulation, technical drainage design, and the involvement of local communities and stakeholders. This integrated methodology aims to develop an efficient and sustainable drainage system while also providing policy recommendations to improve flood risk mitigation in Medan City. Additionally, the research includes the modeling of rainfall frequency and duration that typically trigger flood events.

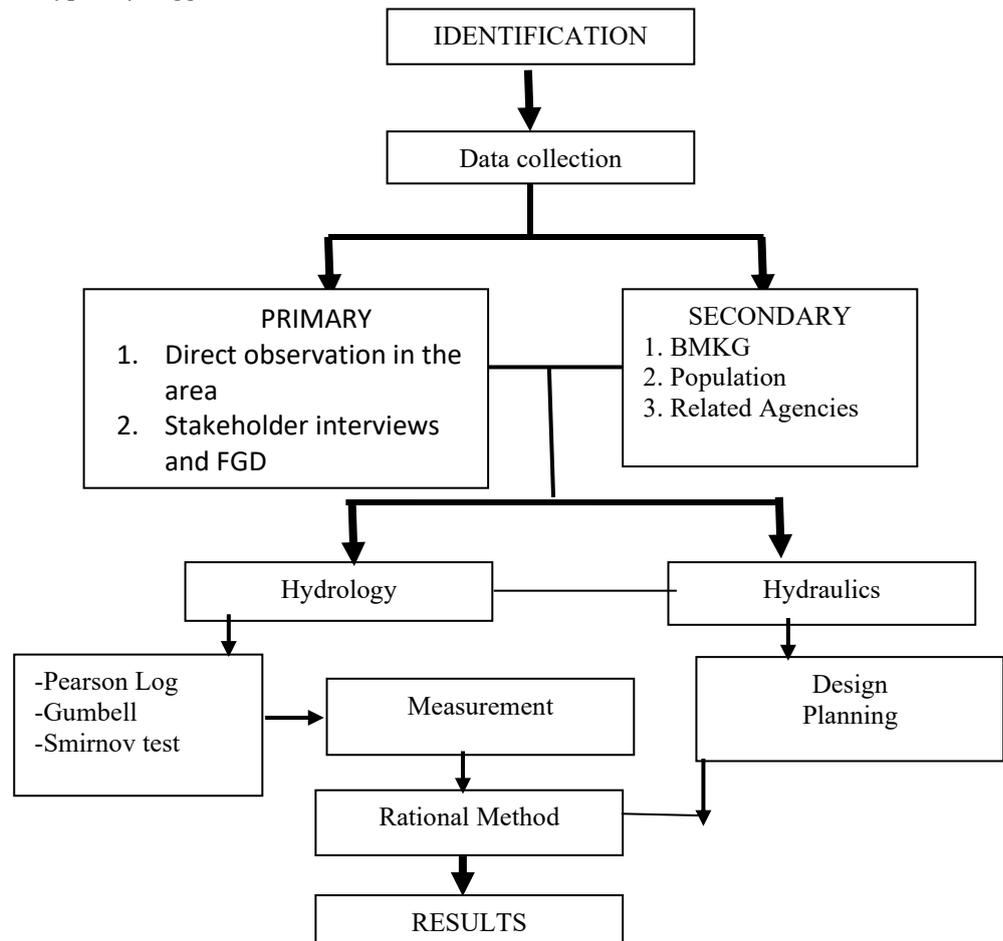


Figure 1. Research flowchart

3. Results and Discussion

3.1. Drainage Planning Plan in Medan City



Figure 1. Flood conditions around the Merdeka Field area

Based on the results of the field survey, there are flood points spread across 3 sub-districts, namely: 1. West Medan Sub-district 2. Medan Petisah Sub-district 3. East Medan Sub-district as shown in the image below. 2-Dimensional and 3-Dimensional Drainage Channel Design Plans [11].

