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Flood Susceptibility Mapping in Gending District by Comparison Frequency Ratio and Weight of Evidence for Mitigation Strategy

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A B S T R A C T

Floods are natural disasters that occur all over the world. Gending District in Probolinggo Regency, East Java, is an area that often experiences floods and causes various losses. A flood susceptibility map needed to prepare appropriate mitigation actions. Choosing the right method will produce a more accurate flood susceptibility map. The research aims to make a flood susceptibility map in Gending District by comparing the Frequency Ratio (FR) and Weight of Evidence (WofE) methods and providing appropriate mitigation recommendations. Six data factors that cause flooding are used: slope, elevation, land use, normalized difference vegetation index (NDVI), curvature, and rainfall. The data obtained were processed using the FR and WofE methods, which were then validated using the Receiver Operating Characteristics (ROC) method. The validation value is calculated using the ROC chart's Area Under Curve (AUC). The higher the AUC value, the better. The study's results revealed that the correct method for making a flood susceptibility map in Gending District was FR with an AUC value of 92.8%, while the WofE method was 90.4%. The flood susceptibility map illustrates that 14% of the area is in very high and high flood-prone zones, 23% is in the moderate zone, and 63% is in the safe zone. The appropriate mitigation strategy based on the highest FR value is creating drainage networks, and green open spaces, normalizing rivers in residential areas, and implementing selective logging and reforestation programs. The results of this study are used to reduce the impact and risk of future flood disasters.

1. Introduction

Flood is a natural disaster often faced by humans and occurs almost worldwide [1]. Indonesia recorded that more than 1,500 floods occurred throughout 2022 and became the most disasters. Floods occur due to heavy and prolonged rains, causing water in rivers and reservoirs to overflow into the surrounding areas. The flood caused damage to various buildings and disrupted community activities [2]. This flood causes various losses in the social and economic sectors.

Gending District is one of the areas in Probolinggo Regency, East Java, which often experiences flooding during the rainy season. One reason is the location of Gending District, which is in the lowlands, so the floods that occur tend to be sent from higher ground. In addition, the Gending sub-district has a gentle slope, so rainwater is difficult to absorb and flows quickly into the rivers around the area. Floods that frequently occur in Gending District have significantly impacted the lives of the local community. Therefore, it is necessary to have flood mitigation to minimize the risks posed.

Flood mitigation can be done with various efforts, such as normalizing drainage networks, building dams, and regulating land use [3]. However, a flood susceptibility map is needed to prepare appropriate mitigation actions. The map can be used to describe places that have the potential to experience flooding. In addition, flood susceptibility maps can be used to determine the location of flood control infrastructure development and identify influencing factors [4].

Flood susceptibility maps can be made using various methods such as frequency ratio [5], [6], analytic hierarchy processes (AHP) [7], [8], logistic regression [9], fuzzy logic[10], weights-of-evidence [11] and decision trees [12]. Matej Vojtek and Jana Vojteková used the AHP method to map Slovakia's flood susceptibility [13]. However, this method has the disadvantage of relying on expert judgment. While the frequency ratio (FR) method can produce a simple flood susceptibility map but provides a high area under curve (AUC) validation value. [14], [15] [16]. Besides that, the weights of evidence (WofE) method can also provide a high AUC validation value [17]. This shows that both methods can produce flood susceptibility maps [14]. The FR method is a statistical method that calculates the ratio between flood events and the factors that influence flood events in an area [18]. In comparison, the basic principle of the WofE method is to calculate the weight of the factors that influence flood events. Each factor related to flooding is given a weight based on the probability of flooding in the area affected by that factor [19].

Choosing the right method is crucial because each method produces different results at different locations. Comparison of the results of different methods in the same location is very helpful in assessing the method's reliability. The accuracy of a method is based on many things, such as the scale of the study area and the factors that cause the flooding used [20]. With an area of 34.74 km^2 in Gending District and using six factors that cause flooding, namely slope, elevation, land use, normalized difference vegetation index (NDVI), curvature, and rainfall, it is necessary to know the appropriate method for making a flood susceptibility map in Gending District.

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This research aims to make a flood susceptibility map in Gending District by comparing the FR and WofE methods and providing mitigation recommendations. This research will obtain a flood susceptibility map with the highest AUC validation value and an appropriate disaster mitigation strategy. So that it is expected to reduce the impact and risk of flood disasters in the future.

