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Analysis of Flood Inundation Vulnerability to the Deli Watershed of North Sumatra Using Remote Sensing and GIS Techniques

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ABSTRACT

Deli watersheds are listed as one of the most heavily damaged watersheds in Indonesia, and this causes many problems, such as floods, flash floods, and landslides. Studying this watershed becomes essential because the Deli watershed passes through a major city and has become the main source of flood and other natural disasters in the city such as Medan, The study aims to detect the vulnerability level of the areas around the watershed and the most rapid and possible way to study it is by using remote sensing and GIS, the overlay method by considering several parameters that affect the level of vulnerability to flooding in Deli Watershed, North Sumatra. Some of the parameters considered include the topographic wetness index, slope, land elevation, river flow density, land use cover, normalized difference vegetation index, distance to river, and rainfall. Each parameter is given a weight and value according to each classifier. The overlay process is carried out using ArcGIS 10.8.1 software, results are divided into 5 levels of area vulnerabilities all around the area, the study shows that all parts of Medan City in the Deli watershed have a high level of flood vulnerability and some areas with higher ground elevation such as Tanah Karo have spots area that is vulnerable with floods such as Daulu District with 0.45 ha and Semangat Gunung District with 0.63 ha of its areas are vulnerable to floods. The Topographic wetness index, Normalized difference vegetation Index, slope, and land use are the main factors causing flooding with weighting values 16, 13, 11, and 14. The other parameters elevation, flow density, distance to the river, rainfall, and soil class each have weighting values 7, 10, 11, 8, and 10. Slope with a range of 0-8% in most areas of Medan City are classified as very prone to flood inundation. This is due to the area's flat topography and low river flow density, the existing 3.5 km old sewer in the Deli Tua area is unable to accommodate the flood inundation load in the city of Medan and it is necessary to build two new sewers which are more effective and efficient in diverting the flow of water, before entering the city of Medan which makes the area vulnerable to becoming a water catchment area when it rains, thereby increasing the risk of flooding. With this flood-prone map, efforts to manage and mitigate floods in Medan City can be carried out. Information on vulnerable locations can be used to take appropriate preventive and countermeasures, such as building adequate drainage, regulating land use, and controlling river flows.

Keywords: Flood Inundation, Deli River Basin, Overlay Scoring, Remote Sensing

1. Introduction

The problem of flooding and standing water during the rainy season in urban areas, including in Medan City can cause a decrease in environmental quality. Changes in land use from open land to residential areas can increase the risk of flooding. Global climate change also contributes to the intensity and severity of floods in various countries, including several big cities in Indonesia.

The condition of the other Watersheds around Medan City also exacerbates the risk of flooding. DAS Belawan and DAS Deli often experience flooding during the rainy season. Most of the watershed areas in North Sumatra are currently in critical condition, mainly due to the conversion of green belt land into plantations, settlements, and shops. DAS Deli, for example, has a percentage of forests that is far below the minimum target set by the MDGs (Millennium Development Goals) it only has 5.6% of forest from its total area, and the flood damage has been increasing due to the population growth and urbanization of the city and its surrounding area (from 1990 to 1995, the average population growth rate of the project area was 2.2%, which far exceeded the national average rate of 1.7% in the same period). In fact, according to the executing agency, the flood that occurred in Deli River in November recorded an inundated area of 45 km² (Puspita, 2022)

The significant damage to the Deli watershed causes a high potential for flood disaster for the surrounding community and most of the journals about Deli Watershed only study some parts of the watershed, those limited to Medan City, limited Deli Serdang Area, or just a small fraction of the Deli Watershed area. It is essential to study all the watershed areas to get a better picture of the real problem that caused the problems.

2. Method

2.1. Time and Location of Research

This research was conducted in January - May 2023, the research location was the Sei Deli watershed in North Sumatra which stretches from upstream (Berastagi Karo and Sibolangit) to downstream (Belawan). The boundaries of the Deli watershed include to the north of the Belawan watershed, to the south of the Wampu watershed, to the west by the Belawan watershed, and to the east by the Batang Kuis watershed.

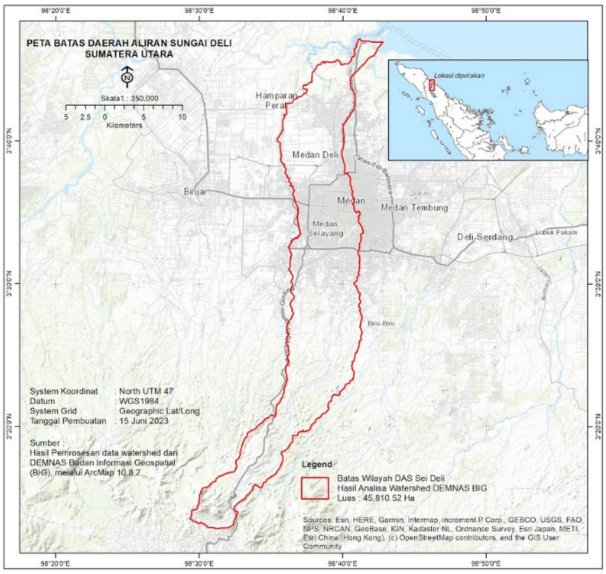


Figure 1., Deli Watershed Boundary
Source: Data processing, 2023

2.2. Research Tools and Objects

The main methodology to achieve the expected result of this research is using the spatially weighted overlay of some variables which are:

1. Topographic wetness index analysis
2. Slope analysis
3. Elevation analysis
4. Flow density analysis
5. Land use analysis
6. NDVI analysis

