

Flood vulnerability and flood-prone area map at Medan City, Indonesia

R Dian¹, L Lismawaty², D E Pinem¹ and B B Sianipar¹

¹Medan Institute of Technology, Regional, and City Planning Department, Jalan Gedung Arca No 52, Medan, Indonesia

²Medan Institute of Technology, Geology Department, Jalan Gedung Arca No 52, Medan, Indonesia

Correspondent author: rdians@yahoo.com, eresina22@yahoo.com, liz_geoitm@yahoo.com

Abstract. Medan is the third largest city in Indonesia. It is a lowland with topography tend to ramps and as an encounter place of two rivers namely Deli River and Babura River. Medan city is prone to flood because it is a downstream area traversed by those two rivers. According to the Regional Disaster Management Agency, the most frequent disaster in Medan City is a flood, which occurred almost every year over the last 10 years. Climate change has caused increasing frequency and intensity of rainfall in North Sumatra in recent years. It triggers the occurrence of floods. The purpose of this study was to determine the area which is vulnerable and *prone* to flood. The objectives are making a map of flood prone area and flood vulnerability map. The research is descriptive, which *used Geographical Information System* (GIS) analysis. GIS is used to produce disaster-prone maps by sequencing data such as slope, land use and landform. From the research above, it found that Medan City is generally a flood-prone area and has a high vulnerability for flooding. Medium and high flood-prone areas reach 95% of the entire area of Medan City. Meanwhile vulnerable areas are low and medium reaching 98%.

1. Introduction

Medan is the third largest city in Indonesia with an area of 26,510 ha and a population of up to 2,229,408 in 2016. The city is located on the East Coast of Sumatra, with an altitude of 2.5-40 m above sea level, and a slope of 0-3% so that it is a lowland with a sloping topography. Medan is also an encounter place for two rivers, the Deli River and Babura River.

As a downstream area that is traversed by 2 rivers, Deli River and Babura, the City of Medan is one of the flood-prone cities. According to the National Board for Disaster Management, the most frequent disaster in Medan City is a flood disaster. Over the past 10 years, floods have almost occurred every year in the city of Medan. Since 2008 until mid-2018, there have been 30 flood events with the death toll of 6 people, displaced 669,997 people, lightly damaged houses with 616 units, and submerged houses reaching 136,861 units. More details can be seen in figure 1.

According to the National Board for Disaster Management inventory [1], in 2010-2012, Medan Polonia, subdistrict, Medan Selayang and Medan Baru were the most affected districts. Flooding in Medan Polonia during this period occurred 18 times, in Medan Selayang 18 times and Medan Baru 17 times.



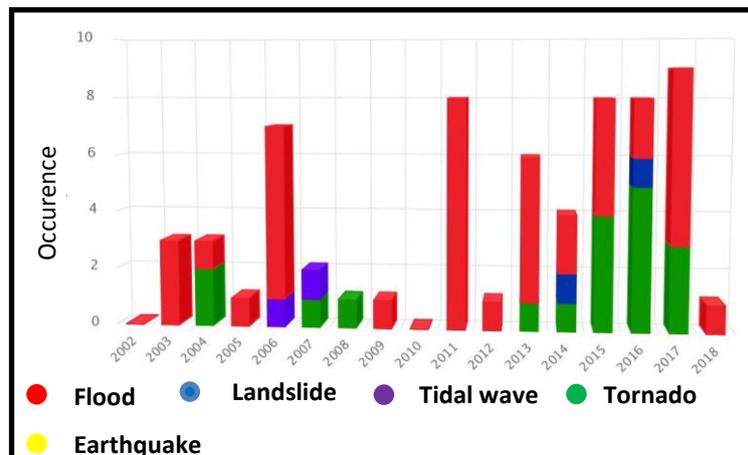


Figure 1. The trend of the last 15 years of disaster in Medan City

Floods in Medan City estimated due to several things, namely:

- Changes in land use from forests to non-forests in the upstream area,
- Refinement of river or channel sections because of a large number of buildings on the banks of the river.
- Silting of rivers and channels due to littering.
- The overflow of seawater to the mainland (tidal flood) that occurred in the District of Medan Belawan.
- Sidewalks that closed so that water cannot enter the drainage channel.

