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Spatial Modeling of Flood Inundation to Evaluate Drainage Channel, Case Study of East Banjarmasin South Kalimantan, Indonesia

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Abstract:- January 2021 Floods hit South Kalimantan in 10 cities, and floodwaters inundated at least 24,379 houses. The government of South Kalimantan announced Emergency Status for Flood Disasters a day after water washed that region on January 15, 2021. Given the data of the phenomenon, Banjarmasin's Public Works and Spatial Planning Department has submerged 90% of East Banjarmasin and 40% of South Banjarmasin. The runoff ratio to rivers' carrying capacity in East Banjarmasin is ± 7 (seven) times greater than its capacity, including narrowing, silting, and blockages in the channels and rivers.

This study intends to model the distribution of high inundation that occurs using the Storm Water Management Model (SWMM) and also aims to obtain a Priority Analysis based on the impact of inundation that occurs by referring to the Procedure of Compiling a Master Plan for Urban Drainage Systems from the Directorate General of Human Settlements, Ministry of Public Works and Housing. The research location is in the SimpangLayang and Veteran Flood Control Area (FCAs), East Banjarmasin, with an area of 2,078,740 ha.

From the nine modeled Sub-Systems, the average flood inundation height in the Simpang Layang FCA is about 0.886 m. The average inundation height for the Veterans FCA is about 0.838 m from the eight modeled Sub-Systems. This modeling obtained 195 points of inundation that occur in both FCA. Recommendations will be made for Priority Analysis of the Control Flood Inundation to validate the data on the distribution of inundation points. This study took five validation points: Jl Ayani, Komplek Kenanga, Komplek Smanda III, Jl Mahat Kasan, and Jl. Pramuka. Jl. Pramuka is the location with the highest priority, assessed based on inundation parameters, economic losses, social disturbances, government facilities, transportation disturbance losses, housing losses, and personal/household property rights losses. The area with this highest priority number requires forward mitigation because this area has been most severely affected and inundated for a long time. This area is also one of the centers of government, economic commodities, various companies, health center facilities, residential and public transportation centers in Banjarmasin, and other public facilities

Keywords:- *Spatial mapping, Flood Inundation Modeling, Drainage System Analysis, Inundation Priority Analysis, Capacity Evaluation of Drainage.*

I. INTRODUCTION

Flood is a disaster that commonly happens in large and densely populated cities in Indonesia. In March 2021, The National Disaster Management Agency (BNPB) recorded 345 flood events in Indonesia. Floods also hit South Kalimantan, 24,379 houses flooded in January 2021 in 10 Cities, including Banjarmasin as the capital. This situation raised the emergency status of the province by the Government of South Kalimantan on January 15, 2021.

Regional Disaster Management Agency (BPBD) published that East Banjarmasin is the most severely affected, submerging around 90% area and 45,000 people (35% of the society), experiencing high inundation for more than ten days since the emergency status was declared.

Inundation is an event of no drainage system, or it does not function properly, or inability of the drainage system function optimally, causing the overflow (out of the canal) and disrupting and harming community activities.

This research must be carried out to obtain a map of the distribution of high inundation on January 14, 2021, in East Banjarmasin District most severely affected area in Banjarmasin City, so that priority recommendations for activities and handling can be made for inundation events that occur. January 14 was chosen because it is when high inundation occurred and with maximum January rainfall data of 83.83 mm, according to the CHIRPS rainfall data obtained. This rise in the water level has also resulted in the existing sewers being unable to drain the wastewater into the river channels. When floods coincide with high tides, the flood water level in the cross-section of the river becomes large because backwater occurs, thus inundating the surrounding area and causing losses to the community (Makasaehe et al., 2020).

II. METHODOLOGY

This research was conducted in several stages, which include:

- Identification of problems
- Study of literature
- Data collection
- Data analysis

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- Discussion and Conclusion

The research location was carried out in the scope of the drainage network in East Banjarmasin District, in the Simpang Lay River River Inundation Handling Area (WPG) and WPG Veterans, which are presented in Figures 1 and 2. This study used some secondary data such as:

- Hydrology data (rainfall data, high inundation data, and tidal data);
- Geospatial data (DEM data, geographic data, regional administrative boundaries, river data, land cover, Banjarmasin City drainage network data, inundation point data, Banjarmasin City Inundation Control Area Unit (SWPG) Data;
- Hydraulic data (drainage channel dimensions) and channel profile shapes;
- Supporting data (inundation map and South Kalimantanfloodriskmap).

The analysis carried out in this study is described as follows and is given in Figure 1 Research Flowchart:

- Conducting an analysis of the research location map, including determining the research boundaries and land use maps with ArcGIS software;
- Perform design rainfall calculations to determine rainfall for the T-year return period and perform a Compliance Test with Hec-DSSVue, Hec-SSP, and EasyFit Professional;
- Perform calculations of design rain intensity, design rainfall distribution, adequate rain, unit hydrograph analysis, and design discharge;
- Performing inundation modeling simulations with EPA Software SWMM 5.1;
- Evaluate runoff of channel dimension samples with EPA Software SWMM 5.1;
- Conducting an analysis of the priority scale of activities is carried out based on the AHP (Analytical Hierarchy Process) with modeling of the inundation conditions obtained.