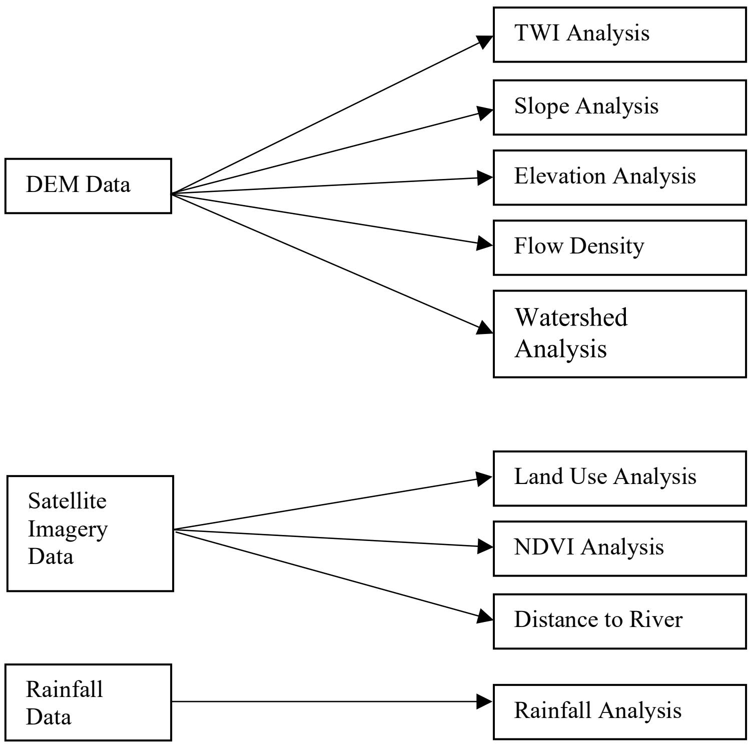
7. Distance analysis with river.
8. Rainfall analysis

The tools used in this study were GPS (global positioning system) as a coordinate point taker, ArcGIS 10.8 software, stationery, and digital cameras as documentation used when conducting ground truthing of land cover processing results data. Below is the table of all the required data, data types, dates, and sources.

Table 1. Primary and secondary research data

No	Data Name	Data type	Source	Year
1	Latest Sentinel 2 Satellite Imagery (with cloud cover < 20%)	Secondary	Earth Explorer	2021-2022
2	NATIONAL DEM data	Secondary	Geospatial Information Agency	2020
3	Annual Rainfall Data	Secondary	Meteorology and Climatology	2012 - 2022
4	Map of the Sei Deli Watershed Area	Secondary	BPDAS Wampu	2022
5	Topographic Map of Indonesia	Secondary	Tanahair.indonesia.go.id	2022
6	Administrative Map of The North Sumatra Region	Secondary	Tanahair.indonesia.go.id	2022
7	Interview Data	Primary	Field survey	2023
8	Ground Truth data	Primary	Field survey	2023

With those primary and secondary data collections, they will analyse into 8 weighted variables data.



The analysis result of every variable will come with five levels.

2.3 Watershed Boundary
The research object is the Sei Deli watershed obtained from the BPDAS which later the watershed boundary or area will be re-analysed by remote sensing by delineating topographical features using primary and secondary data.

2.4. *TWI Analysis*
Conceptually, TWI processing can also be done manually through calculations using the following algorithm:

$$ln \frac{a}{\tan b}$$

Information:
a : Slope rate is up.
tan b : Degree of slope in radians.

Table 2. TWI class range values

TWI Index Value	Flood Danger Level
-5.90 - 6.00	Very low
6.10 – 8.00	Low
8.10 – 10.00	Currently
10.10 – 14.00	Tall
>14.10	Very high

(Source: Rinaldi & Rakuasa, 2023).

2.5. Slope Analysis
The slope or slope is processed using DEM data using ArcGIS tools.

Table 3. The Value of the range of the slope

Slope Index Value (%)	Classification
0% - 8%	Low
9% - 15%	rather low
16% - 25%	Currently
26% - 45%	Somewhat High
>45%	Tall

(Source: Paimin et al. 2009).

2.6. Elevation Analysis
Obtained from point extraction carried out on DEMNAS data by providing distribution points evenly within the coverage area then analysed it by kriging type interpolation.

Table 4. Value range of elevation

Area Altitude Index Value	Classification
0 m – 14.4 m	Low elevation plains
14.5m – 38.8m	The elevation is rather low
38.9 m – 55.2 m	Moderate elevation
55.3 m – 75.6 m	The elevation is rather high
75.6 m – 96 m	High elevation plains

(Source: Mudjiatko *et al.* 2017).

2.7. Flow Density Analysis
This analysis aims to analyse the existing flow density in an area. Flow density is used in determining the class of flood inundation hazard because flow density is related to the drainage properties of the watershed where the smaller the flow density will cause a poor drainage system that can trigger inundation and vice versa (Madani et al., 2022)]; (Sidiq et al., 2022); (Utama et al., 2018). This means that a higher flow density can minimize flood inundation.

Table 5. Value range of flow density

Flow Density Index Value	Classification
0 – 1.41	Very High Density
1.42 – 2.90	High Density
2.91 – 3.87	Currently
3.88 – 4.58	Low Density
4.59 – 6.89	Very Low Density

(Source: Geospatial Information Agency, 2012).