According to the Constitution of Republic of Indonesia Number 24/2007 concerning about disaster management [2], mitigation is an effort to reduce disaster risk, both through physical development and awareness and capacity building to face disaster threats. Mitigation is the initial stage of natural disaster management to reduce and minimize the impact of disasters. Examples of mitigation activities include making maps of disaster-prone areas, building earthquake-resistant buildings, planting mangrove trees, reforesting forests, and providing education and raising awareness of people living in earthquake-prone areas.

Because flooding is a disaster that occurs almost every year in the city of Medan, it is necessary to mitigate floods in the city of Medan, one of them create a vulnerability map of flood disasters and flood hazard in Medan.

The purpose of this study was to initiate flood mitigation efforts in the city of Medan through the creation of vulnerability maps, and maps of flood vulnerability in the city of Medan by the GIS method. The objectives of this study are:

- Creating a vulnerability map for flood disasters in Medan City using landform, slope, soil type, and land use variables.
- Making a map prone to flooding in Medan City using variables of soil texture, slope, and land use.

2. Methodology

This research is a descriptive research using geographic information system (GIS) method or also called spatial analysis. Spatial analysis is done by overlaying several maps then generate a new map of the analysis results. Spatial data is data that designates geographic positions where each characteristic has one location that must be determined in a unique way. To determine the position in absolute terms based on the coordinate system. For small areas, the simplest coordinate system is a regular rectangular grid. For larger areas, based on commonly used cartographic projections [3].

Map overlays are the process of two thematic maps with the same area and laying out one another to form a new map layer. The map overlay address is an intersecting and complementary relationship between spatial features. Map overlays combine spatial data and attribute data from two input themes.

Three types of input features, through an overlay which is a polygon, namely:

- A point with a polygon, producing output in the form of dots.
- Line with polygons, produce output in the form of lines
- Polygons with polygons produce output in the form of polygons.

In the preparation of spatial maps, the integration of various geological data (inputs) is a very helpful process to predict areas that have potential in urban planning, in this case determining areas prone to flood disasters, etc. Considering that geological data has a spatial dimension, GIS technology can be implemented to evaluate areas that have data that refers to vulnerability and vulnerability for flooding. Work procedures from GIS can be seen in the following figure:

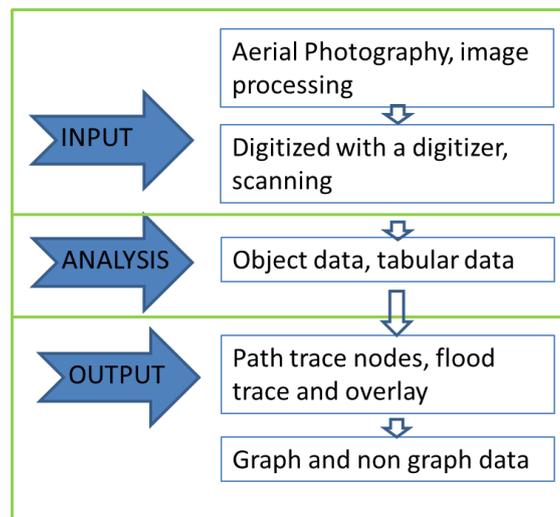


Figure 2. GIS Work Procedures

Spatial data input is to create a map for geographic data. If the map is made only through ordinary estimates, the results of the digital map that will be produced become invalid. Examples of spatial data input in this study are landform layer, slope layer, land use layer, etc. The analysis includes activities such as making thematic maps and so on. Where in general this analytical activity includes:

- Creating buffers around points, lines and polygons.
- Analyze maps with points, lines and polygons and overlay them with slice, union, identity, delete, clip and paste operations methods.

By creating a buffer, a new area, polygon or zone will be formed that covers or covers spatial objects in the form of point, line or area objects.