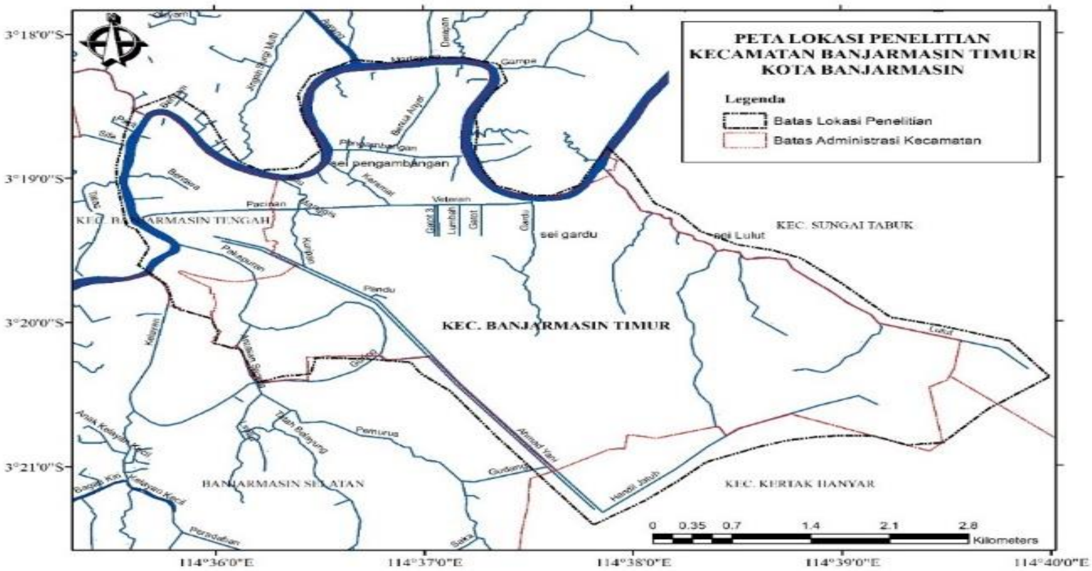

Fig. 1: Map of East Banjarmasin Research Locations

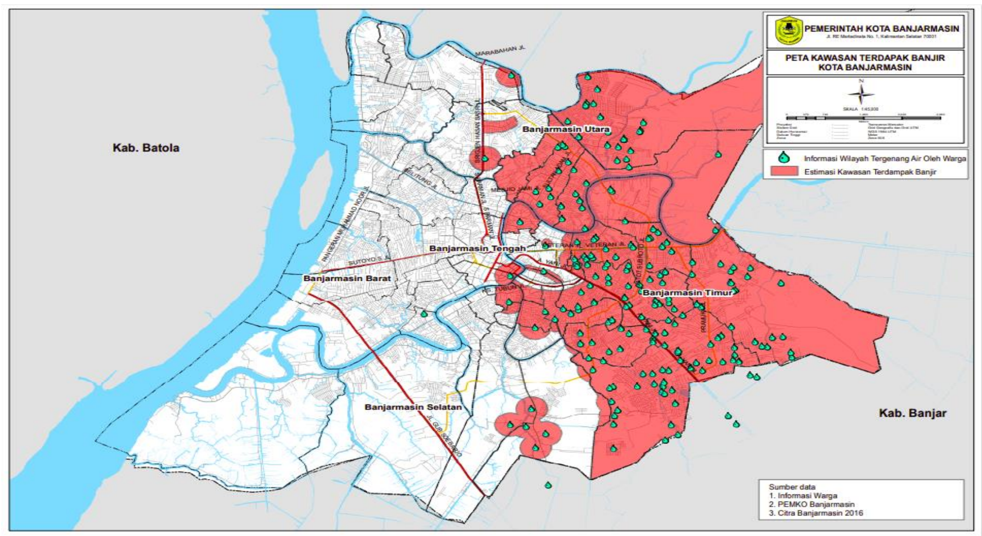

Fig. 2: Map of Flood Affected Areas in Banjarmasin (PUPR Banjarmasin, 2021)

III. RESULTS AND DISCUSSION

A. Geometry Analysis

➢ *Performing Geometry Data Corrections in QGIS 3.10*

The catchment area in this study is in the Martapura sub-watershed. This catchment area needs to be corrected for geometric data. The Catchment Area has been obtained from DEM data, Geoportal, and the Barito Watershed and Protected Forest Management Office. This analysis produces Validity Status Geometry Data, which is ready to be used for further analysis. Correction results are given in Figure 3 below.