2.8. Land Cover Analysis

In Landsat satellite imagery, land use classification is carried out using a supervised classification process to characterize each type of land use. Land use classification is used as a guide or reference in the process of interpreting remote sensing imagery for land use mapping purposes (Arsyad, 2002). This classification clarifies the objects in the research location such as settlements, plantations, and rivers.

Table 6. Range values of land use

Land Use Class Group	Classification
Jungle	Very Not Vulnerable
Degraded Forest	Not Prone
Moor/Plantation/Brush	Somewhat Prone
Water Field / Dry Rice Field / Ponds	Prone
Settlements/Open Land	Very Prone

(Source: Geospatial Information Agency, 2012).

2.9. Analysis of Vegetation Index Value

(Normalized Difference Vegetation Index) analysis is intended to be able to separate plants that have a good level of health from those that are not good, because this greatly affects the level of water absorption in that area. With the calculation above the NDVI value ranges from -1 (which is usually water) to +1 (dense vegetation).

Table 7. Range values of the vegetation index

Vegetation Index Value	Classification of Green Level
-0.10 – 0.13	Land not vegetated
0.14 – 0.22	Very low vegetation
0.23 – 0.30	Low vegetation
0.31 – 0.38	Moderate vegetation
0.39 – 0.72	High vegetation

(Source: Lestari *et al.* 2018).

2.10. Distance Analysis with River

Each land use will be analysed by using a bearing to line to detect the distance of the object from the river. Distance to the river is one of the parameters for predicting flood inundation. Another term is buffer. Analysis of the variable distance from the river or river buffer using multiple ring buffer tools in the Arc GIS 10.8.2 software (Tarkono et al., 2021); (Ariyora et al., 2015).

Table 8. Range values from the distance to the river

Distance Index Value with River (m)	Proximity Level Classification
0 – 50	Very close
51 – 100	Near
101–250	Currently
251–500	Far
>500	Very far

(Source: Haghizadeh *et al.* 2017).

2.11. Rainfall Analysis

Rainfall is the volume of water that falls in a certain area, the amount of rainfall can be expressed in m 3 per unit area or generally expressed in the height of the pool of water (Anggraini et al., 2021). Rainfall data was obtained from the Meteorology and Geophysics Agency.

Table 9. Range values of the rainfall index

Rainfall Index Value (mm)	Rain Intensity Classification
0 – 50	Very dry
51–150	Dry
151–300	Medium/moist
300 – 400	Wet
>500	Really wet

(Source: Tarkono *et al.* 2021).

2.12. Weighting Value
Weighting value is obtained from the research analysis**.**

Table 10. Weighting values

No	Items Affecting Flooding	Weighting Value
1	Topographic Wetness Index	16
2	Slope	11
3	elevation	7
4	Flow Density	10
5	Land use	14
6	NDVI	13
7	Distance to the River	11
8	Rainfall	8
9	Soil Class	10

(Source: Darmawan, *et al.* 2017; Lestari, *et al.* 2018; & Results of research analysis).

Also combined by searching for data utilizing literature studies and updating data from various sources of journals that have a good reputation level from various institutions and competent authors.

3. Discussion
After processing all the required data, the topographic wetness index, slope analysis, elevation analysis, flow density analysis, land use analysis, NDVI analysis, distance analysis with the river, and rainfall analysis the results are described as follows.

The Topographic Wetness Index (TWI) method is very often used to see the potential for waterlogging or soil moisture, as in research by (Riadi et al., 2018) to identify and delineate flood-prone areas in Karawang Regency, and (Rinaldi et al., 2023) to map potential areas of flood inundation in Bogor Regency using this analysis. The following is the result of processing the Topographic Wetness Index (TWI) Map which can be seen in Figure 2.

The results of the Deli Watershed Topographic Wetness Index analysis which were fully processed using DEMNAS data in Figure 9 divide the TWI index value class range into 5 classes namely: index value -5.90 - 6.00 has a very low flood hazard level and is labelled dark green, index value 6.10 – 8.00 has a low flood hazard level and is labelled light green, index values 8.10 – 10.00 have a moderate flood hazard level and are labelled yellow, index values 10.10 – 14.00 have a high flood hazard level and are labelled orange, and index value > 14.10 has a very high flood hazard level and is labelled in red.

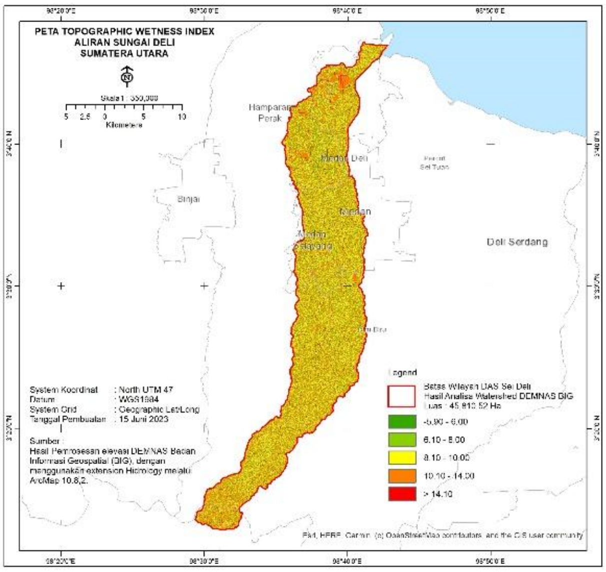


Figure 2. Distribution of Deli Watershed TWI levels

The slope of the slope is one of the factors that can increase the chance of flooding because it is related to the nature of water that moves from high to low areas (Ariyora., 2015). The higher the slope of an area, the higher and faster the water will flow. The possibility of inundation due to falling rainwater is small because the water will flow directly and not inundate the area, so the risk of flooding is smaller.

