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Development Area for Floating Solar Panel and Dam in The Former Mine Hole (Void) Samarinda City, East Kalimantan Province

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***Abstract*— This study discusses using a multi-criteria decision model (MCDM) to determine a suitable area for floating solar panels and dams in former mine holes (voids) in Samarinda City. The existence of open coal mining activities causes damage to the surrounding environment. One of the damages is the formation of former mine holes (voids). The voids can be detected by satellite imagery. Samarinda City has hundreds of voids and has the potential to increase. Therefore, this study aims to describe areas that can become areas for developing floating solar panels and dams. In this study, MCDM was implemented using Fuzzy GIS (a technique that integrates Fuzzy Logic and GIS) concepts. Fuzzy GIS is used to determine the suitability area of several predetermined criteria. The land suitability criteria are classified using the Fuzzy Membership and the Fuzzy Overlay process. The results showed that there were 442 voids with a total area of 7,901 km^2. The suitability of floating solar panels and dams is divided into four classes, namely S1, S2, S3, and N. The number of voids in the suitability class of floating solar panels is 17, 26, 40, and 359 respectively. The number of voids in the suitability of the dams are 45, 133, 210, and 54, respectively. The majority of voids are spread in areas with low accessibility with more distances from 1 km, are in an area with high enough solar radiation with 1800-1900 kWh/m2/year, and are in an area with a slope of more than 10%.**

***Keywords*— Dam; fuzzy GIS; floating solar panel; Samarinda; void.**

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I. INTRODUCTION

In Indonesia until 2019, the realization of void reclamation is as much as 6,748 Ha and in 2020 has a target of 7,000 Ha [1]. As the number of coal mining activities increases, so will the post-mining area that must be reclaimed. On the other hand, the need for national electrical energy has increased every year. This must be balanced with an increase in power generation capacity. The actual installed capacity of power plants in 2019 is 69,1 Giga Watt (GW), or an increase of 4,2 GW compared to 2018. Meanwhile, the target for 2020 is 74,8 GW [1]. Looking at these data and facts, it is necessary to have alternative power sources besides coal that are also environmentally friendly in the future.

The location of astronomical Indonesia, which is passed by the equator, has the potential for an average solar radiation intensity of 4,8 kWh / m2 / day [2]. This potential must be maximized as well as possible, but there are challenges where it is a suitable and efficient place to place the solar panels unit. Like Indonesia, Thailand is a large country with much space for solar power development, but the land there is very fertile and valuable [3]. Waters can be used as an alternative as a medium other than land, especially in reservoirs in dam areas [3]. So, the construction of a floating solar panel unit cannot be separated from the dam-building as a floating medium.

During its development, the voids will be inundated by water and will increasingly develop into new waters in the area [4]. Floating solar panels and dams development areas have physical characteristics of the area similar to former mine holes lakes, namely in the form of water fields that tend to be deep and broad. In this research, the planning for the potential for inundated voids will be directed as a development area for floating solar panels and dams. The urgency of planning the use of voids to become areas of floating solar panels and dams is seen from the environmental conditions in Indonesia which have thousands of hectares of post-mining land, especially voids that must be reclaimed immediately, the reality of increasing energy needs and as a concrete step in carrying out the mandate of the concept of sustainable development.

Departing from these problems, Remote Sensing (RS) and Geographical Information System (GIS) technologies are present as an alternative method of modeling and planning potential voids. Voids can be identified using Remote Sensing technology by hue in satellite imagery. Furthermore, the distribution of detected voids can be modeled based on land suitability analysis using GIS tools and using the Fuzzy Logic method. Land suitability analysis is the process of determining the suitability of a particular plot of land for a specified use [5]. Remote Sensing Methods, Geographical Information Systems, and Fuzzy Logic are vital tools for identifying, comparing, and analyzing multi-criteria decision-making from good land suitability planning and management [6]–[10].

This research was conducted in Samarinda City, East Kalimantan Province. According to the Environment Agency (BLH) Samarinda City [16] in 2016, this area has the potential for voids covering an area of 6.000 Ha from the coal mining concession area throughout Samarinda City of around 30.000 Ha. Based on the following data, it is necessary to plan in the form of spatial modeling and study the potential use of voids in Samarinda City to have sustainable economic, social and environmental benefit values.

Research on the potential and utilization of former mine holes has been carried out by several previous researchers [4], [12], [13]. All are local scale studies from one mining area, whereas this research is a regional scale study covering many mining areas in one city. Several previous researchers have researched land suitability analysis for solar panels [14]–[19] and regarding the suitability of areas for dams [20]–[24]. All of these studies have never been linked to the location of former mine holes, while this study is a study that examines the suitability of the area in the former mine holes as an area for floating solar panels and dams.