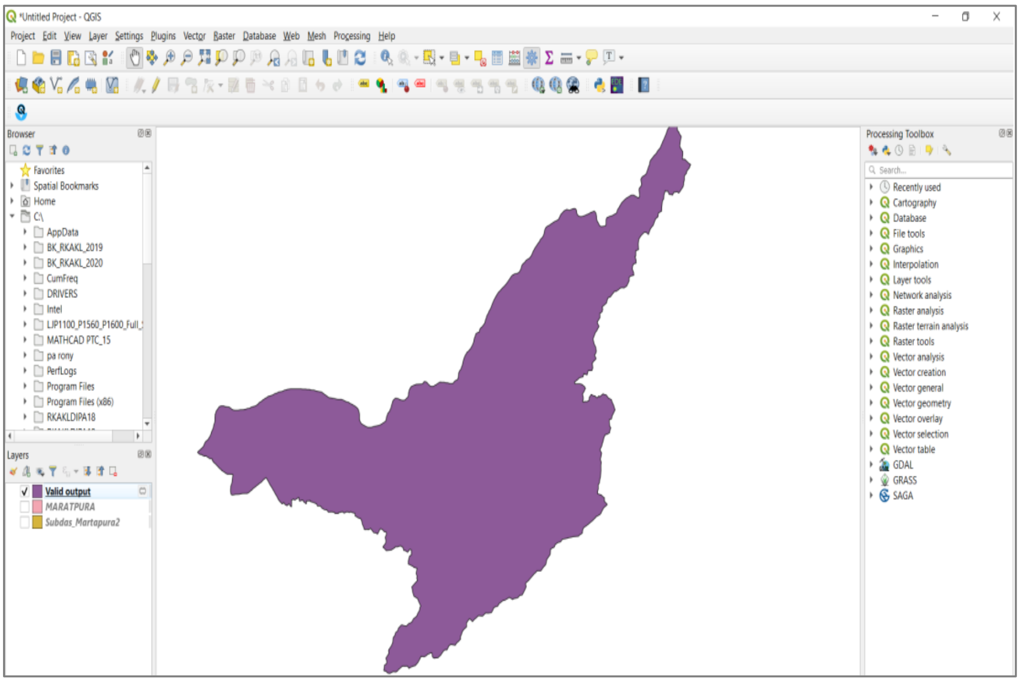

Fig. 3: Correction of Geometry Data in QGIS 3.10

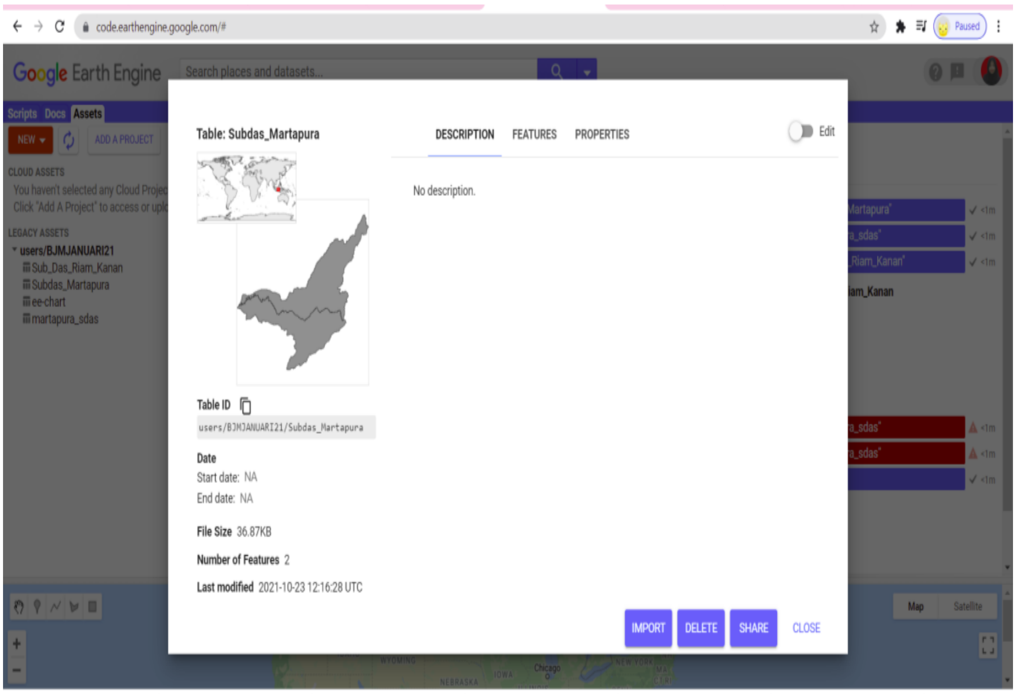

Fig. 4: Google Earth Engine

➢ *Chirps Data Extraction on Climate Engine*

Geometry data uploaded to the Google Earth Engine is required to obtain CHIRPS daily rainfall data by the catchment area at the research location, the extraction stage in Figure 5 below.

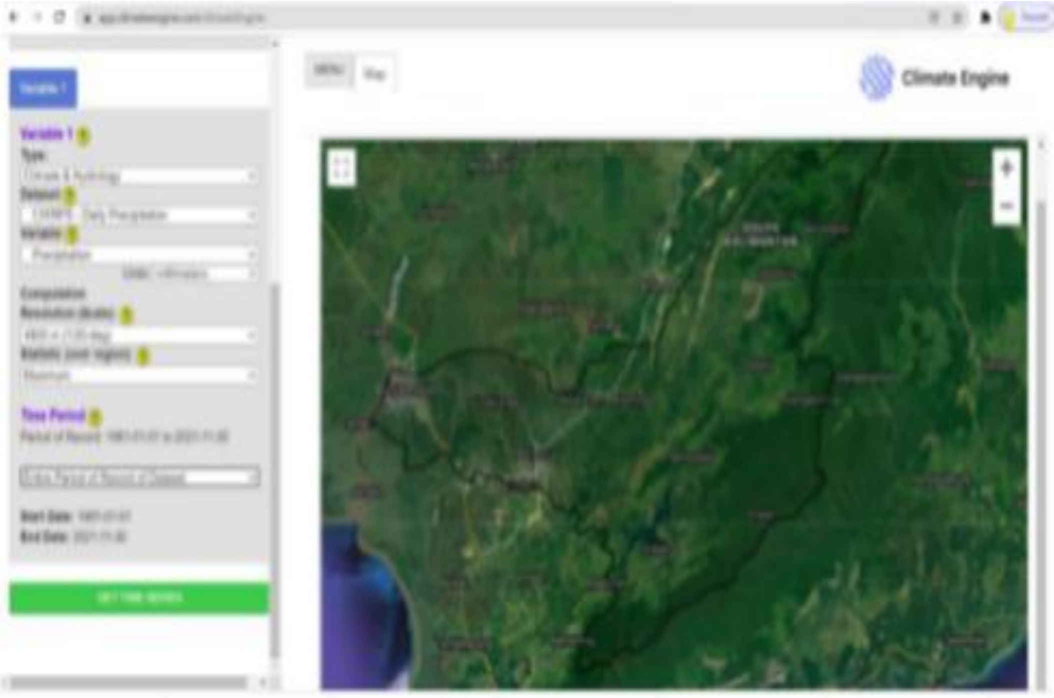

Fig. 5: CHIRPS Data Extraction

➢ *Transformation of Daily Rain to Hourly Rain*

The daily rain obtained using CHIRPS data will then be processed into hourly precipitation data with GSMap and is given in Figure 6 below. Hourly Rainfall data is given in Table 1.