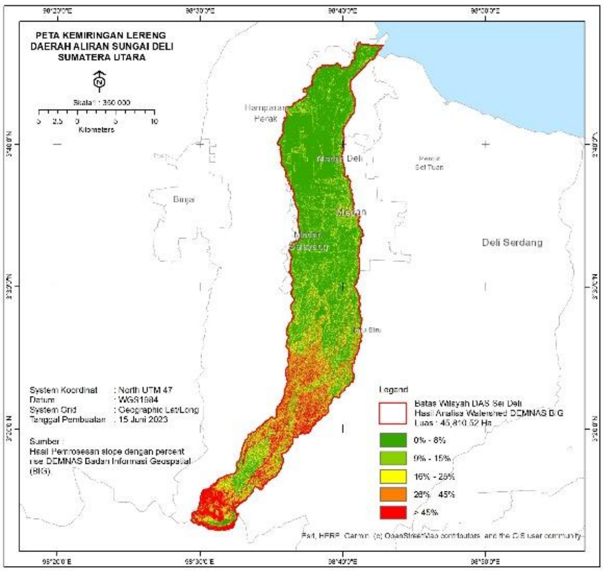


Figure 3. Distribution of the slope levels of the Deli Watershed slope

Processing the results of the slope analysis is used to see the high or low slope of the slopes in the Deli watershed. This slope index has a relationship with the elevation level because in the highlands it will form a steep slope and vice versa. The results of the processing of the slope map presented in Figure 3 show that the Deli Watershed in the Karo and Deli Serdang Regencies has a high and rather high slope because this area is highland, and the slope has a correlation with elevation. This is in line with what was stated by (Gambaran Umum Kabupaten Karo, 2022) and (Pemerintah Kaupaten Deli Serdang, 2022) stating that the Deli Watershed in the upstream part is in their territory.

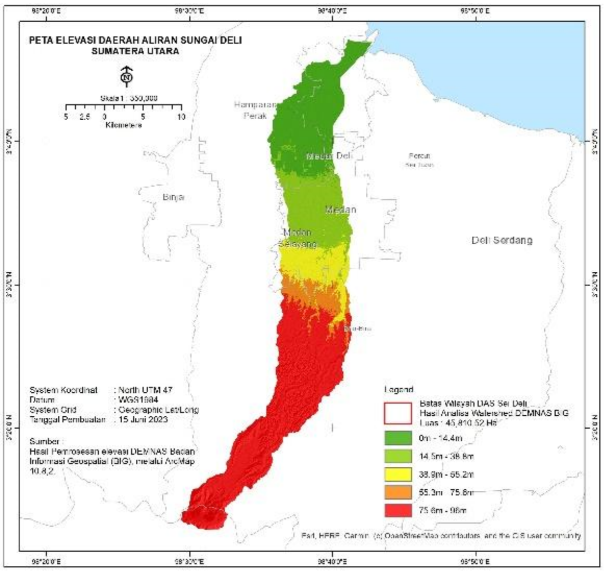


Figure 4. Distribution of Deli Watershed elevation levels

The elevation is used to determine the class of flood vulnerability because the height of an area affects the process of puddles that cause flooding. The nature of water always flows from high areas to lower areas, so areas with lower elevations are potentially prone to flood inundation compared to higher areas (Ariyora, 2021). The following is the result of processing the Deli Watershed Elevation Map, which can be seen in Figure 4.

The results of the processing of the flow density map presented show that the Deli watershed is more dominant in yellow with a moderate classification, although there are several other colours. According to (Sidiq, 2022), the flow density index is of moderate value, meaning that the condition of the river flow tends to be good and rarely experiences inundation. The following is the result of processing the Flow Density Map of the Deli Watershed, which can be seen in Figure 5.

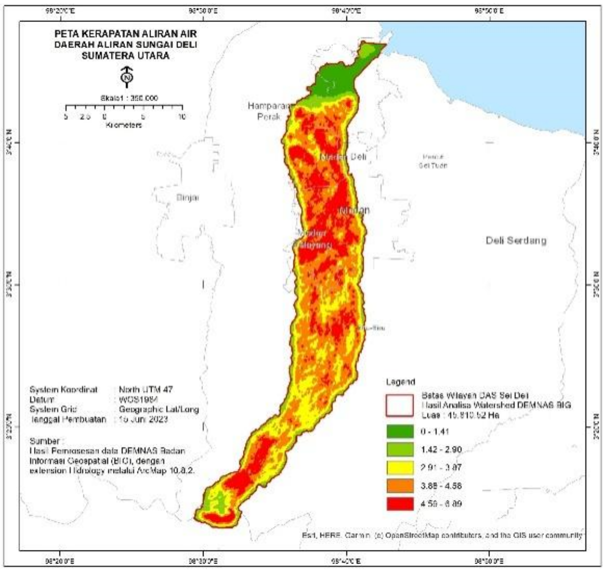


Figure 5. Distribution of the Deli Watershed flow density levels

Land use will affect the flood vulnerability of an area. Land use will play a role in the amount of runoff water resulting from rain which has exceeded the infiltration rate (Darmawan et al., 2017); (Standard Operating Procedures Tentang Pemetaan Kerapatan Aliran, 2012). Areas that are overgrown with trees will find it difficult to drain runoff water.

Land cover such as settlements which are predominantly concrete and asphalt, if not equipped with good drainage channels will have the potential to become flood-prone areas. The following is the result of processing the Deli DAS Land use Detail Map, which can be seen in Figure 6.