II. Material and Method

A. Study Area and Data

The research area was conducted in Samarinda City, East Kalimantan Province. According to BPS Samarinda [41], astronomically Samarinda City is located between 0º21'81" - 1º09'16" South Latitude and 116º15'16" - 117º24'16" East Longitude and is traversed by the equator line or the equator which is located at latitude 00º.

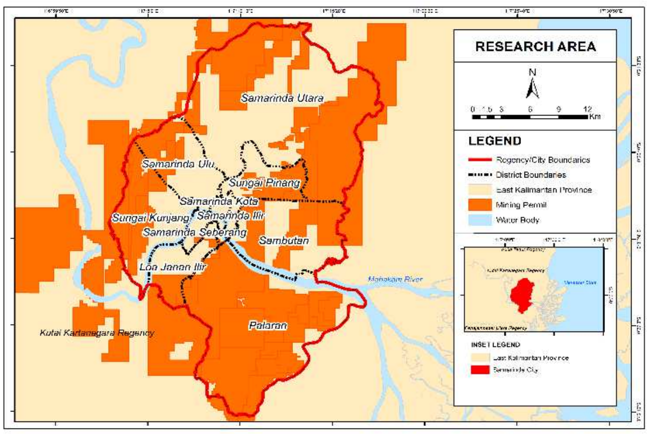

Fig. 1 Research Area

Based on its geographical position, Samarinda City is surrounded by Kutai Kartanegara Regency. Samarinda is divided into 10 districts, namely Palaran, Samarinda Ilir, Samarinda Kota, Sambutan, Samarinda Seberang, Loa Janan Hilir, Sungai Kukung, Samarinda Ulu, Samarinda Utara, and Sungai Pinang. The imageries used to identify voids are the processed imageries that available on the ESRI Imagery Basemap and Google Earth, and the Landsat 8 OLI satellite imagery. In this study, the ESRI Imagery Basemap and Google Earth were used to map the boundaries of the voids in Samarinda City. Whereas Landsat 8 OLI is used to produce land cover maps in Samarinda City.

B. Variable and Data Collection

The first analysis used is descriptive spatial analysis, where the spatial distribution of the voids will be described based on the concept of location, distribution, and spatial pattern. The distribution data were then validated using sampling and field survey techniques. In the next analysis, namely descriptive spatial analysis and GIS data analysis, the physical characteristics of the area such as geological resistance, slopes, soil texture, and land cover are presented and analyzed based on numbers and classified each suitability class based on the weight and assumptions that have been set. Accessibility variables such as distance from the road, distance from the river, and distance from the power grid will be analyzed based on proximity among other buffers, multiple ring buffers, and based on distance, namely Euclidean distance. Furthermore, climate variables such as rainfall values and solar radiation were analyzed using interpolation techniques for rainfall station points and solar radiation measurement points to obtain classification zones. Then all variables were analyzed using the fuzzy GIS approach. The research variables are presented in table 1, weights of solar panel suitability are shown in table 2, and weights of dam suitability are shown in table 3 below.

TABLE I
Research Variable

No	Variable Name	Indicator	Data source	Unit
1	Accessibility	Distance from Main Road	Road Network 1: 50,000 BIG and Road Network 1: 250,000 Open Street Map in 2019	km
		Distance from Power Grid	Electricity Network 150 kV 1: 250,000 ESDM Geoportal in 2020	km
		Distance from river	River Network 1: 50,000 BIG	km
2	Climate	Rainfall	BMKG and [25] in 2005-2011	mm/year
		Solar radiation	NASA Prediction of Worldwide Energy Resources (POWER) in 1983-2005	kWh/m²/y
3	Physical Characteristics	Geological Resistance	Geological Map of the Geological Development Research Center 1: 250,000 in 1983	type of host rock resistance
		Soil Texture	Map of Soil Type 1: 50,000 Ministry of Agriculture in 2016	soil texture classification
		Slope	DEMNAS	%

			1:50.000 BIG	
4	Former Mine Hole (Void)	Land Cover	Landsat 8 OLI Path: 116 Row: 60 (04/01/2019) USGS in 2019	land classification
		Actual Voids	(Maxar Technologies) ESRI Imagery Basemap and Google Earth in 2018-2020	coordinates and km²
		Mining Permit Area in Samarinda City	Mining Permit of the Directorate General of Mineral and Coal, Ministry of Energy and Mineral Resources (update October 28) in 2019	coordinates and km²

TABLE II
WEIGHTS OF SOLAR PANEL SUITABILITY

Indicator	Class	Range	Source	Unit
Distance from Main Road	**1**	<0,2	Modifications of [26]	km
	2	0,2-0,5		
	3	0,5-1		
	N	>1		
Distance from Power Grid	**1**	<0,5	Modifications of [16]	km
	2	0,5-1		
	3	1-1,5		
	N	>1,5		
Solar radiation	**1**	>1900	Modifications of [27]	kWh/m²/year
	2	1800-1900		
	3	1700-1800		
	N	<1700		
Slope	**1**	<3	[18]	%
	2	3-7		
	3	7-10		
	N	>10	[19]	