2.1. Variables and Criteria

Floods are events or a series of events that threaten and disrupt people's lives and livelihoods caused by natural factors due to damage to the buffer zone in the watershed area resulting in human casualties, environmental damage, property losses, and psychological impacts. Flood disaster mitigation is a series of efforts to reduce the risk of flood disasters, both through physical development and awareness and capacity building to face the threat of flood disasters [4].

A flood hazard area is areas that are expected to flood targets. Flood-prone areas are areas that are easy or tend to be flooded [5]. The vulnerable areas of fare usually located in flat areas, close to rivers, feeling in the concave areas and in tidal areas [4].

2.2. The level of flood prone area

To get a map of the level of flood prone, a map of soil texture, slope and land use is overlaid. These three parameters are given weight and dignity so that they form the level of vulnerability to floods. The values and weights used are [4] :

$$PBB = 3T + 5L + 2LU \quad (1)$$

PBB : flood prone area

T : soil texture map

L : slope map

LU : land use map

The score distribution can be seen in table 1.

Table 1. Indicators of flood prone area level

No	Indicators	Degree	Weight	Score
1	Soil texture			
	Smooth (clay)	5		15
	A bit smooth (clay, dusty clay, clay dusty clay)	4		12
	Medium (clay, dust)	3	3	9
	Somewhat rough (sandy clay)	2		6
	Coarse (sand, clay sand, dusty sand)	1		3
2	Slope (%)			
	0-2	5		25
	2-7	4		20
	7-14	3	5	15
	14-21	2		10
	> 21	1		5
3	Land Use			
	Open land, rivers, reservoirs, swamps, reeds	5		10
	Settlements, mixed gardens, yard crops	4		8
	Agriculture, rice fields, moor	3	2	6
	Plantations, bushes	2		4
	Forest	1		2

Source: Hermon, et al. (2008) in Hermon (2015) [4]

Making the value of the flood hazard class interval aims to distinguish flood prone area classes from one another. The formula used to create an interval class namely [4] :

$$I = \frac{c-b}{k} \quad (2)$$

Where:

I : large class interval;

c: highest number of scores (50)

b: lowest score amount (10)

k: number of classes desired (3)

The flood prone area interval can be seen in table 2.

Table 2. Results of calculation of flood prone area level intervals

Zone	Interval	Land Characteristic	Flood Hazard Levels
I	<23.3	The land is very stable	Low
II	23.3-36.6	The land is rather stable	Medium
III	>36.6	Unstable land	High

Source: Hermon (2012) in Hermon (2015) [4]

Zoning of the level of flood prone area consists of three zones:

- Zone A: low level of flood prone area: there is no flood hazard at all that threatens community settlements.
- Zone B: the level of flood prone area is moderate: the chance of a flood occurring once in 5 years.
- Zone C: high level of flood prone area: chance of catastrophic flooding once a year

2.3. Flood Disaster Vulnerability Level

The Vulnerability level resulted from overlaying land use maps, slope slopes, soil types and landforms [4]. The formula used to obtain a flood vulnerability map is [4]:

$$KB = (BL \times 4) + (KL \times 3) + (JT \times 1.5) + (PL \times 1.5) \quad (3)$$

KB = Flood vulnerability

BL = Land Form

KL = Slope

JT = Type of soil

PL = Land Use

Analysis to determine the flood vulnerability zoning used the formula proposed by Dibyosaputro (1999) [6]. The level of flood vulnerability interval can be seen in table 4.

Table 4. Calculation results of flood disaster vulnerability levels

Zone	Interval	Flood Disaster Vulnerability Levels
I	<9.6	Low
II	9.6-14.6	Medium
III	>14.6	High

Source: Hermon (2012) in Hermon (2015) [4]

3. Results and Discussion

The map obtained from the Geospatial Information Agency (BIG) with the scale of 1: 50,000, taken at 2013. Using these data, a number of thematic maps were obtained which became the basis for making the hazard map and vulnerability to flood disasters. Landforms in Medan City are divided into 4, namely plains, alluvial plains, beaches, mountains, and tidal swamps. Each area can be seen in table 5.