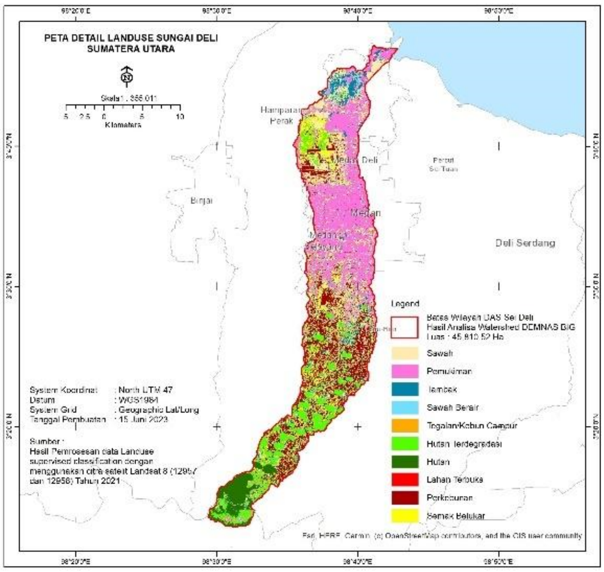


Figure 6. Distribution of Deli watershed land use levels

According to (Hidayah et al., 2022); and (Lestari et al., 2018), a smaller NDVI value indicates that there is no vegetation in the area, which means that nothing can reduce the velocity of runoff on the ground surface. The possibility of flooding will also increase. The following results from the processing of the North Sumatra Deli River Vegetation Index Value Map can be seen in Figure 7.

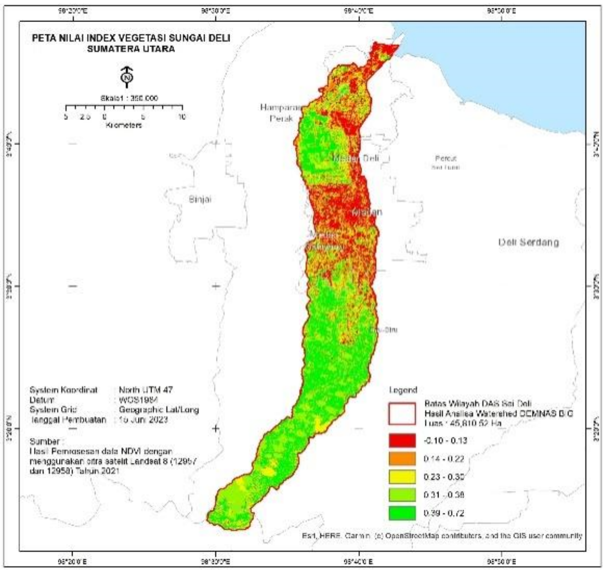


Figure 7. Distribution of vegetation index levels in the Deli Watershed

Analysis of NDVI map processing shows that the Karo and Deli Serdang Regencies are dominant in dark green and light green, which means that the vegetation in these two areas has a high to medium green level. This is due to the existing field facts showing that the two areas are still quite dense in vegetation. Whereas in the Medan City area, the dominant colours of the area are red and orange which means that Medan City has a low vegetation density to non-vegetated land and the NDVI value is quite small.

The distance to the river flow is used as one of the parameters in determining the flood hazard. This is intended to estimate the riparian areas that are safe from river overflows/floods (Ferdi et al., 2021); (Haghizadeh et al., 2017); (Standard Operating Procedures Tentang Pemetaan Kerapatan Aliran, 2012).The distance to the river in the Deli watershed is classified based on the characteristics of the river according to PERMEN PUPR No. 26/PRT/2015 concerning the Diversion of river channels and/or utilization of ex-river sections. Areas that are close to very close to the flow of river water will certainly be very vulnerable and dangerous if there is an overflow of river water (flood). Conversely, the farther the distance from the river flow, the less affected the area (Rakuasa et al., 2022). The following results from the processing of the River Distance Map with the Deli River Basin, North Sumatra, can be seen in Figure 8.

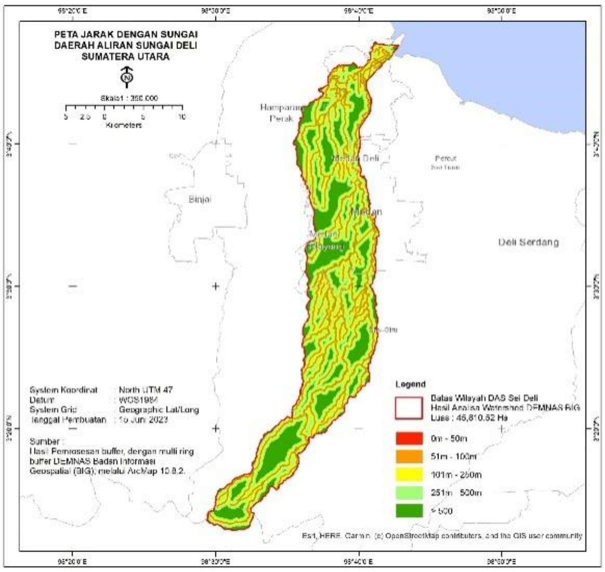


Figure 8. Distribution of distance levels with rivers.

Rainfall data is obtained from the agency related to rain data, namely BMKG (Meteorology and Geophysics Agency). In this study, rainfall data was put into one classification because the data source coordinates of the rain observation centre in the Deli River watershed were incomplete.