2. Research Method

This research was conducted in Gending District in Probolinggo Regency. The research data is a Flood Inventory Map, Slope, Elevation, Curvature, Land Use, Rainfall, and NDVI. The data is divided into 70% for training and 30% for validation. Then carried out training on the parameters used and reclassified using the natural break method so that a flood susceptibility map will be obtained, which will then be compared with the Receiver Operating Characteristic (ROC) method.

2.1 Study Area

Gending is a district located on the coast of Probolinggo Regency, to be precise between 13°12' – 13°24' E and 7°42' – 7°54' S. Administratively, Gending District consists of 13 villages/wards.

Source: DEM SRTM 30 Map, Rupa Bumi Indonesia Map, Landsat 8 (OLI) Imagery.

Figure 1. Study Area.

2.2 Data Requirements

In making the flood susceptibility map, 30 x 30 m resolution is used with DEM SRTM data. The derivative of DEM produces slope, elevation, and curvature layers. Rupa Bumi

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Indonesia Map can be reduced to a land use layer. The rainfall layer uses rain station data and annual rainfall obtained from Dinas PUPR Probolinggo. meanwhile, the red and infrared band derivatives from Landsat 8 (OLI) imagery are used to calculate NDVI. The data layer source can be seen in **Table 1.** below.

Table 1. Data Source.

No	Data Type	Source
1	Flood Inventory Map	Dinas PUPR Probolinggo
2	Slope	DEM SRTM 30
3	Elevation	DEM SRTM 30
4	Curvature	DEM SRTM 30
5	Land Use	Rupa Bumi Indonesia Map
6	Rainfall	Dinas PUPR Probolinggo
7	NDVI	Landsat 8 (OLI) Imagery

Source: Author Research Methods.

2.3 Frequency Ratio Model

The Frequency Ratio (FR) is a straightforward probabilistic model that is simple to comprehend and implement by calculating the ratio of disaster events to the total area also the ratio of the probability of disaster events to the occurrences of disasters for the given attribute component [21]. This approach to mapping flood susceptibility can be described as the ratio of the research region's total area to the area where a flood susceptibility can occur or as the ratio of the likelihood of an occurrence to the absence of an affair [14], [21]. The FR value is calculated by the equation below (1):

$$FR = \frac{A / B}{M / N} \tag{1}$$

Where A is the Number of flood occurrence pixels for each parameter class; B is the Number of flood occurrence pixels in the study area; M is the Number of pixels for each parameter class; and N is the Number of pixels for the total study area. The flood susceptibility index (FFSI) is calculated by adding each weighting factor.

2.4 Weights-of-Evidence Model

Based on Bayesian statistical theory, the weights-of-evidence method is a quantitative data-based approach that integrates data sets[22]. According to various research that has thoroughly detailed the formulation of the Weights-of-Evidence technique, The weights in each class for each parameter are obtained according to the occurrence/non-occurrence of floods in an area (2), (3), [23]–[25].

$$W_i^{+} = \ln \frac{P\{B|A\}}{P\{B|\bar{A}\}} \tag{2}$$

$$W_i^{-} = \ln \frac{P\{\bar{B}|A\}}{P\{\bar{B}|\bar{A}\}} \tag{3}$$

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Where P is the probability, B is the influence of the parameters that cause floods, $\bar{B}$ Is the absence of the influence of the parameters that cause floods, A is the presence of floods, $\bar{A}$ is the non-existence of floods and W+ also W–, which are the positive and negative weights of the parameters that represent the presence/absence of the influence of each parameter on the flood event. The two weights' differences are defined as contrast (C), used to measure and see the spatial relationship between the slide and the evidence feature.

$$C = W_i^{+} - W_i^{-} \quad (4)$$

Then, the final weight can be calculated using the following equation.

$$S^2(W^+) = \frac{1}{N\{B \cap A\}} + \frac{1}{\{B \cap \bar{A}\}} \quad (5)$$

$$S^2(W^-) = \frac{1}{N\{\bar{B} \cap A\}} + \frac{1}{\{\bar{B} \cap \bar{A}\}} \quad (6)$$

$$S(C) = \sqrt{S^2(W^+) + S^2(W^-)} \quad (7)$$

$$W = C/S(C) \quad (8)$$

Where $S(W^+)$ also $S(W^-)$ are the categories of positive and negative weights, also S(C) is the standard deviation of C.