Table 5. Landforms in Medan City

Land Forms	Area (ha)
Plain	8,877.334
Alluvial Plain	14,948.030
Beach	1,501.404
Mountains	0.006
Tidal swamps	3,534.487
Total	28,861.261

Table 5. Flood vulnerability criteria

No	Unit Model	Criteria	Score
1	Land Use (PL)	Housing Area	3
		Golf course	3
		garden	3
		Grave	3
		Industry	3
		Industrial Estate	3
		Rice fields (2 times a year)	4
		Rice fields (once a year)	4
		Mixed gardens	2
		Plantation	2
		Meadow	3
		Shrubs	3
		Pond / pond	4
		Swamp	4
		Lake	4
		Forest	4
		Critical Land	1
2	Slope (%) (KL)	0-2	5
		> 2-15	4
		15-40	3
		> 40	1
3	Soil Type (JT)	Histosols	5
		Ferralsols	3
		Gleysols	5
		Vertisols	5
		Acrisols	5
		Lithosols	3
		Podzols	2
		Andosols	3
		Regosols	2
		Grumusols	5
4	Land Form	Lowland coastal zone	5
		Lowland zone	5
		Highland zone	3
		Hills zone, slope <15%	4
		Hill zone, slope >= 15% - <40%	3
		Hill zone, slope >= 40%	2
		Mountain zone, slope <15%	3
		Mountain zone, slope >= 15% - <40%	2
Mountain zone, slope >= 40%	1		

Source: MAFF-Japan (Zain, 2002) [7]

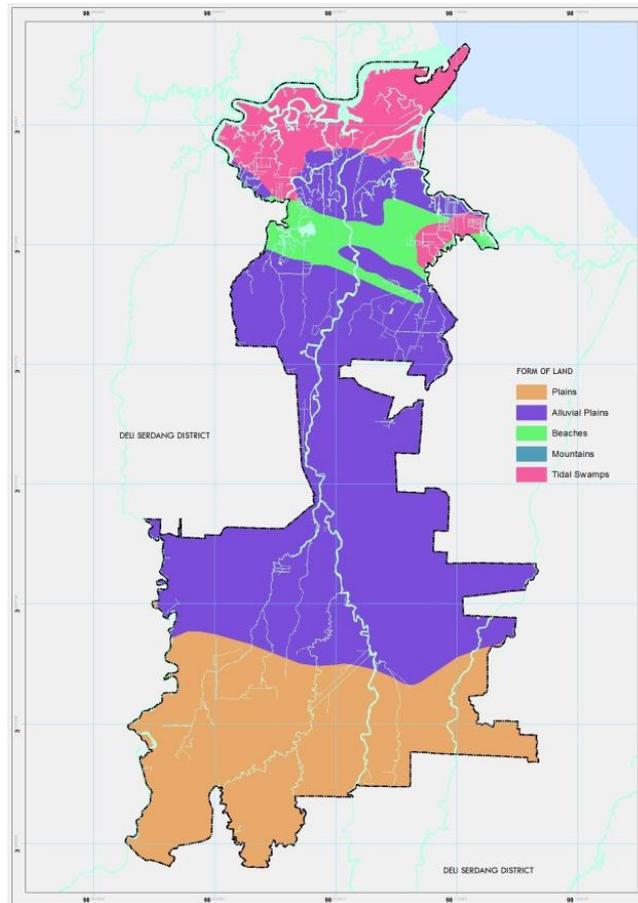


Figure 3. Map of landforms in Medan City

There are four soil types of Medan City, namely Regosols, Andosols, Lithosols, and Acrisols. More details can be seen in Figure 4 and Table 6.