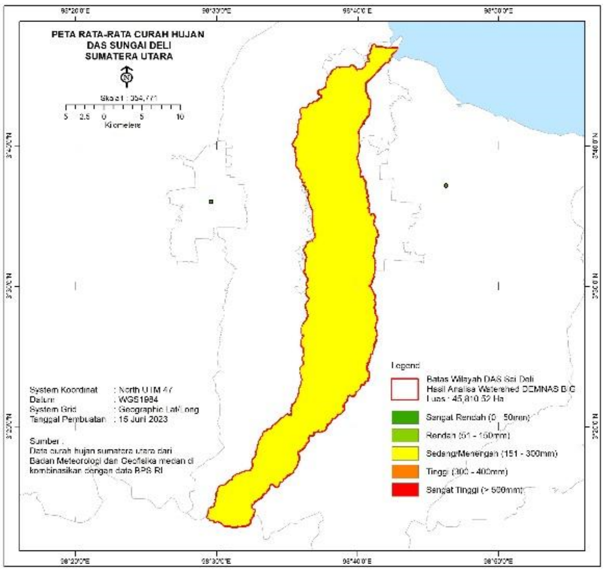


Figure 9. Distribution of Deli Watershed rainfall levels

The processing of rainfall maps uses the IDW (Interpolation Distance Weight) point interpolation method which is in ArcGIS 10.8.2 Point interpolation is a procedure for estimating unknown values using known values at adjacent locations. The results of the analysis in Figure 9 show that all classifications are in the medium class.

Vulnerability Level

Areas that have high rainfall will also have a high chance of flooding (Tarkono et al., 2021). The level of vulnerability of areas affected by flood inundation is identified from the characteristics of the area such as landforms, slopes, meandering, natural dams, and the presence of control structures. flood inundation (Anggraini et al., 2020); (Paimin et al., 2020); (Mudjiatko et al., 2017)

Results of the distribution map analysis of the location of the inundation in the Deli River Basin, North Sumatra, which is shown in the figure below, namely the area for the most extensive distribution of flood inundation is the colour cream with a potential level of medium/low inundation covering an area of 21330.72 Ha and for distribution that has no potential for flood inundation only an area of 0.27 Ha with dark green color.

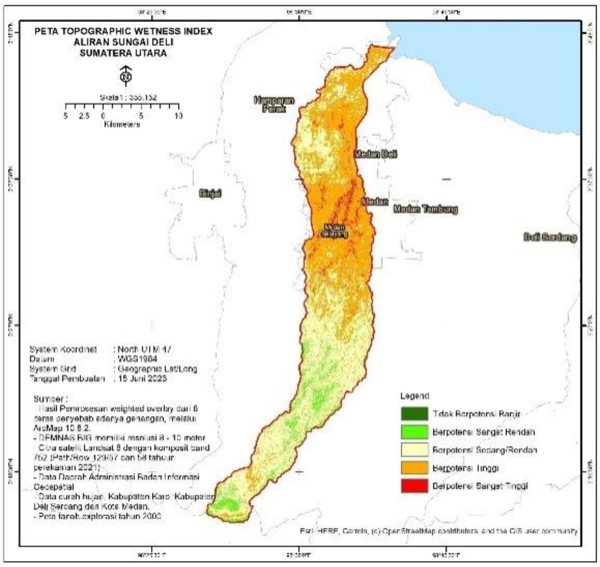


Figure 9. Distribution of Deli Watershed rainfall levels

Table 10. Results of Flood Vulnerability Level Analysis

Colour	Classification of Flood Inundation	Area (Ha)
Lv.1, Dark green	No potential for flooding	2,810.69
Lv.2, Light green	Very low potential	3,166.47
Lv.3, Cream	Medium/low potential	18,520.30
Lv.4, Orange	High potential	19,821.78
Lv.5, Red	Very high potential	1,033.65

Based on the analysis data from the research there is a 1,033ha area of the Deli Watershed in the Red Zone, and its clustering is mostly in the city of Medan, shown in Figure 10, in the higher ground like Tanah Karo and Deli Serdang also have red zone area but it's only very minor.

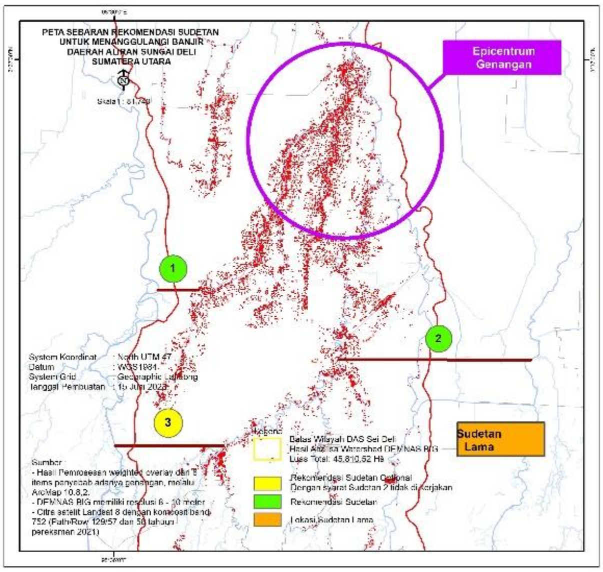


Figure 10. Distribution of level 5 inundation levels

This study recommends the location of 2 new sewers so that they can accommodate the water load and divert it to reduce inundation & flood discharge by considering the river channel is stable, namely at points 1 and 2.

Top 10 biggest area of Deli Watershed that is categorized flood vulnerability level 5.