TABLE III
WEIGHTS OF DAM SUITABILITY

Indicator	Class	Range	Source	Unit
Distance from river	**1**	<0,5	Modifications of [22]	km
	2	0,5-1		
	3	1-1,5		
	N	>1,5		
Rainfall	**1**	>950	Modifications of [21]	mm/ year
	2	800-950		
	3	650-800		
	N	<650		
Geological Resistance	**1**	High	Modifications of [23]	type of rock resistance
	2	Moderate		
	3	Slightly Low		
	N	Low		
Type of soil	**1**	Clayey	Modifications of [22]	soil classification
	2	Loamy		
	3	Sandy Loam		
	N	Sandy		
Slope	**1**	<9	Modifications of [22]	%
	2	9-16		
	3	16-25		
	N	>25		
Land Cover	**1**	Open field	[23]	land classification
	2	Shrubs & Scrubs		
	3	Forest		
	N1	Agricultural land		
	N2	Built Land & Water Bodies		

In Fuzzy GIS operations, there are scenarios and Fuzzy rules (variables). Two trends indicate the Fuzzy set scenario, namely "fuzzy-up" (close to 1 → positive) and "fuzzy-down" (approaching 0 → negative). The Fuzzy rules used in this study are:

- If the distance from the main road is close, the distance from the power grid is close, the solar radiation value is high, and the slope is low, then the suitability level of a solar panel is high
- If the distance from the river is close, the intensity of rainfall is high, the geological resistance is high, the soil texture is clayey, the slope is low, and the land cover is an open type, then the suitability level of the dam is high

III. RESULT AND DISCUSSION

A. Distributions of Voids Mapping

The distribution of voids can be done by processing the ESRI Imagery Basemap using digitizing techniques. This technique is used to detect the presence of water-saturated voids. The appearance in the image in the form of a puddle is then digitized according to the water appearance boundary. Based on Figure 2, the locations of voids are scattered in almost all study areas, namely Palaran District, Sambutan District, Samarinda Utara District, Samarinda Ulu District, Sungai Kunjang District, Loa Janan Hilir District, Samarinda Seberang District, and Sungai Pinang District.

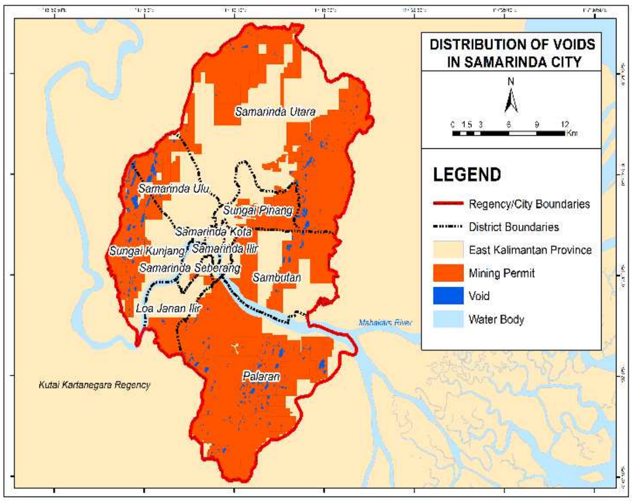

Fig. 2 Distribution of Voids

The following is the area of voids and mining business license areas registered in Samarinda City which have been calculated in the administrative area of Samarinda City only.

TABLE IV
AREA OF VOIDS AND MINING PERMIT

Region	Large (km²)	Percentage
Mining Permit in Samarinda City	436,804	59,170
Not Mining Permit	301,419	40,830
Samarinda City	738,223	100
Void	7,091	1,6 of Mining Permit

B. Suitability of Solar Panels Mapping

Land suitability for the potential for solar panel development can be done using the Fuzzy GIS method. This method is used to perform overlay analysis such as site selection and suitability models. Several data variables were fuzzified using Fuzzy Membership and then overlayed using Fuzzy Overlay. The following is a map of the results of Fuzzy Membership and Fuzzy Overlay:

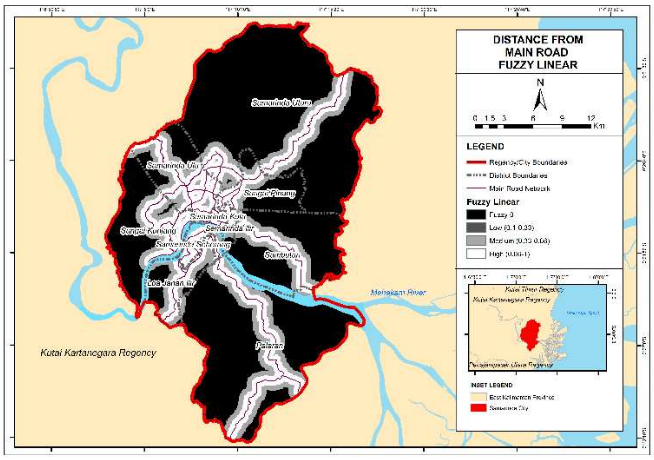

Fig. 3 Distance from Main Road Fuzzy

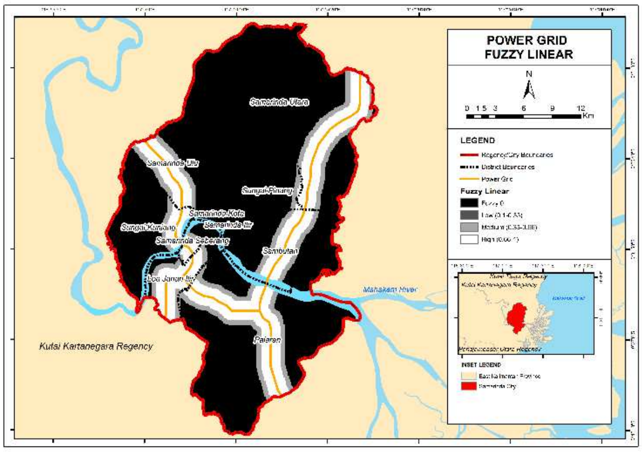

Fig. 4 Power Grid Fuzzy

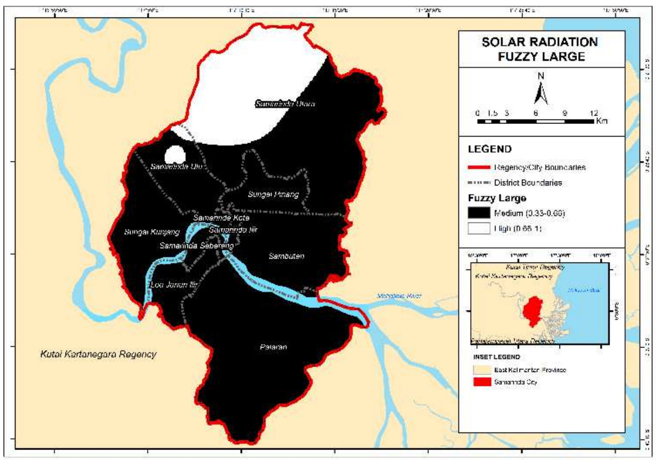

Fig. 5 Solar Radiation Fuzzy

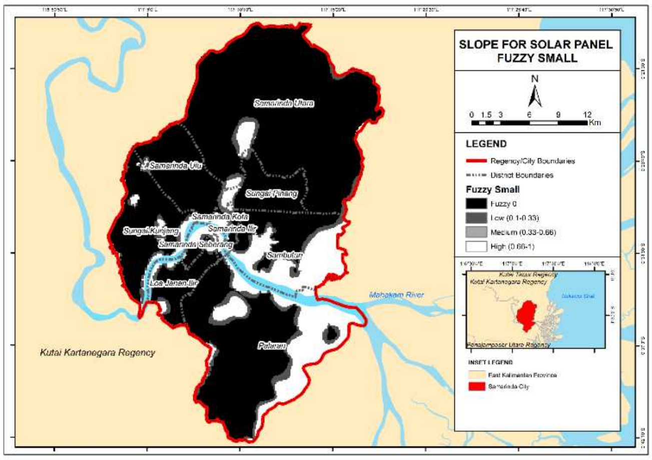

Fig. 6 Slope for Solar Panel Fuzzy

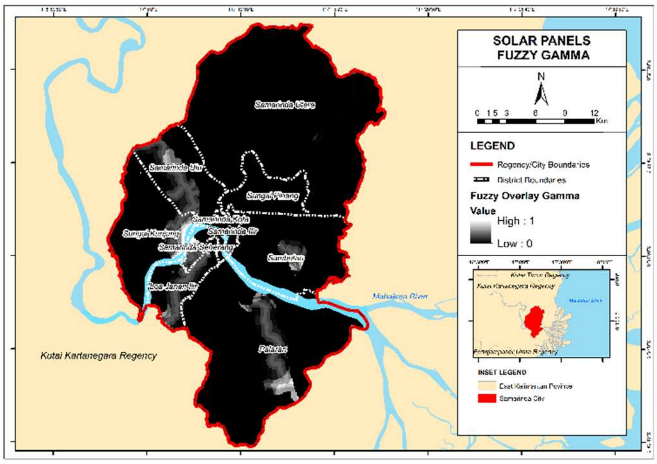

Fig. 7 Solar Panels Fuzzy

The suitability of the potential area for developing a floating solar panel is obtained from the overlay between the Fuzzy Gamma Solar Panel and the existing voids. Fuzzy Overlay Gamma Solar Panel is obtained from combining raster data processed from Fuzzy Membership Solar Panel. The selection of the Fuzzy Gamma function in the overlay process is aimed at when one or more input data shows the largest possible membership while the other shows the smallest possible membership, then the combination of the two (Fuzzy OR and AND) will produce a possibility somewhere between the two possibilities that are controlled by the amount of input data used.