Table 6. Soil types of Medan City

Soil Type	Total (ha)
Regosols	18,219.878
Andosols	2,979.692
Lithosols	7,654.568
Acrisols	7,123.000
Total	28,861.261

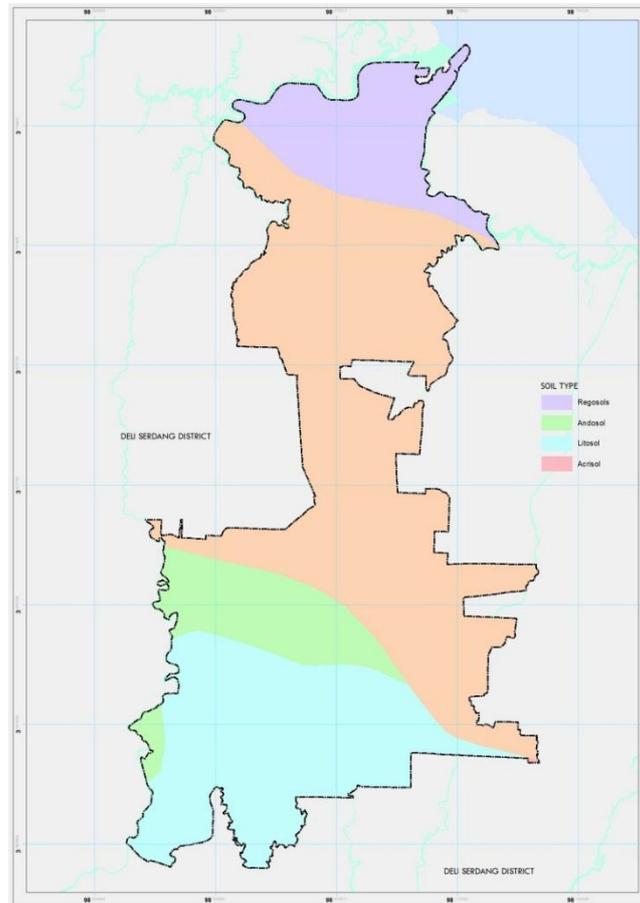


Figure 4. Map of Medan City soil types

The slope in Medan City is about 0-2%. More details can be seen in Figure 5. There are several types of land use in the Medan, namely plantations, settlements and activities, swamps, rice fields, shrubs, etc. More details can be seen in table 7 and figure 6.

Table 7. Land use of Medan City

Land Use	Area (ha)
Lake / Situ	36.344
Pond	69.239
Mangrove / Mangrove Forest	43.708
Plantations / Gardens	3,013.123
Settlements and Activities	15,906.310
Swamp	17.613
Rice fields	1,804.500
Shrubs	3,163.460
River	681.472
Embankment	1,345.119
Moor / Field	2,780.374
Total	28,861.261