Table 11. Top 10 biggest areas of level 5.

No	Locations (Regency, District, Village)	Flood Size (HA)
1	Medan, Medan Sunggal, Tanjung Rejo	67.05
2	Medan, Medan Selayang, Tanjung Sari	62.78
3	Medan, Medan Barat, Sei Agul	43.58
4	Medan, Medan Selayang, Padang Bulan Selayang	40.43
5	Medan, Medan Selayang, Padang Bulan Selayang	40.43
6	Medan, Medan Barat, Karang Berombak	39.74
7	Deli Serdang, Labuhan Deli, Helvetia	39.23
8	Deli Serdang, Sunggal, Helvetia	39.23
9	Medan, Medan Helvetia, Helvetia	39.23
10	Medan, Medan Sunggal, Babura	33.98

This study also recommends water reservoir construction in areas that have large flood zones, as shown in Figure 11. The green dots are 10 units suggested water reservoir locations in Deli Watershed,

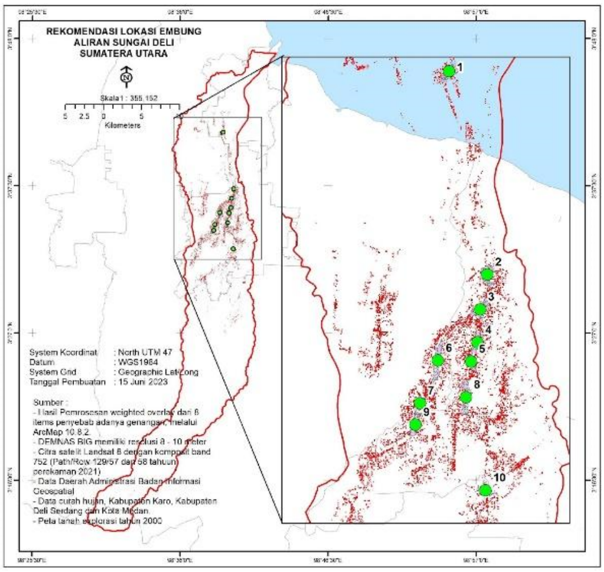


Figure 11., Distribution of suggested water reservoir.

Table 12. Suggested water reservoir locations.

No	Size (Ha)	X Coordinate	Y Coordinate
1	11,07	98° 39' 2.070" E	3° 41' 18.367" N
2	17,64	98° 39' 47.418" E	3° 37' 17.025" N
3	16,2	98° 39' 38.940" E	3° 36' 35.497" N
4	13,68	98° 39' 35.765" E	3° 35' 56.192" N
5	9,81	98° 39' 28.138" E	3° 35' 33.619" N
6	22,5	98° 38' 48.846" E	3° 35' 34.789" N
7	8,01	98° 38' 27.819" E	3° 34' 44.051" N
8	17,01	98° 39' 22.284" E	3° 34' 51.148" N
9	12,78	98° 38' 22.420" E	3° 34' 18.559" N
10	11,43	98° 39' 45.308" E	3° 33' 0.444" N

3. Conclusion

1. The Topographic wetness index, Normalized difference vegetation Index, slope, and land use are the main factors causing flooding
2. Whereas the existing 3.5 km old sewer in the Deli Tua area is unable to accommodate the flood inundation load in the city of Medan and it is necessary to build two new sewers which are more effective and efficient in diverting the flow of water, before entering the city of Medan.
3. Medan is the worst area to experience flood inundation, this factor is influenced by the land use of this area which has a very big impact on the results of the analysis, namely especially in areas that have land uses such as housing and open land, which are the centers of inundation.
4. Areas with higher ground elevation such as Tanah Karo have spots area that is vulnerable with floods such as Daulu District with 0.45 ha and Semangat Gunung District with 0.63 ha of its areas are vulnerable to floods.

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References

Lestari, M., Mira, M., Joko Prasetyo, S. Y., & Fibriani, C. (2021, May 27). Analisis Daerah Rawan Banjir Pada Daerah Aliran Sungai Tuntang Menggunakan Skoring dan Inverse Distance Weighted. Indonesian Journal of Computing and Modeling, 4(1), 1–9. https://doi.org/10.24246/icm.v4i1.4615

Madani, I., Bachri, S., & Aldiansyah, S. (2022, August 31). Pemetaan Kerawanan Banjir di Daerah Aliran Sungai (DAS) Bendo Kabupaten Banyuwangi Berbasis Sistem Informasi Geografis. Jurnal Geosaintek, 8(2), 192. https://doi.org/10.12962/j25023659.v8i2.11907

Sidiq, W. A. B. N., Hanafi, F., Priakusuma, D., Haruman, W., Sumarso, M. Y., & Setyowati, N. (2022, December 3). Analisis Banjir Genangan di Kawasan Tembalang dan Sekitarnya. *Jurnal Riptek*, *16*(2), 137–144. https://doi.org/10.35475/riptek.v16i2.159

KAJIAN MORPHOMETRI PADA DAERAH ALIRAN SUNGAI (DAS) BATANG KURANJI TERHADAP DEBIT BANJIR. (2018, April 1). *FRONTIERS: JURNAL SAINS DAN TEKNOLOGI*, *1*. https://doi.org/10.36412/frontiers/001035e1/april201801.07