The Fuzzy Membership data integration process results above are in the form of a new Gamma index value with a range (0 - 1). This can be seen in Figure 7. From the results of the Fuzzy value, it can be analyzed that the area that has the suitability of S1 as a solar panel has a Fuzzy value that is getting closer to 1. This value has the same meaning as the previously created Fuzzy rule, where if the distance from the main road is close, the distance from the power grid is close, the value of solar radiation is high, and the slope of the slope is low, the suitability of the solar panel is high. In Figure 7 it can also be seen that the proportion of the suitability area is dominated by Fuzzy 0. Samarinda Utara District has 100% of its area with Fuzzy 0, while Palaran and Samarinda Ulu Districts have the largest proportion of Fuzzy 1 suitability areas.

From the Fuzzy Gamma map, the suitability of solar panels is then classified into 4 suitability classes (S1, S2, S3, and N). The map is overlaid with the existing voids map, as shown in Figure 8. The results of the cross-section produce a map of the suitability of the floating solar panel's area. The following is the number of voids in each suitability class presented in Table V. The majority of voids fall into the N suitability class, with a total of 359 voids.

TABLE V
NUMBER OF VOIDS ON SUITABILITY OF SOLAR PANELS

	Suitability Class				
	S1	S2	S3	N	Total
Amount	17	26	40	359	442

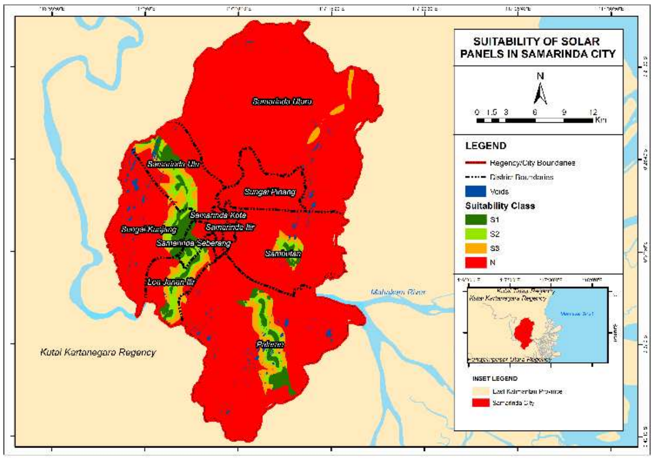

Fig. 8 Suitability of Solar Panels

C. Suitability of Floating Solar Panels Mapping

Figure 9 is a map of the suitability distribution of floating solar panels in Samarinda City. The map is generated from the intersect process of the suitability of the solar panels with the distribution of voids. Based on the information in Table V, the distribution of floating solar panel locations is mostly in the N class, the second is in the S3 class, the third is in the S2 class, and the fourth is in the S1 class. This shows that the majority of voids in Kota Samarinda are not suitable to be developed into floating solar panels. There are 17 voids in the S1 class that are very suitable to be developed into floating solar panels in Samarinda City.

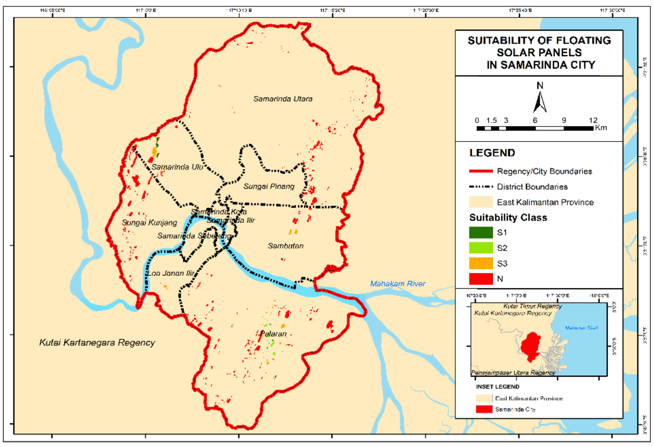

Fig. 9 Suitability of Floating Solar Panels

Besides being able to see Figure 8 and 9, Table VI can also provide information about the suitability of solar panels and the suitability of floating solar panels in the study area as follows:

TABLE VI
COMPARISON OF FLOATING SOLAR PANELS WITH SOLAR PANELS

		Floating Solar Panel Suitability Area (km^2)	Solar Panel Suitability Area (km^2)	Ratio (%)
Class	1	0,292	31,271	0,934
	2	0,289	33,316	0,867
	3	0,789	36,371	2,169
	N	6,531	637,265	1,025
Total		7,901	738,223	