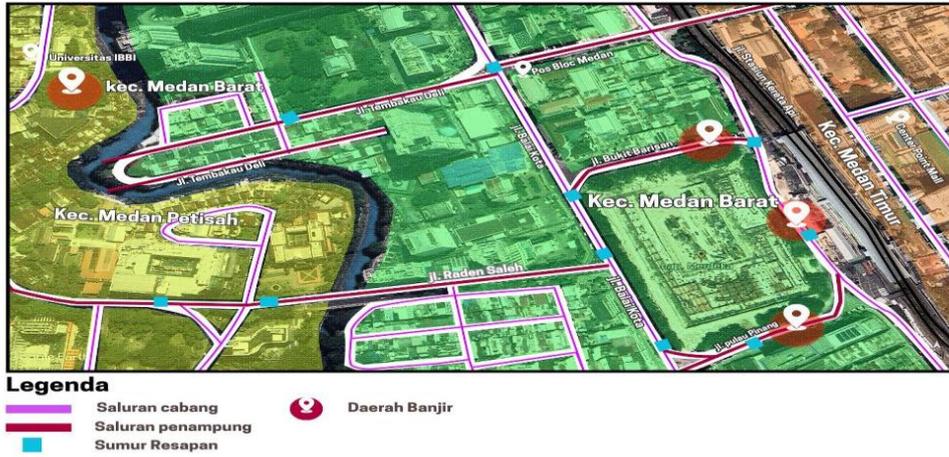


Figure 2. Flood conditions in 3 districts around Medan city



Figure 3. 3-dimensional Drainage Plan

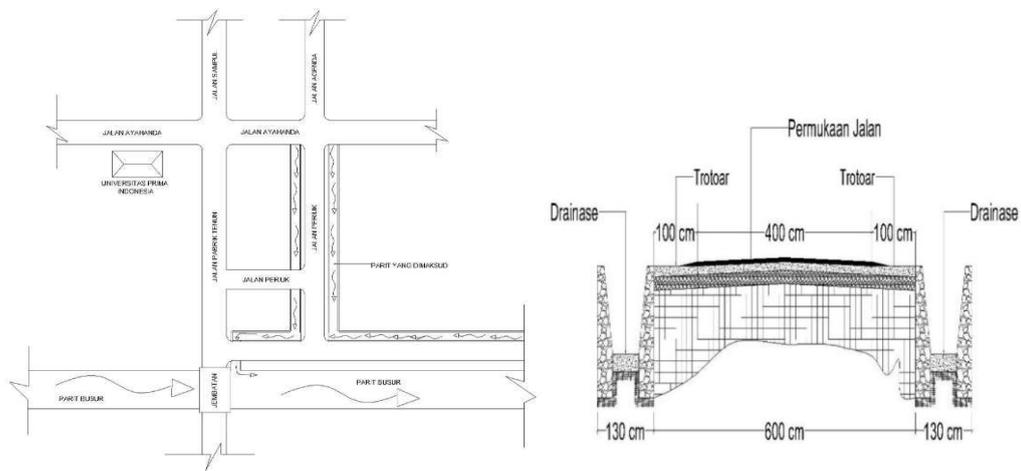


Figure 4. Jl. Periuk Ling. IV, Sei Putih Tengah Subdistrict, Medan Petisah District

3.2 General Conditions and Study Location

The study location chosen by the author to conduct this research was obtained from the Google Earth map, where the map explains the condition of floodwaters at the location of each channel [8]. This display can be seen in Figures 5.