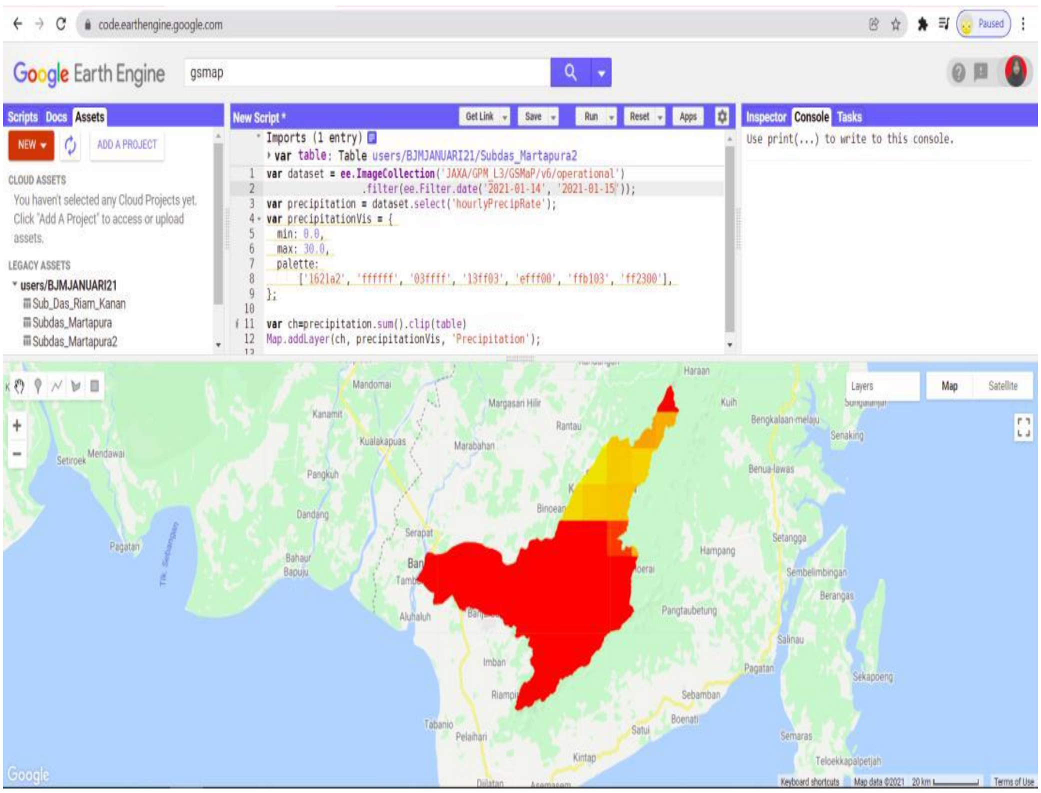

Fig. 6: Hourly Rain on GSMap

Table 1: Rain Hours January 14th, 2021

hours (WITA)	Hourly Precipitation (mm/hour)	hours (WITA)	Hourly Precipitation (mm/hour)
1	0.000	13	3.845
2	2.528	14	1.960
3	2.528	15	4.456
4	17.341	16	0.000
5	6.939	17	0.000
6	9.210	18	0.000
7	14.038	19	0.000
8	12.573	20	0.000
9	2.392	21	0.000
10	1.507	22	0.000
11	1.972	23	0.000
12	2.544	24	0.000

(Source: GSMAP Analysis January 14th 2021)

B. *Frequency Analysis*

Frequency analysis of rain data is intended to determine the amount of design rain. The frequency analysis process in this study uses the help of HEC-SSP and EasyFit software and is given in Table 2 and Table 3. HEC-SSP has limited distribution options, while EasyFit has more distribution types and is easier to use. The value of the probability distribution of rainfall generated by HEC-SSP and EasyFit does not have a significant difference, so both values are valid and can be used as input data for inundation modeling. The maximum rainfall in January 2021 of 83.83 mm is between the 2 and 5-year return period.

Table 2: Results of Frequency Analysis using HEC-SSP

Periode Ulang	Prop (%)	Distribusi Probabilitas		
(Tahun)		Gumbel	Log Pearson Type III	Normal
Memenuhi Pengujian		Kolmogorov-Smirnov	Kolmogorov-Smirnov	Kolmogorov-Smirnov
		Chi-Squared	Chi-Squared	Chi-Squared
2	50	78,33	78,65	80,93
5	20	92,3	92,73	94,23
10	10	101,55	101,72	101,19
20	5	110,43	110,16	106,93
50	2	121,91	120,95	113,4
100	1	130,52	129,01	117,71
200	0,5	139,09	137,07	121,65
500	0,2	150,41	147,81	126,43

Table 3: Probability distribution with Easy Fit

Return Period (year)	Distribution Probability				
	Gumbel Max	Gumbel Min	Log Pearson Type III	Normal	Gen. Logistic
Type of Distribution	Kolmogorov-Smirnov	Chi-Squared	Kolmogorov-Smirnov	Kolmogorov-Smirnov	Kolmogorov-Smirnov
	Anderson-Darling		Anderson-Darling	Anderson-Darling	Anderson-Darling
	Chi-Squared		Chi-Squared	Chi-Squared	Chi-Squared
2	78.36	83.56	78.66	80.96	78.72
5	92.35	93.96	92.76	94.29	91.61
10	101.61	98.38	101.78	101.25	100.59
25	113.31	102.51	112.94	108.67	113.12
50	121.99	104.92	121.13	113.47	123.56
100	130.61	106.93	129.25	117.79	135.07
200	139.20	108.66	137.38	121.73	147.86
500	150.52	110.63	148.23	126.52	167.02
850	157.08	111.65	154.61	129.11	179.43
1000	159.08	111.94	156.57	129.88	183.48