2.5 Receiver Operating Characteristic (ROC)

Receiver Operating Characteristic (ROC) is a technique for visualizing, organizing, and classifying several categories determined in a statistical model based on their performance [26]. The ROC graph illustrates the relationship between the True Positive Rate (TPR) and the False Positive Rate (FPR). The relationship between TPR and FPR values is related to each other. If there is an increase in TPR, the FPR will decrease, and vice versa. ROC graphs can produce a diagonal line by determining a random classification called Random Performance [27]. When all classification data includes TPR and FPR, the data can be plotted onto the ROC graph. Each point representing the data from the classification can be connected to become a ROC curve [28]. The model's probability or accuracy level is calculated based on the Area Under Curve (AUC) on the ROC graph. The higher AUC value, the better the model is [29].

The Receiver Operating Characteristics (ROC) method is used in evaluating the accuracy of the results because this method is general and easy to understand [1]. The predicted success rate should be evaluated as a result of each modeling process [30]. This method is the right method to validate flood susceptibility maps for the FR and WofE method [1]. The data needed to validate the flood susceptibility map are flood inventory data for testing (30%) and the flood susceptibility map that has been formed.

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3. Results and Discussions

3.1 Flood Susceptibility Mapping Using Frequency Ratio Model

Frequency ratio values for six conditions factors were derived according to how they related to flooding. There is a significant association between conditioning factors and flood events, as indicated by a larger frequency ratio [31]. Therefore, a relationship is considered strong or weak if its value is greater or lower than 1.

Table 2. Calculation Results of FR for all Classes of Parameters.

Factor	Class	Area (pixel)	%	Floods (pixel)	%	FR
Slope	0 - 1,57	14544	34,11	55	40,74	1,19
	1,57 - 3,06	16416	38,50	61	45,19	1,17
	3,06 - 5,08	8771	20,57	18	13,33	0,65
	5,08 - 9,19	2331	5,47	1	0,74	0,14
	9,19 - 19,04	581	1,36	0	0	0
	Total	42643	100	135	100	3,15
Elevation	-4,44 - 5,07	18093	42,43	68	50,37	1,19
	5,07 - 13,06	12827	30,08	67	49,63	1,65
	13,06 - 27,31	10256	24,05	0	0	0
	27,31 - 56,45	1024	2,40	0	0	0
	56,45 - 94,57	443	1,04	0	0	0
	Total	42643	100	135	100	2,84
Land Use	Plantation Forest	2864	6,72	0	0	0
	Settlement	6276	14,72	105	77,78	5,28
	Dryland Farming	16908	39,65	23	17,04	0,43
	Ricefield	9896	23,21	7	5,19	0,22
	Pond	6699	15,71	0	0	0
	Total	42643	100	135	100	5,93
NDVI	-0,15 - 0,09	4467	10,48	8	5,93	0,57
	0,09 - 0,21	8747	20,51	55	40,74	1,99
	0,21 - 0,32	10077	23,63	37	27,41	1,16
	0,32 - 0,43	11076	25,97	31	22,96	0,88
	0,43 - 0,63	8276	19,41	4	2,96	0,15
	Total	42643	100	135	100	4.75
Curvature	-2,17 - -0,4	4194	9,84	13	9,63	0,98
	-0,4 - -0,11	11108	26,05	40	29,63	1,14
	-0,11 - 0,15	14679	34,42	41	30,37	0,88
	0,15 - 0,48	9618	22,55	33	24,44	1,08
	0,48 - 2,24	3044	7,14	8	5,93	0,83
	Total	42643	100	135	100	4,91
Rainfall	1011 - 1042,19	21673	50,82	133	98,52	1,94
	1042,19 - 1085,66	9103	21,35	0	0	0
	1085,66 - 1148,04	3403	7,98	2	1,48	0,19
	1148,04 - 1206,63	3622	8,49	0	0	0
	1206,63 - 1252	4842	11,35	0	0	0
	Total	42643	100	135	100	2,13

Source: Research Result.

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The slope has a close relationship with the possibility of flooding. The slope influences the infiltration process, where the higher the slope gradient will increase surface runoff and slow down the infiltration process. As a result, water will stagnate and become flooded in areas with low slope gradients [14]. The slope parameter that has the highest FR value is in class 0 – 1,57 with an FR value of 1,19 also, the lowest FR value is in class 9,19 – 19,04 with an FR value of 0,00.

The elevation is a significant component that influences flooding. The frequency ratio typically decreases as elevation rises, meaning that the influence of floods is most and least affected by the lowest and highest elevation values, respectively [14]. This is shown in the FR calculation results for the elevation parameters above. The highest values are in class 5.07 – 13.06, with an FR value of 1.65.