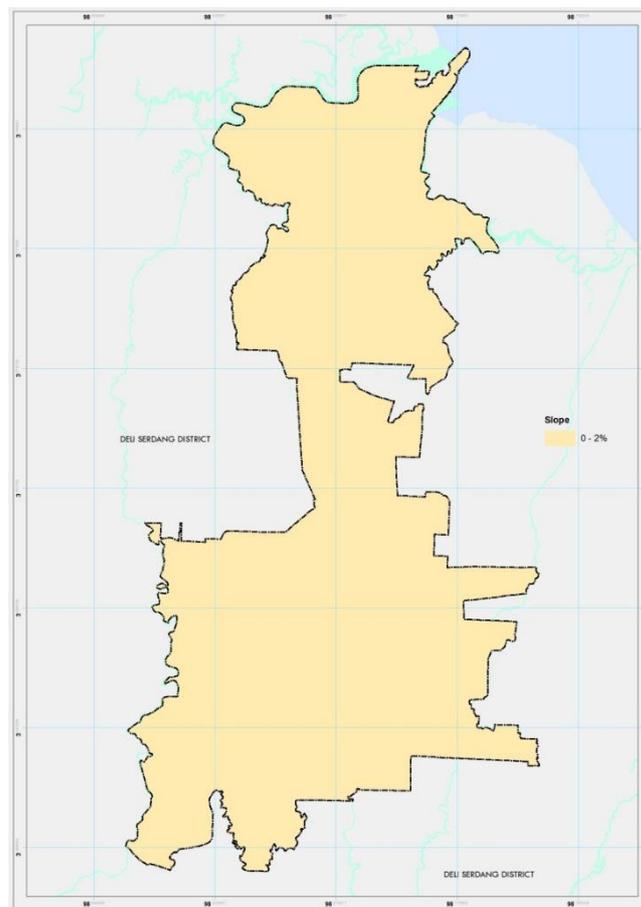


Figure 5. The slope of Medan City

The soil texture of Medan City consists of a slightly smooth texture, rather rough and smooth. More details can be seen in table 8 and figure 7.

Table 8. Land textures of Medan City

Land Textures	Area (ha)
Rather smooth	6,339.668
Rather rough	3,730.552
Smooth	18,791.04
Total	28,861.261

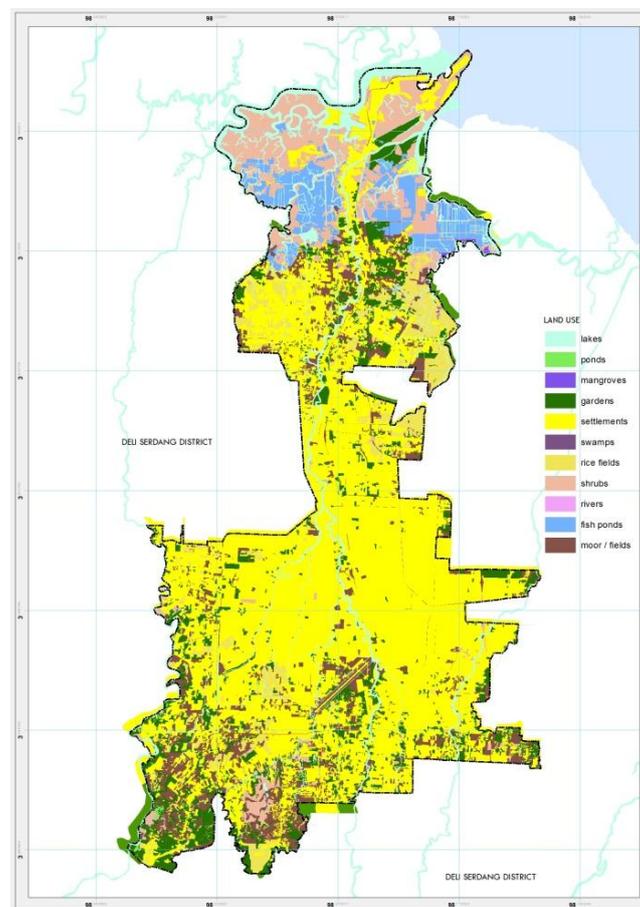


Figure 6. Land use of Medan City

Based on the map and data above, it was overlaid and obtained areas that are prone to and vulnerable to flood disasters in Medan City. Almost all areas of Medan City include into high and medium level flood prone areas. Medan Belawan, Medan Marelan, Medan Labuhan, and Medan Helvetia are sub-districts that have extensive flood-prone areas. It means, in those areas, the chance of flooding is 1 time in 1 year. Medan Selayang, Tuntungan, Johor, Amplas and Polonia are included in the mid-level flood prone area. It means, in this area, the chance of flooding is around 1 time in 5 years. More details can be seen in Figure 8 and table 9.