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C. Rain Intensity Analysis

Calculation of rain intensity states that rainfall intensity is the height of rainfall that occurs when the water is concentrated, with units of mm/hour. The results of this analysis of rain intensity are then presented in a graph in Figure 8. The calculation of rain intensity is intended to obtain the relationship between time and maximum rainfall in 24 hours (mm) to produce intensity curve graphs drawn for the desired return periods. The graph of Rain Intensity that occurs shows that the shorter the rain that occurs, the higher the intensity of the rain that occurs, and vice versa. The longer the rain lasts, the lower the intensity of the rain. Rain data will be used as input data in the Storm Water Management Software Model (SWMM) to evaluate existing drainage systems.

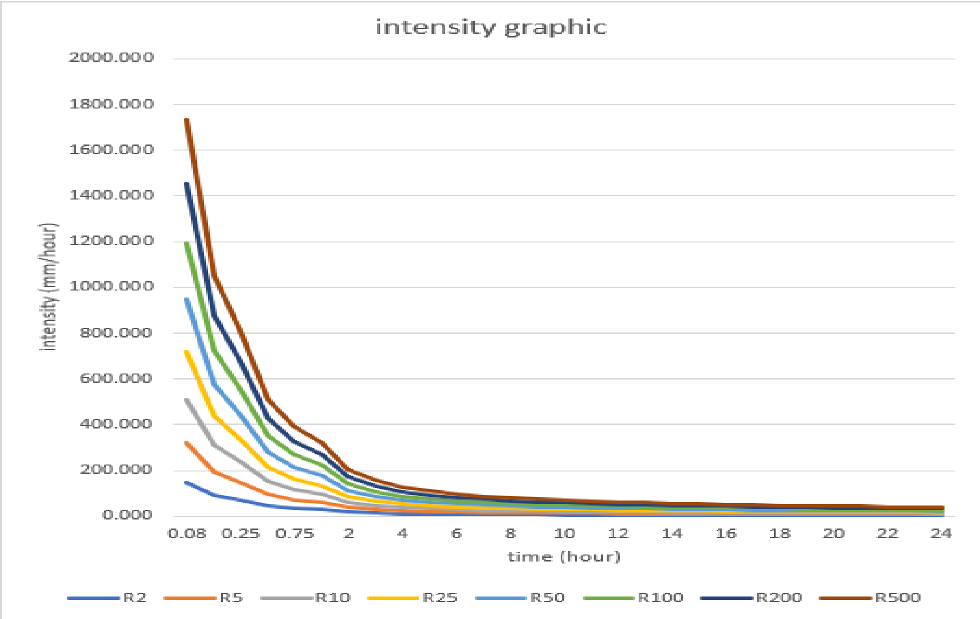

Fig. 7: Rain Intensity Graphic

D. Tidal Analysis

The tidal data used in this study are the Tidal Martapura River from 14 to 15 January 2021 for 48 hours. The Mean Sea Level (MSL) is 2.69 m, the Higher HighWater Level (HHWL) is 3 m, and the Lower Low Water Level (LLWL) is 2.2 m. This tidal data is not carried out by the routing process and is obtained from the Siring Station km.0, Banjarmasin City. The Tidal Chart is given in Figure 8.

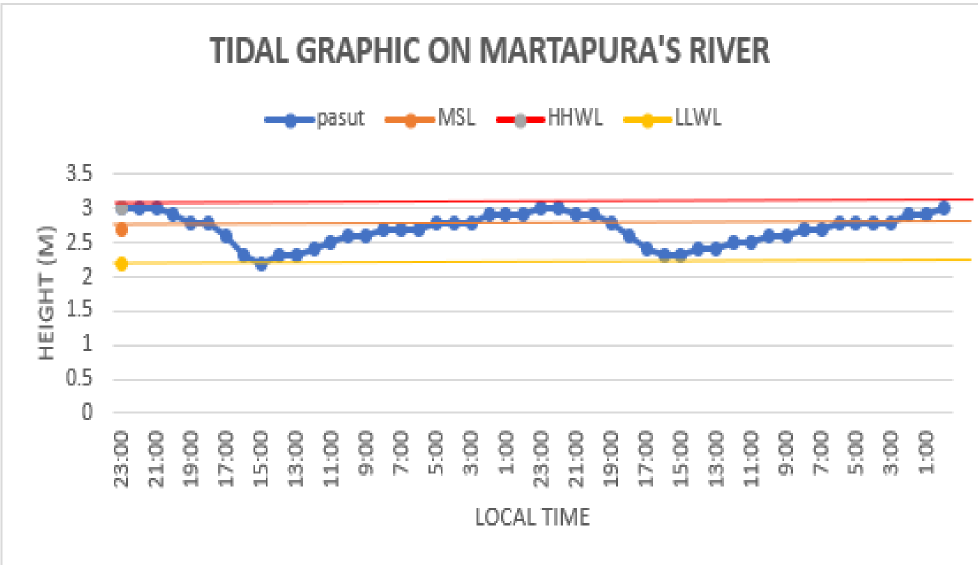

Fig. 8: Graph of the Tidal Martapura River

E. Drainage Analysis with EPA SWMM 5.1

Administratively, there are only 2 WPGs that are included in the East Banjarmasin Region, namely the Sungai Simpang Layang WPG and the Veterans WPG, according to Figure 9. These WPGs will then be analyzed based on the data obtained from the results of previous calculations.