Land use is the most influential parameter in flood events. Land use in urban areas increases surface runoff because the soil is impervious to water. At the same time, agricultural lands increase surface runoff because no ground cover vegetation can control and also prevent the rapid flow of water to the ground surface. Urban areas and agricultural land are at risk of flooding also erosion, so these areas are the most prone to flooding [14]. This is indicated by the analysis results in which the settlement and ricefields have the highest FR values of 5,28, and 0,22, respectively.

A negative value for the NDVI implies water, and a positive value for vegetation. That means the NDVI value ranges from -1 to +1. There is less chance of flooding the higher the NDVI class rating. Conversely, the likelihood of flooding increases as the NDVI class value decreases [14]. **Table 2** shows that the NDVI parameter in the range of 0,09 to 0,21 has the highest FR value of 1,99. While the lowest FR value of 0,15 is assigned to the NDVI parameter with the highest class value.

Similarly, the curvatures are an essential element that characterizes topography. Three categories are used to group the curvature map. Convex surfaces are represented by positive curvature values, flat surfaces by zero, and concave surfaces by negative curvature values. According to the result, the concave surface had the largest FR at a rate of 1,14, while the convex surface had the smallest FR at 0,83.

The calculation of FR rainfall parameters uses the Inverse Distance Weighted (IDW) method, where this method considers that each input point has a local influence and decreases with distance. This is shown in the FR calculation results for the rainfall parameter above, the

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highest value is in the lowest class with an FR value of 1,94, and the value will decrease as the parameter class increases.

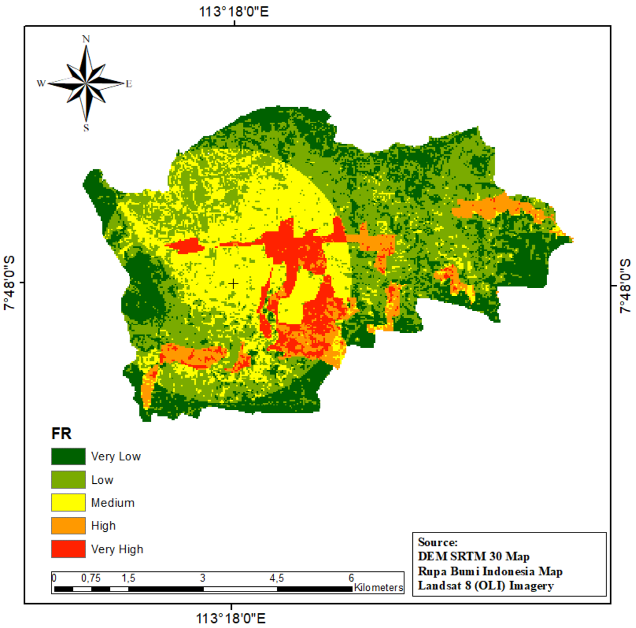
After preparing the six factors that cause flooding and giving weight to each parameter using the FR method, a flood susceptibility map is obtained by adding all the factors. The value of flood susceptibility is divided into five sub-classes, which are deficient, low, medium, high, and very high. This class is obtained from the result of reclassification using the natural breaks method in ArcGIS.

Table 3. Flood Susceptibility Index FR Method.

No.	Zone	Area (pixel)	%
1	Very Low	10371	24,48
2	Low	16263	38,39
3	Medium	9783	23,09
4	High	3041	7,18
5	Very High	2907	6,86
	Total	42365	100

Source: Research Result.

Table 3 shows that around 14% of the total area is in very high and high flood-prone zones, 23% is in the moderate zone, and 63% is in the safe zone. In the study area, land use has the largest contribution to landslides with an FR value of 5,94 followed by curvature with an FR value of 4,91.



Source: Research Result.

Figure 2. Flood Susceptibility Map FR Method.

The flood susceptibility map illustrates that areas with a very high level of flood susceptibility are mostly located in areas with low slopes, flat curvature, and land use in the form of settlements.

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3.2 Flood Susceptibility Mapping Using Weights-of-Evidence Model

Like the FR method, the weights-of-evidence technique establishes the connection between flood episodes and the flood triggering elements listed in **Table 4**.

Table 4. Calculation Results of Wof E for all Classes of Parameters.