Based on Table VI, it can be seen that the largest suitability area for floating solar panels is in N class, with an area of 6,531 km^2. The largest suitability area for solar panels is also in N class. However, the largest ratio is in the S3 class with 2.169%. This shows that the suitability 3 class has a high-density level. The map of the suitability of the floating solar panels is analyzed based on the district boundary analysis unit in Samarinda City. The following is information about the number of voids by the district. This information is presented in Table VII as follows:

TABLE VII
VOIDS ON THE SUITABILITY OF FLOATING SOLAR PANELS AREAS BY THE DISTRICT

District	Number of Voids				
	Class				Total
	S1	S2	S3	N	
Loa Janan Hilir	0	0	2	1	3
Palaran	11	19	19	129	178
Samarinda Ilir	0	0	0	0	0
Samarinda Kota	0	0	0	0	0
Samarinda Seberang	0	4	0	0	4
Samarinda Ulu	5	3	8	13	29
Samarinda Utara	0	0	9	124	133
Sambutan	1	0	2	17	20
Sungai Kunjang	0	0	0	75	75
Sungai Pinang	0	0	0	0	0
Total	17	26	40	359	442

Based on the information in the table, Palaran District has the highest total number of voids with 178 voids. Palaran District has the most S1 class voids for floating solar panels with 11 voids. Samarinda Ilir, Samarinda Kota, and Sungai Pinang Districts were detected as having no voids in their regional administrations.

D. Suitability of Dams Mapping

The suitability of the area for potential dam development can be done using the Fuzzy GIS method. This method is used to perform overlay analysis such as site selection and suitability models. Several data variables were fuzzified using Fuzzy Membership, and then overlay analysis was performed using Fuzzy Overlay. There are the variables used in the analysis of the suitability of the dam area:

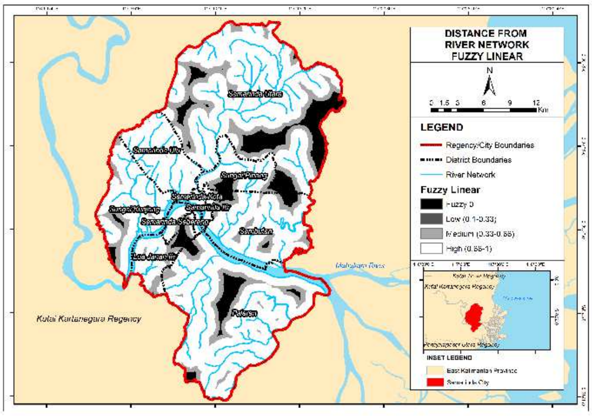

Fig. 10 Distance from River Fuzzy

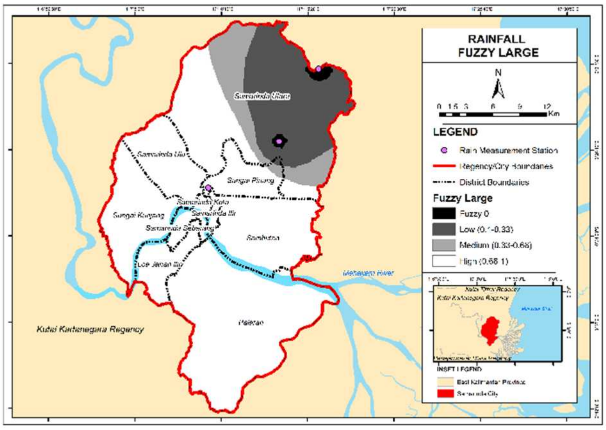

Fig. 11 Rainfall Fuzzy

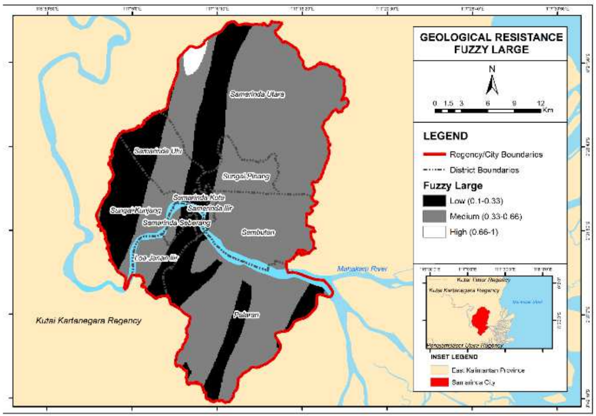

Fig. 12 Geological Resistance Fuzzy

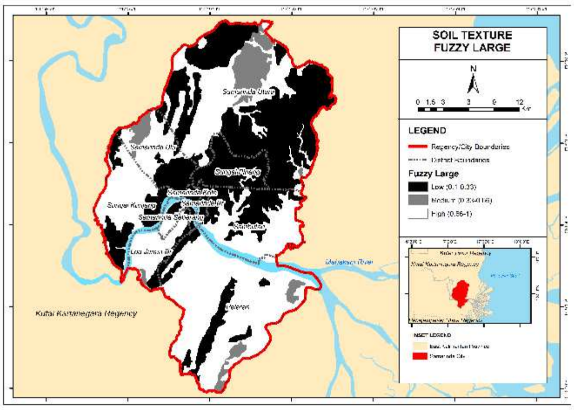

Fig. 13 Soil Texture Fuzzy

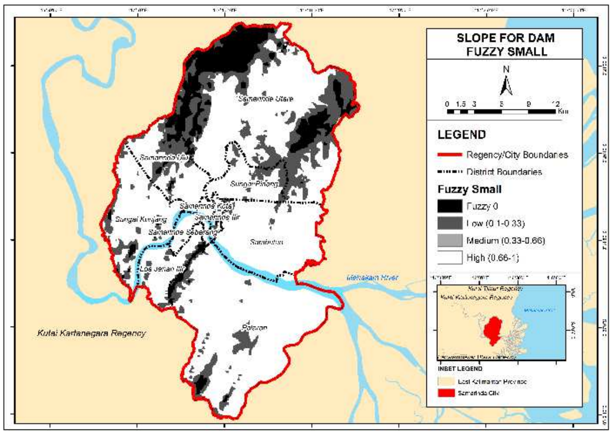

Fig. 14 Slope for Dam Fuzzy

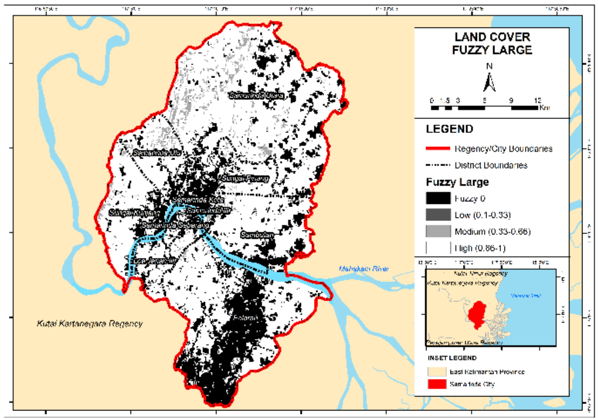

Fig. 15 Land Cover Fuzzy

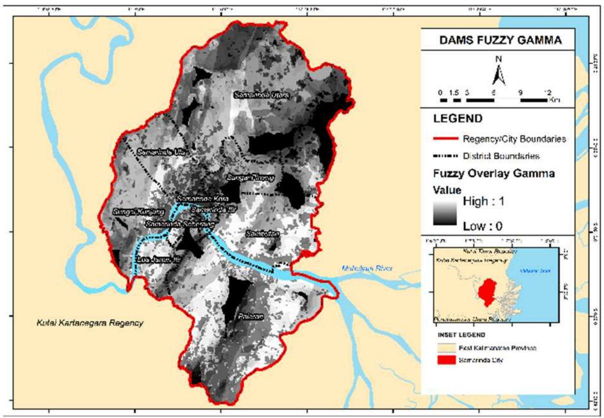

Fig. 16 Dams Fuzzy

The suitability of the potential area for dam development on the voids is obtained from the overlay between the Fuzzy Gamma dam and the existing voids. Fuzzy Overlay Gamma Dam is obtained from combining raster data processed from Fuzzy Membership Dam. The selection of the Fuzzy Gamma function in the overlay process is aimed at when one or more input data shows the largest possible membership while the other shows the smallest possible membership, then the combination of the two (Fuzzy OR and AND) will produce a possibility somewhere between the two possibilities that are controlled by the amount of input data used.

The Fuzzy Membership data integration process results above are in the form of a new Gamma index value with a range (0 - 1). This can be seen in Figure 16. From the results of the Fuzzy value, it can be analyzed that the area that has the suitability of S1 as a dam on the void has a Fuzzy value closer to 1. This value has the same meaning as the previously made Fuzzy rule, where if the distance from the river is close, the rainfall intensity is high, the geological resistance is high, clay-textured soil texture, low slope, and open field land cover, so the suitability level of the dam on the voids is high. In Figure 16 it can also be seen that the proportion of the suitability area varies greatly. Fuzzy 0 and Fuzzy 1 value ranges are spread in almost all areas of suitability.

From the Fuzzy Gamma map, the suitability of the dam is then classified into 4 suitability classes (S1, S2, S3, and N). The map is overlaid with the existing void map as shown in Figure 17. The results of the cross-section produce a map of the suitability of the dam area on the voids. The following is the number of voids in each suitability class presented in Table VIII. The majority of voids fall into the S3 class with 210 voids.