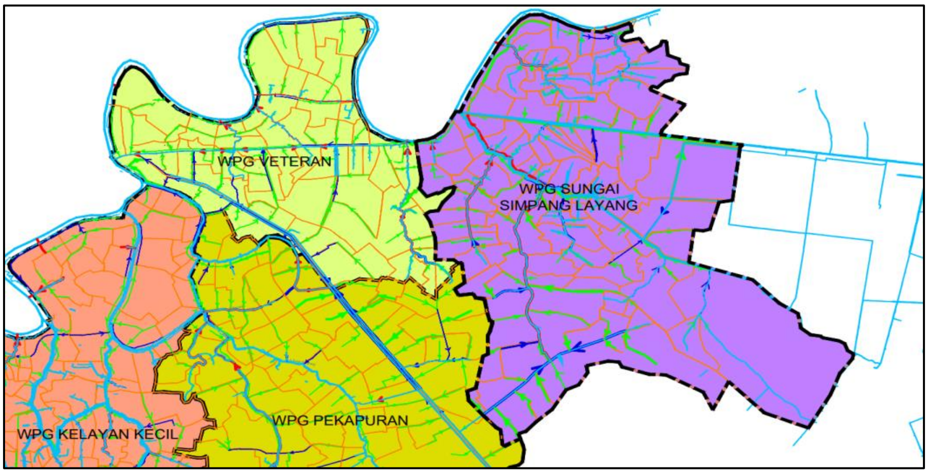

Fig. 9: WPG Sungai Simpang Layang and WPG Veteran

F. River Sub-System Modeling

9 Sub-systems of Sungai Simpang Layang WPG as follows:

- Bakung River Sub System 1
- Bakung River Sub System
- Lulut River Sub System 1
- Lulut River Sub System 2
- Lulut River Sub System 3
- Lulut River Sub System 4
- Lulut River Sub System 5
- Simpang Layang 1 River Sub System
- Simpang Layang 2 River Sub System

8 Veteran River WPG Sub-systems as follows:

- Ayani River Sub System
- Ayani River Sub System 2
- AES Nasution River Sub System
- Banua Anyar River Sub System
- Gardu River Sub System
- Sub-System of the Sacred River
- Kuripan River Sub System
- Sub-System of the Pengambangan River

As an example given Modeling in the Ayani River 2 Sub System with SWMM 5.1, with some input data as follows:

- Subcatchment Area
- Channel Dimensions, Shape Profile
- Land and Channel Elevation
- Rain Intensity
- Hourly Rain Data
- Tidal Data
- Flow Direction