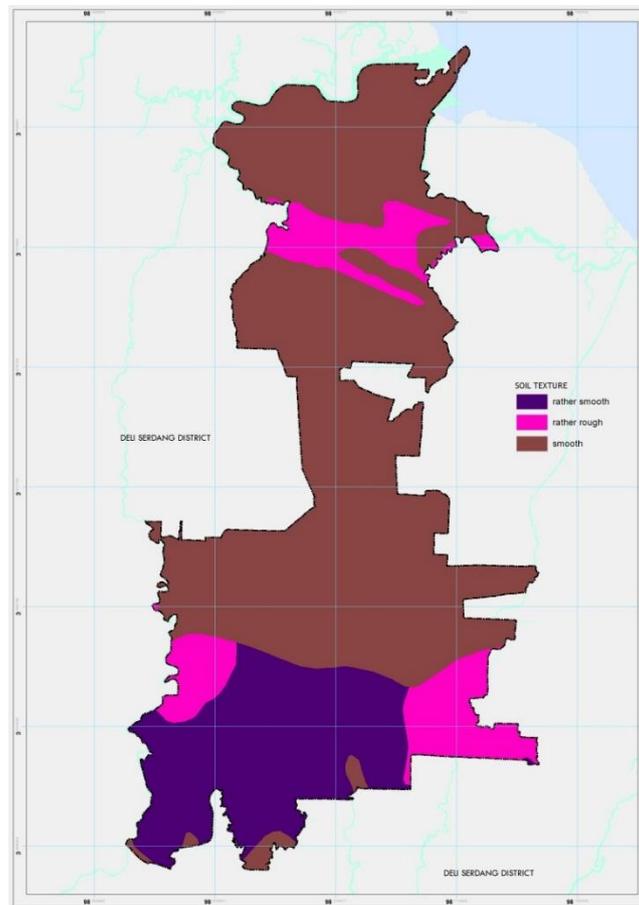


Figure 7. Land textures of Medan City

Medan City generally has areas with moderate vulnerability (18,217,212 ha). Areas that have a high level of vulnerability are scattered in Medan Tuntungan, Medan Selayang, and Medan Sunggal Subdistrict. More details can be seen in Figure 9 and table 10.

Table 9. Levels of Medan City flood prone area

Flood prone area	Area (ha)	Percent
Low	1,388.088	4.81
Moderate	13,359.860	46.29
High	14,113.314	48.90
Total	28,861.261	100.00

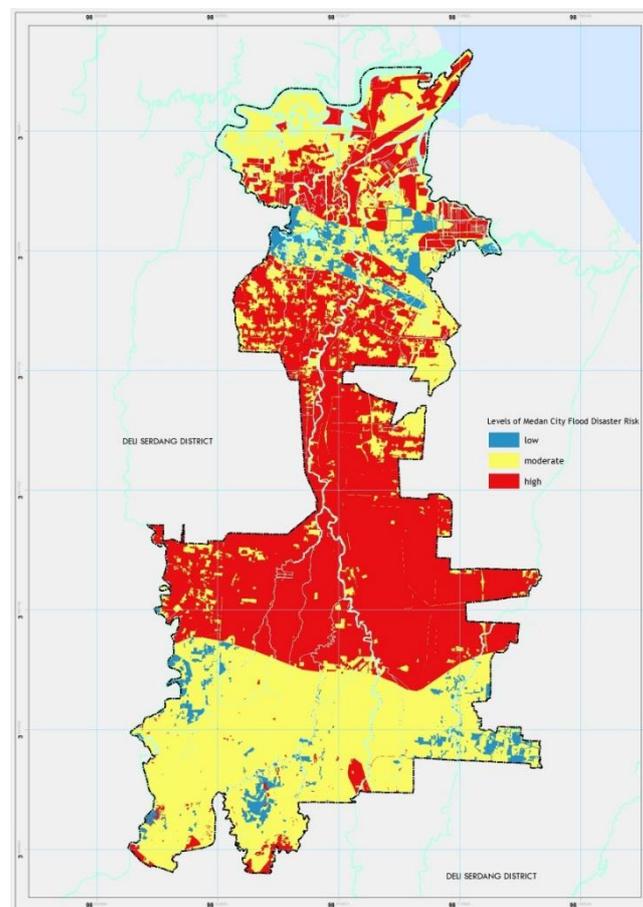


Figure 8. Map of Medan City flood prone area

Table 10. Level of the vulnerability of flood disasters in Medan City

Level of Vulnerability	Area (ha)	Percent
Low	2,515.576	63.12
Moderate	25,635.400	34.42
High	710.285	2.46
Total	28,861.261	100.00