TABLE VIII
NUMBER OF VOIDS ON SUITABILITY OF DAMS

	Suitability Class				
	S1	S2	S3	N	Total
Amount	45	133	210	54	442

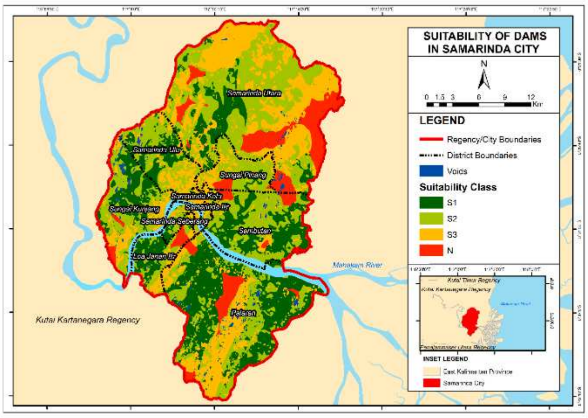

Fig. 17 Suitability of Dams

E. *Suitability of Dams on Voids Mapping*

Figure 18 is a map of the suitability distribution of dams on voids in Samarinda City. The map is generated from the intersect process of the suitability of the dams with the distribution of voids.

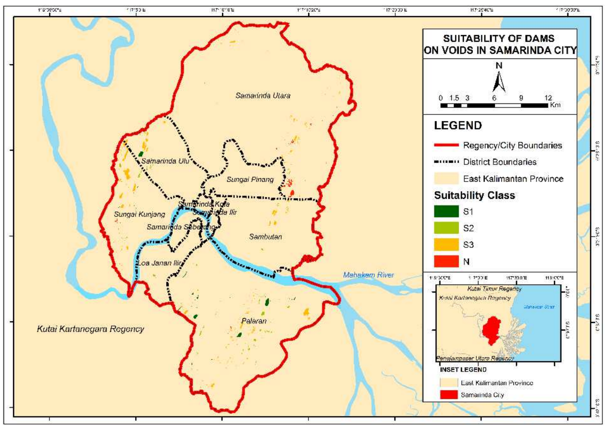

Fig. 18 Suitability of Dams on Voids

Based on the information in Table VIII, the distribution of dam locations on voids is mostly in S3 class, the second in the S2 class, the third in the N class, and lastly in the S1 class. This shows that the majority of voids in Samarinda City are moderately developed into dams. However, 45 voids have S1 class, which is very suitable to be developed into dams. Besides being able to see Figure 17 and 18, Table IX can also provide information about the suitability of the dams on the voids and the suitability of the dams in the study area as follows:

TABLE IX
COMPARISON OF DAMS ON THE VOIDS WITH DAMS

		Dam on Void Suitability Area (km2)	**Dam Suitability Area (km2)**	**Ratio (%)**
Class	**1**	1,104	183,028	0,603
	2	1,352	283,472	0,477
	3	4,642	207,709	2,235
	N	0,803	64,014	1,254
Total		7,901	738,223	

Based on Table IX, it can be seen that the area of the suitability of the dams on the voids is in the S3 class with an area of 4,642 km^2. The largest dam suitability area is in the S2 class with 283,472 km^2. The biggest comparison is in the S3 class with 2,235%. This indicates that the S3 class has the highest density level. The suitability of dams on the voids map was also analyzed based on the district boundary analysis unit in Samarinda City. The following is information about the number of voids by the district. This information is presented in Table X as follows:

TABLE X
VOIDS ON THE SUITABILITY OF DAMS ON VOIDS AREAS BY THE DISTRICT

District	**Number of Voids**				
	Class				**Total**
	S1	**S2**	**S3**	**N**	
Loa Janan Hilir	0	3	0	0	3
Palaran	24	59	89	6	178
Samarinda Ilir	0	0	0	0	0
Samarinda Kota	0	0	0	0	0
Samarinda Seberang	0	3	0	1	4
Samarinda Ulu	8	10	11	0	29
Samarinda Utara	0	21	73	39	133
Sambutan	1	6	10	3	20
Sungai Kunjang	12	31	27	5	75
Sungai Pinang	0	0	0	0	0
Total	45	133	210	54	442

Based on the information in Table X, Palaran District has the highest total number of voids with 178 voids. Palaran District has 24 voids with the most S1 class for dams on voids. Samarinda Ilir, Samarinda Kota, and Sungai Pinang Districts were detected as having no voids in their regional administrations.

IV. CONCLUSION

Samarinda City has a void area of 7,901 km^2 which is spread over 7 districts. The total number of voids detected in the study area was 442 voids. The highest number of voids distribution is in Palaran District with 178 voids. The regional suitability level for the development of floating solar panels in Samarinda City is divided into 4 suitability classes, namely S1, S2, S3, and N with details of the number of voids in a row as many as 17, 26, 40, and 359. The voids that have the most S1 classes are in the District Palaran with 11 voids. While the level of suitability of the area for dam development on voids in Samarinda City is also divided into 4 suitability classes, namely S1, S2, S3, and N, with details of the number of voids in a row as many as 45, 133, 210, and 54. The voids have the most S1 classes located in Palaran District, with 24 voids.

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