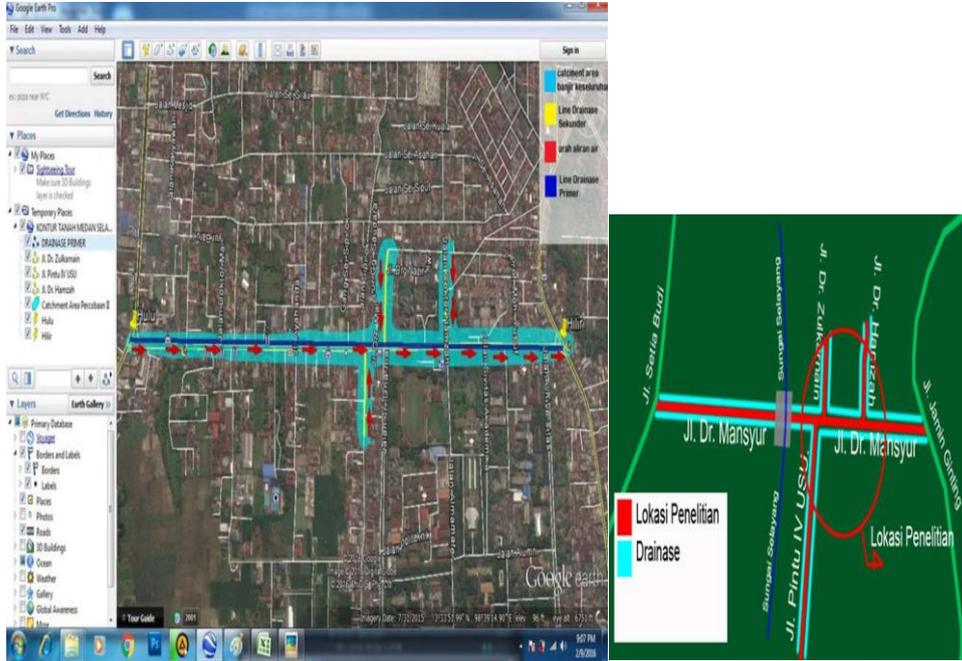


Figure 5. Location of the Channel Catchment Area (Google Earth)

3.3 Planned Rainfall Analysis

Within the realm of statistics, there are several known types of frequency distributions, and in hydrology, there are four methods commonly used in rainfall analysis calculations: the Normal, Log-Normal, Log-Pearson III, and Gumbel distributions [7]. The average value is taken to obtain the areal rainfall value. Observations of maximum daily rainfall based on the Meteorology, Climatology, and Geophysics Agency (BMKG) Sampali Station for 10 years are shown in Table 1.

Table 1. Maximum daily rainfall

Year	Maximum Daily Rainfall (mm)
2015	112
2016	107
2017	159
2018	201
2019	160
2020	127
2021	131
2022	109
2023	111

N = 10 Years

1334

From the average maximum rainfall data, the distribution pattern is then calculated using frequency analysis. The distributions for which frequency analysis will be conducted include the Gumbel Distribution and the Log Pearson Type III Distribution.

3.4. Frequency Analysis

Frequency analysis is a procedure for estimating the frequency of an event in the past or future. This procedure can be used to determine design rainfall for various return periods based on theoretical and empirical rainfall distributions. This design rainfall is used to determine the rainfall intensity required for peak flow rates (flood discharge).

Table 2: Frequency analysis calculation for Gumbel Distribution

No	Tahun	Xmax	Xt	Xi-Xt	(Xi-Xt) ²	(Xi-Xt) ³	(Xi- \bar{X} t) ⁴
1	2015	112	201,000	67,60	4570	308915,776	20882706,458
2	2016	107	160,000	26,60	707,56	18821,096	500641,154
3	2017	159	159,000	25,60	655,360	16777,216	429496,730
4	2018	201	131,000	-2,40	5,760	-13,824	33,178
5	2019	160	127,000	-6,40	40,960	-262,144	1677,722
6	2020	127	117,000	-16,40	268,960	-4410,944	72339,482
7	2021	131	112,000	-21,40	457,960	-9800,344	209727,362
8	2022	109	111,000	-22,40	501,760	-11239,424	251763,098
9	2023	111	109,000	-24,40	595,360	-14526,784	354453,530
10	2024	117	107,000	-26,40	696,960	-18399,744	485753,242
Total			334,000	0,00	8500,400	285860,880	23188591,952
Average \bar{X}		133,400					
S		30,733					
Cs		1,368					
Ck		5,158					
Cv		0,230					

Table 3. Frequency analysis calculations for Log Normal and Log Pearson Type III Distributions.

No	Tahun	Xmax	Xi	Log Xmax	Xi-Xt	Log(Xi-Xt) ²	Log(Xi-Xt) ³	Log(Xi-Xt) ⁴
1	2015	112	201	2,303	0,187	0,035	0,007	0,001
2	2016	107	160	2,204	0,088	0,008	0,001	0,000
3	2017	159	159	2,201	0,085	0,007	0,001	0,000

4	2018	201	131	2,117	0,001	0,000	0,000	0,000
5	2019	160	127	2,104	-0,012	0,000	0,000	0,000
6	2020	127	117	2,068	-0,048	0,002	0,000	0,000
7	2021	131	112	2,049	-0,067	0,004	0,000	0,000
8	2022	109	111	2,045	-0,071	0,005	0,000	0,000
9	2023	111	109	2,037	-0,079	0,006	0,000	0,000
10	2024	117	107	2,029	-0,087	0,007	-0,001	0,000
Total			1334	21,159	0,000	0,076	0,006	0,001
Average \bar{X}			133,4	2,116				
S			0,092					
Cs			1,078					
Ck			4,175452					
Cv			0,001					