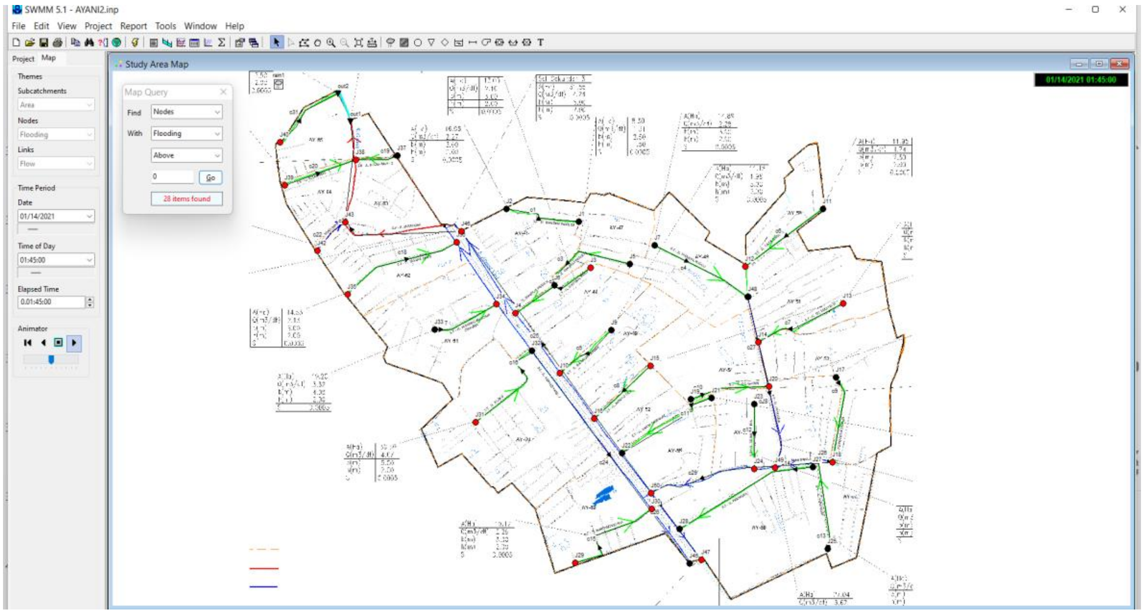

Fig. 10: Modeling of the Ayani River 2 Sub System with EPA-SWMM 5.1

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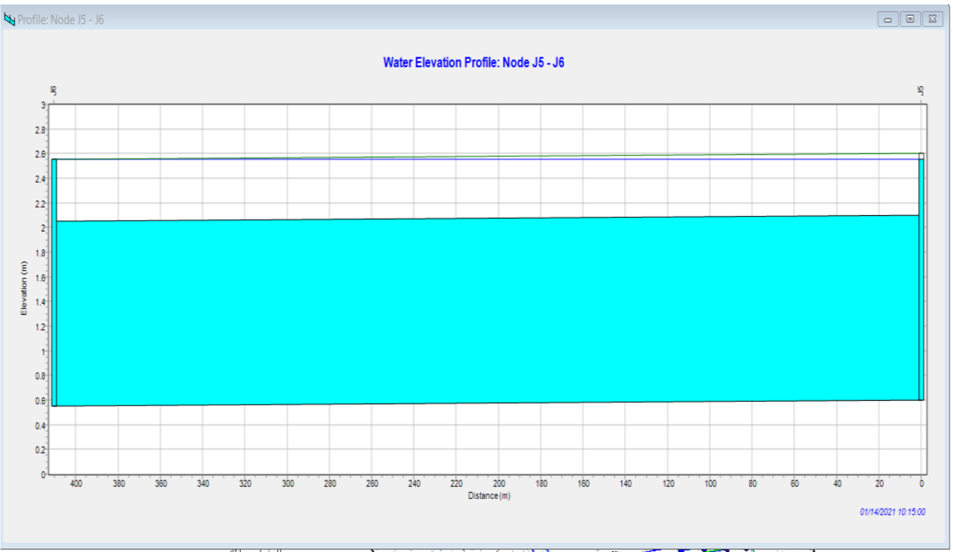

Fig. 11: Analysis of Drainage Channels for the Ayani River Sub System 2 with EPA-SWMM 5.1

This modeling produces data on the distribution of inundation points in the Ayani 2 River sub-system in the Sungai Veteran WPG, which has 42 inundation points with an average inundation height of 0.52 m. The distribution data can be seen in Figure 10, denoted by a red dot. Other Sub System Modeling will be given in Table 4 below.

Table 4: Summary of High Inundation Simulation Results in East Banjarmasin District

Sub-System	Inundation's point	Average Inundation Height (m)
Sub-System Bakung 1	16	0.85
Sub-System Bakung	8	0.80
Sub-System Lulut 1	2	1.19
Sub-System Lulut 2	5	0.89
Sub-System Lulut 3	6	0.68
Sub-System Lulut 4	21	0.90
Sub-System Lulut 5	7	1.06
Sub-System Simpang Layang 1	8	1.04
Sub-System Simpang Layang 2	2	0.44
Sub-System Ayani	19	0.96
Sub-System Ayani 2	42	0.52
Sub-System Aes Nasution	6	1.04
Sub-System Banua Anyar	2	1.05
Sub-System Gardu	19	1.04
Sub-System Keramat	10	1.10
Sub-System Kuripan	11	0.92
Sub-System Pengambangan	11	1.02
TOTAL	**195**	

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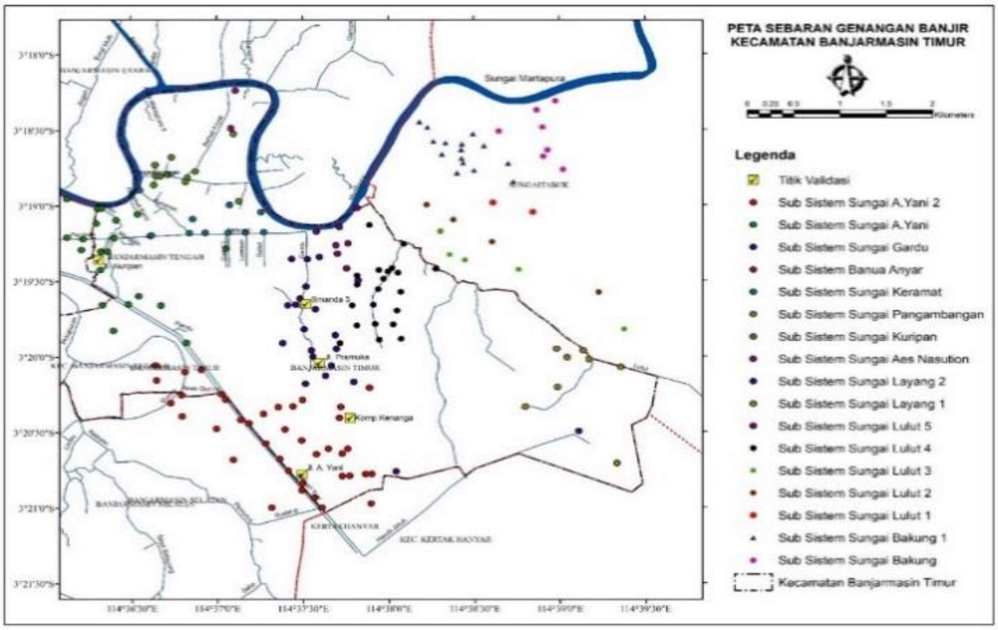

Fig. 12: Map of Flood Inundation Distribution in East Banjarmasin

The modeling results that have been obtained are then presented in the Inundation Distribution Map for the East Banjarmasin Region to determine inundation points which will then be validated according to the High Inundation event on January 14, 2021.

G. Inundation Priority Analysis

Inundation is caused by the absence of a drainage system/non-functioning drainage system/the inability of the drainage system to function optimally, causing water to overflow (out of the canal) and disrupting and harming community activities. This study uses the Analytical Hierarchy Process with five main validation points described in Table 5. These validation points are also depicted in the Flood Inundation Distribution Map in East Banjarmasin, which is notated in yellow in Figure 11.

Table 5: Research Validation Locations for AHP

No	Titik Validasi	WPG	Sub Sistem Sungai
1	Komplek Smanda III RT 20, Kelurahan Sungai Lulut	Sungai Layang	Sub Sistem Sungai Lulut 4
2	Komplek Kenanga I RT 01, Kelurahan Kebun Bunga	Veteran	Sub Sistem Sungai Ayani
3	Jl. Pramuka Km 6	Veteran	Sub Sistem Sungai Ayani
4	Jl. Mahat Kasan Kuripan	Veteran	Sub Sistem Sungai Ayani
5	Jalan Ahmad Yani km 5	Veteran	Sub Sistem Sungai Ayani

Based on the Inundation Priority Analysis that has been carried out, it can be seen that Jl. Pramukais ranked first for handling the inundation that occurred, Jl. Mahat Kasan Kuripan is in second place, Jl. Ayani is in third place, Jl. Kenanga is ranked fourth, and Jl. Smanda III is in the last rank. This priority scale is then validated based on data on the distribution of inundation obtained and on direct field observations. The Priority Analysis of Inundation results in East Banjarmasin is presented in Table 6 and Table 7 below.