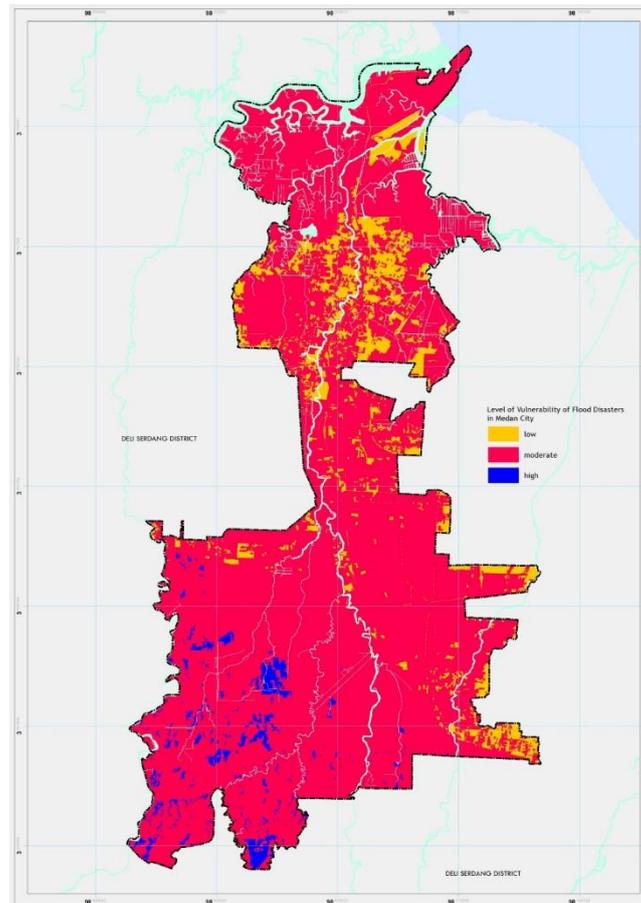


Figure 9. Map of Medan City vulnerability of flood disaster

4. Conclusion

From the research above, it was found that Medan City is generally a flood-prone area and has a moderate vulnerability for flooding. Moderate and high flood-prone areas reach most all of the entire area of Medan City. Areas including high flood-prone areas are Medan Belawan District, Medan Deli, Medan Perjuangan, Medan Barat, Medan Petisah, Medan Area, Medan Kota and parts of Medan Baru. It means in those areas, the chance of flooding is 1 time in 1 year. The regions which have high vulnerability is in the District of Medan Tuntungan. The lowest vulnerability is generally in areas with high numbers of floods, namely Medan Labuhan, Medan Marelán, and Medan Belawan.

References

- [1] BNPB 2018 *Statistik Bencana Alam di Indonesia* URL: <http://bnpb.cloud/dibi/grafik1a>
- [2] Undang-Undang Republik Indonesia No 24 Tahun 2007 tentang *Penanggulangan Bencana*. (Jakarta: Government of Republic of Indonesia)
- [3] Handayani D, Soelistijadi R and Sunardi 2005 Pemanfaatan Analisis Spasial Untuk Pengolahan Data Spasial Sistem Informasi Geografi *Jurnal Teknologi Informasi Dinamik* **10** 108
- [4] Hermon D 2015 *Geografi Bencana Alam* (Jakarta: Rajawali Press)
- [5] Wismarini Th D and Sukur M 2015 Penentuan Tingkat Kerentanan Banjir Secara Geospasial *Jurnal Teknologi Informasi Dinamik* **20** 57
- [6] Dibyosaputro 1999 Longsor Lahan di Kecamatan Samigaluh Kabupaten Kulon Progo *Majalah Geografi Indonesia* **23** 3-34
- [7] Zain A F M 2002 *Distribution, Structure and Function of Urban Green Space in Southeast Asian Mega-Cities with Special Reference to Jakarta Metropolitan Region (Jabotabek)* Doctoral Thesis (Tokyo: Tokyo University)