Arsyad. (2022). *Pengetahuan Tentang Bumi*. Universitas Negri Makassar Press

Tarkono, Humam, A., Humam, A., Vidia Mahyunis, R., Fauziah Sayuti, S., Annisa Hermastuti, G., Sitanala Putra Baladiah, D., & Rahmayani, I. (2021, September 30). PEMETAAN DAERAH POTENSI RAWAN BANJIR DENGAN SISTEM INFORMASI GEOGRAFI METODE WEIGHTED OVERLAY DI KELURAHAN KETEGUHAN. *BUGUH: JURNAL PENGABDIAN KEPADA MASYARAKAT*, *1*(3). https://doi.org/10.23960/buguh.v1n3.138

Ariyora, Y. K. S., Budisusanto, Y., & Prasasti, I. (2015, February 1). PEMANFAATAN DATA PENGINDERAAN JAUH DAN SIG UNTUK ANALISA BANJIR (STUDI KASUS : BANJIR PROVINSI DKI JAKARTA). *Geoid*, *10*(2), 137. https://doi.org/10.12962/j24423998.v10i2.805

Anggraini, N., Pangaribuan, B., Siregar, A. P., Sintampalam, G., Muhammad, A., Damanik, M. R. S., & Rahmadi, M. T. (2021, August 13). 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

Riadi, B., Barus, B., Widiatmaka, Yanuar, M. J. P., & Pramudya, B. (2018, May). Identification and delineation of areas flood hazard using high accuracy of DEM data. IOP Conference Series: Earth and Environmental Science, 149, 012035. https://doi.org/10.1088/1755-1315/149/1/012035

Rinaldi, M & Rakuasa, H, (2023). Pemetaan daerah potensi genangan banjir di Kecamatan Gunung Putri, Kabupaten Bogor menggunakan data DEMNAS dengan metode topographic wetness index. *Jurnal Ilmiah Multidisiplin 2*(6), 2269-2280.

Gambaran Umum Kabupaten Karo, Pemerintah Daerah Kabupaten Karo. (2017). Accesed: https://web.karokab.go.id/profil/gambaran-umum.

Potensi daerah Kabupaten Deli Serdang, Pemerintah Daerah Kabupaten Deli Serdang (2022).
Accesed:
https://bapenda.deliserdangkab.go.id/website/web/detail/19/potensi_daerah_kabupaten_deli_serdang#:~:text=Potensi%20Utama%20adalah%3A%20Pertanian%20Pangan,Pertambakan%2C%20Peternakan%20Unggas%20dan%20Pariwisata.

Puspita, R,. (2022). Badan Nasional Penanggulangan Bencana (BNPB): Hutan di Sepanjang DAS Deli Kota Medan Tersisa 5,6 Persen. Harian Republika News Online. Accesed: https://news.republika.co.id/berita/rh16z7428/bnpb-hutan-di-sepanjang-das-deli-kota-medan-tersisa-56-persen.

Darmawan, K., Hani'ah., Suprayogi, A. (2017). Analisis tingkat kerawanan banjir di Kabupaten Sampang menggunakan metode overlay dengan scoring berbasis sistem informasi geografis. *Jurnal Geografi Undip 6*(1), 31-40.

Hidayah, E., Widiarti, W. Y., & Ammarulsyah, A. R. (2022, November 30). Zonasi Tingkat Kerawanan Banjir Bandang dengan Sistem Informasi Geografis di Sub-DAS Kaliputih Kabupaten Jember. *Jurnal Teknik Pengairan*, *13*(2), 273–282. https://doi.org/10.21776/ub.pengairan.2022.013.02.12

Ferdi., Maliki, R. Z., Saputra, I. A. (2021). Pemetaan bahaya banjir di Kecamatan Baolan Kabupaten Tolitoli Provinsi Sulawesi Tengah. *Jurnal Dialog Penanggulangan Bencana 12*(1), 13-20.

Rakuasa, H., Helwend, J. K., & Sihasale, D. A. (2022, December 1). Pemetaan Daerah Rawan Banjir di Kota Ambon Menggunakan Sistim Informasi Geografis. *Jurnal Geografi : Media Informasi Pengembangan Dan Profesi Kegeografian*, *19*(2), 73–82. https://doi.org/10.15294/jg.v19i2.34240

Mudjiatko., Sutikno, S., Teriyoko, W. (2017). Klasifikasi dan pemetaan wilayah rawan banjir genangan di Kota Pekanbaru. *ACE Conference*, 205-216.

Paimin., Sukresno., Pramono, I. B. (2009). Teknik mitigasi banjir dan tanah longsor. Tropenbos International Indonesia Programme. ISBN: 978-979-3145-46-4.

Lestari, M., Mira., Prasetyo, S. Y., Fibriani, C, (2018). Analisis daerah rawan banjir pada daerah aliran sungai tuntang menggunakan skoring dan inverse distance weighted. *Indonesian Journal of Modeling and Computing 4*(1), 1-9.

Haghizadeh, A., Siahkamari, S., Haghiabi, A. H., & Rahmati, O. (2017, March 29). Forecasting flood-prone areas using Shannon's entropy model. *Journal of Earth System Science*, *126*(3). https://doi.org/10.1007/s12040-017-0819-x

Standard operating procedures tentang pemetaan kerapatan aliran, Badan Informasi Geospasial. Lampiran 10 Keputusan Deputi Bidang Indormasi Geospasial Tematik. (2012). Accesed: https://web.karokab.go.id/profil/gambaran-umum

Darmawan, A., Suprayogi, A., & Hani'Ah. (2017). Analisis Tingkat Kerawanan Banjir Di Kabupaten Sampang Menggunakan Metode Overlay Dengan Scoring Berbasis Sistem Informasi Geografis. *Journal Geodesi Undip.* ISSN: 2337-845X.