Table 6: Analysis of Priority of Inundation in East Banjarmasin

No	Location	District	inundation parameters						Economic Losses		Social Disturbances and Government Facilities	
			Kedalaman	Nilai	Lama	Nilai	Frekuensi	Nilai	Efek	Nilai	Efek	Nilai
1	Jl. Kenanga I RT. 1	Kebun Bunga	>0.5 m	100	>24 jam	100	Less often (3 times/ year)	50	small	30	Very small	0
2	Jl. Mahat Kasan Kuripan	Kuripan	>0.5 m	100	>24 jam	100	often (6 times/ year)	75	moderate	65	moderate	65
3	Jl. Pramuka	Pemurus Luar	>0.5 m	100	>24 jam	100	Very often (10 times/ year)	100	moderate	65	high	100
4	Jl. Semanda III	Sungai Lulut	>0.5 m	100	>24 jam	100	rarely (1 times/ year)	25	small	30	Very small	0
5	Jl. A. Yani km 6	Kebun Bunga	>0.5 m	100	>24 jam	100	Less often (3 times/ year)	50	small	30	high	100

Table 7: Priority Analysis of Inundation in East Banjarmasin (continued)

No	Location	District	Transportation Interruption Losses		Losses In Residential Areas		Loss of Private/Household Property Rights		Total Points	Priority Scale
			Efek	Nilai	Efek	Nilai	Efek	Nilai		
1	Jl. Kenanga I RT. 1	Kebun Bunga	high	100	moderate	65	moderate	65	510	4th
2	Jl. Mahat Kasan Kuripan	Kuripan	high	100	moderate	65	moderate	65	635	2nd
3	Jl. Pramuka	Pemurus Luar	high	100	high	100	moderate	65	730	1st
4	Jl. Semanda III	Sungai Lulut	high	100	moderate	65	moderate	65	485	5th
5	Jl. A. Yani km 6	Kebun Bunga	high	100	moderate	65	moderate	65	610	3rd

The results of the Inundation Priority Analysis that have been obtained are entered on the High Inundation Distribution Map to determine whether the point is at the location of the distribution of inundation. Furthermore, a field review was carried out to validate the high inundation events, as evidenced by the field review documentation at the time presented in Figures 14 through 18 below.

Fig. 14: Validation Point on Jl. Pramuka

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Fig. 15: Validation Points on Jl. Mahat Kasan Kuripan

Fig. 16: Validation Point on Jl. A. Yani

Fig. 17: Validation Point on Jl. Kenanga

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Fig. 18: Validation Point on Jl. Smanda III

IV. CONCLUSION

In Banjarmasin's topographic condition, the water flow direction is primarily straight towards the Barito River and Martapura River through the rivers, which are the city's primary drainage channels.

A. The condition of the drainage network in East Banjarmasin District based on the inundation study that occurred is as follows:

- Channels are inadequate due to silting and being covered with garbage and mud;
- The channel does not function optimally as a rain-fed storage container;
- There is a building that is above the channel.

B. Distribution of points and height of inundation during high inundation events (January 2021) which were carried out in 2 WPGs in East Banjarmasin District, namely WPG Sungai Simpang Layang and WPG Veteran

- Sungai Simpang Layang WPG has a maximum height of 1.410 m, a minimum height of 0.150, and the average height in this WPG is 0.886 m. This WPG is modeled into nine sub-systems, namely, Bakung River Sub-System, Bakung River 1 Sub-System, Lulut River 1 Sub-System, Lulut River Sub-System 2, Lulut River Sub-System 3, Lulut River Sub-System 4, Lulut River Sub-System 5, Simpang Layang 1 River Sub System and Simpang Layang 2 River Sub System, with a total of 75 inundation points spread over an area of 1,673.36 ha.
- WPG Veteran has a maximum height of 1.260 m, a minimum height of 0.110, and the average height of this WPG is 0.838 m. This WPG is modeled into eight river sub-systems, namely the Ayani River sub-system, Ayani 2 river sub-system, AES Nasution sub-system, Banua Anayar sub-system, Gardu river sub-system, Keramat river sub-system, Kuripan river sub-system, and Pengambangan river sub-system a total of 120 inundation points spread over an area of 405,380 ha.

Recommendations Priority Scale for Flood Inundation Handling is carried out to validate data on the distribution of inundation that occurs. This study takes five validation points. The first rank is on Jl. Pramuka Pemurus Luar, with an inundation height of 0.6 m, the second rank is on Jl. Mahat Kasan Kuripan, with a height of 0.93 m, in third place is on Jl Ayani km 6 with a height of 0.48 m, and fourth place is on Jl. Kenanga I RT. 1 with a height of 0.6 m and the fifth rank is on Jl. Semanda III Lulut River with a height of 0.75 m. The results of this analysis are supported by field observations as evidenced by documentation of inundation when high inundation occurred in January 2021. The results of this analysis can be concluded that Jl. Pramuka has the highest level of treatment because they are the most severely affected and have been inundated for a long time. This area is also one of the community's economic centers, and there are various companies and government agencies, health centers, health facilities, residential areas, and the public area of Terminal Km 6, the major public transportation in Banjarmasin.

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