Factor	Class	W+	W-	C	$S^2(W^+)$	$S^2(W^-)$	S(C)	W_{final}
Slope	0 - 1,57	0,18	-0,11	0,28	0,02	0,01	0,18	1,62
	1,57 - 3,06	0,16	-0,12	0,28	0,02	0,01	0,17	1,59
	3,06 - 5,08	-0,43	0,09	-0,52	0,06	0,01	0,25	-2,06
	5,08 - 9,19	-2,00	0,05	-2,05	1,00	0,01	1,00	-2,04
	9,19 - 19,04	0,00	0,01	-0,01	0,00	0,01	0,09	-0,16
			Total					-1,04
Elevation	-4,44 - 5,07	0,17	-0,15	0,32	0,01	0,01	0,17	1,86
	5,07 - 13,06	0,50	-0,33	0,83	0,01	0,01	0,17	4,81
	13,06 - 27,31	0,00	0,28	-0,28	0,00	0,01	0,09	-3,20
	27,31 - 56,45	0,00	0,02	-0,02	0,00	0,01	0,09	-0,28
	56,45 - 94,57	0,00	0,01	-0,01	0,00	0,01	0,09	-0,12
			Total					3,07
Land Use	Plantation Forest	0,00	0,07	-0,07	0,00	0,01	0,09	-0,81
	Settlement	1,66	-1,34	3,01	0,01	0,03	0,21	14,54
	Dryland Farming	-0,84	0,32	-1,16	0,04	0,01	0,23	-5,08
	Ricefield	-1,50	0,21	-1,71	0,14	0,01	0,39	-4,40
	Pond	0,00	0,17	-0,17	0,00	0,01	0,09	-1,98
			Total					2,26
NDVI	-0,15 - 0,09	-0,57	0,05	-0,62	0,13	0,01	0,36	-1,70
	0,09 - 0,21	0,69	-0,29	0,98	0,02	0,01	0,18	5,59
	0,21 - 0,32	0,15	-0,05	0,20	0,03	0,01	0,19	1,03
	0,32 - 0,43	-0,12	0,04	-0,16	0,03	0,01	0,20	-0,80
	0,43 - 0,63	-1,88	0,19	-2,07	0,25	0,01	0,51	-4,07
			Total					0,06
Curvature	-2,17 - -0,4	-0,02	0,00	-0,02	0,08	0,01	0,29	-0,08
	-0,4 - -0,11	0,13	-0,05	0,18	0,03	0,01	0,19	0,95
	-0,11 - 0,15	-0,13	0,06	-0,19	0,02	0,01	0,19	-0,99
	0,15 - 0,48	0,08	-0,02	0,11	0,03	0,01	0,20	0,53
	0,48 - 2,24	-0,19	0,01	-0,20	0,13	0,01	0,36	-0,55
			Total					-0,14
Rainfall	1011 - 1042,19	0,66	-3,50	4,16	0,01	0,50	0,71	5,85
	1042,19 - 1085,66	0,00	0,24	-0,24	0,00	0,01	0,09	-2,79
	1085,66 - 1148,04	-1,68	0,07	-1,75	0,50	0,01	0,71	-2,46
	1148,04 - 1206,63	0,00	0,09	-0,09	0,00	0,01	0,09	-1,03
	1206,63 - 1252	0,00	0,12	-0,12	0,00	0,01	0,09	-1,40
			Total					-1,84

Source: Research Result.

Based on the final W value from **Table 4**, for the slope factor, the lowest class has the greatest influence on flood events with a weight value of 1,62. For the second causal factor, namely elevation, only the lowest class and class 5,07 – 13,06 affect flood events with positive weight values with successive values of 1,86 and 4,81. At the same time, the other classes

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negatively influence the incidence of flooding. The land use factor that influences the incidence of flooding is the settlement class, with a weight value of 14,54. In other classes, such as plantation forests, dry land farming, rice fields, and ponds, there is no significant relationship to the incidence of flooding and is marked with a negative weight value.

In the NDVI factor, in class 0,09 – 0,21 and class 0,21 – 0,32, it has a positive value which means it affects flood events, while in other classes it does not really have an impact on flood events because of its negative value. For the curvature factor, only class -0,04 - -0,11 and class 0,15 – 0,48 affect the occurrence of flooding with a weight value of 0,95 and 0,53. In comparison, the other classes do not have a significant effect on the incidence of flooding. The last factor causing flooding is rainfall. Almost all have a negative effect on flood events. Only the lowest class has a positive weight value which means it has an effect on flood events.