3.5. Flood Discharge Analysis Plan

3.5.1. Rational Method

The rational method is used because of the wide flow area in the channel. The design flood discharge formula for the rational method is as follows:

$$Q = 0,00278.C.I.A$$

Dimana:

- Q = Deep discharge (m³/sec)
- C = Discharge in (m³/sec)
- I = Rainfall intensity (mm/hour)
- A = Area of drainage (Ha)

In this drainage, a flow coefficient of 0.95 is used because the study area is a densely populated urban area

3.5.2. Look for Q plans

The calculation of rainfall intensity on Jalan Dr. Mansyur for the periods of 2, 5 and 10 years can be seen in Table 4.

Table 4. Calculation of rainfall for return periods of 2, 5, and 10 years

No	Periode	R24 (mm)	C	tc (jam)	I (mm/jam)
1	2	111.0366	0.95	1.099	36.1760

2	5	118.2585	0.95	1.099	38.5289
3	10	122.8456	0.95	1.099	40.0234

The calculation of rainfall intensity on Jalan Dr. Mansyur for the periods of 2, 5 and 10 years can be seen in Table 4.

So the design flood discharge for a 2 year return period is:

$$Q = 0.00278 \text{ C.I.A}$$

$$Q = 0.00278 \cdot 0.95 \cdot 36,1760 \cdot 40$$

$$Q = 3.821 \text{ m}^3/\text{sec}$$

So the design flood discharge for a 5 year return period is:

$$Q = 0.00278 \text{ C.I.A}$$

$$Q = 0.00278 \cdot 0.95 \cdot 38,5289 \cdot 40$$

$$Q = 4.070 \text{ m}^3/\text{sec}$$

So the design flood discharge for a 10 year return period is:

$$Q = 0,00278 \text{ C.I.A}$$

$$Q = 0.00278 \cdot 0.95 \cdot 40,0234 \cdot 40$$

$$Q = 4.228 \text{ m}^3/\text{sec}$$

The design flood discharge calculations for 2-year, 5-year and 10-year return periods are available in Table 5.

Table 5. Calculation of return periods of 2, 5 years and 10 years

No	Periode	L (Km)	C	Tc (hour)	I (mm/hour)	A (Ha)	Q (m ³ /sec)
1	2	2.1	0.95	1,099	36.1760	40	3.821
2	5	2.1	0.95	1,099	38.5289	40	4.070
3	10	2.1	0.95	1,099	40.0234	40	4.228

3.6. Characteristics of Flood Conditions

A flood occurs when excessive water flow submerges land, meaning it's the temporary submersion of land that isn't normally submerged. Flooding on several roads in Medan is often caused by heavy rainfall in the area.

Flooding in this area is caused by the drainage channels being unable to handle the volume of water caused by prolonged rainfall, causing it to overflow onto the roadway. This is also due to the accumulation of garbage, which obstructs the flow of water through the drainage channels located on the right and left sides of the road.

According to a survey conducted among local residents, it was found that the puddles that overflowed onto the body such as Dr. Mansyur Street are along 2100 m of the road with an average height of puddles reaching 50-70 cm at the highest point with a puddle area of around 21.5 Ha for 10-12 hours until the puddles start to shrink and stabilize again, this is caused by

the high intensity of rainfall that often hits the area especially during the rainy season.

4. Conclusion

Mitigating flood disaster risk reduction in the Medan city area has not yet fully functioned optimally in reducing flood risk. This is caused by various factors, including limited channel capacity, blockages by garbage and sediment, and technical designs that are not in accordance with land use developments and increasing rainfall intensity. Flood discharge is approximately 3,821 m³/s over a 2-year period.

Increasing public awareness to maintain the cleanliness of drainage channels is necessary. The approach must be sustainable, educational, and involve direct participation of residents and ensure easy access to drainage channels so that residents can help clean them.

Mapping flood vulnerability through drainage system implementation:

Historical flood data (frequency, inundation height, duration). Flood vulnerability remains high in several areas of Medan City, particularly in the densely populated Petisah, Helvetia, Medan Tembung, and Medan Sunggal sub-districts, low-lying areas, and areas experiencing rapid land conversion without adequate drainage system planning.

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