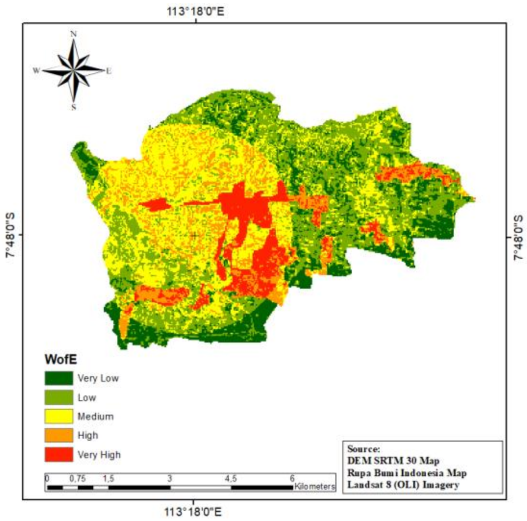
Furthermore, the flood susceptibility map is obtained by adding the W_{final} value for each factor.

Table 5. Flood Susceptibility Index WofE Method.

No.	Zone	Area (pixel)	%
1	Very Low	6178	14,58
2	Low	14118	33,32
3	Medium	12716	30,02
4	High	5591	13,20
5	Very High	3762	8,88
	Total	42365	100

Source: Research Result.

Table 5. shows that around 22% of the total area is in very high and high landslide-prone zones, 30% is in the medium zone, and 48% is in the safe zone.



Source: Research Result.

Figure 3. Flood Susceptibility Map WofE Method

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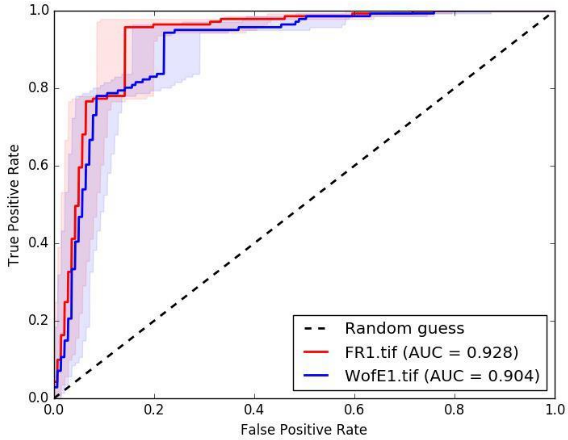
The flood susceptibility map illustrates that areas with a very high level of flood susceptibility are mostly located in areas with low slopes, flat curvature, and land use in the form of settlements.

3.3 Validation of Flood Susceptibility Maps

Map validation is important in identifying susceptible areas to determine their quality, so model results cannot be applied without validation. To validate the two flood vulnerability maps that are formed, a prediction level curve is used based on the location of the flood and each flood susceptibility map. The area under the curve predicted rate indicates how well the model predicts flooding[29]. **Figure 4** shows the results of the prediction rate curve.



Source: Research Result.

Figure 4. Area Under Curve (AUC).

The prediction accuracy value obtained in the FR method is 92.8% (AUC = 0.928). At the same time, the accuracy value obtained from the WofE method is 90.4% (AUC = 0.904). Based on these results, the FR method, which has the largest area under the curve and the highest accuracy (92.8%) compared to the WofE method, is the most precise way for creating flood susceptibility maps in the Gending District.

3.4 Flood Mitigation Strategy

Gending District is an area susceptible to flooding. To deal with floods that regularly occur every year, flood mitigation is carried out based on two main factors that cause flood susceptibility, namely land use and NDVI, which is based on the highest FR value.

1. Based on land use factors, where most of the flood events occur in residential areas, it is necessary to create an adequate drainage network to reduce runoff. Whereas for areas with very little Green Open Space (RTH) and a lot of hardening, this can be overcome by building RTH based on a flood susceptibility map that has been formed. In addition,

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normalization activities can also be carried out on the Gending River to restore the width and depth of the river so that the river can still accommodate the overflow of water when the rain intensity is high enough.

2. NDVI analysis needs to be monitored before the rainy season comes to increase the greenness index. Higher NDVI and dense vegetation reduce and slow water flow. Dense vegetation gives time for water to seep into the ground so that the volume of water is reduced and the possibility of flooding is smaller. Implementation of selective logging and reforestation programs can inhibit surface water flow and optimize infiltration in the upstream area, resulting in decreased runoff and reduced erosion rates [32].

4. Conclusion

The proper method for making a flood susceptibility map in Gending District is FR, with an AUC value of 92.8%, while the WofE method is 90.4%. The flood susceptibility map illustrates that 14% of the area is in very high and high flood-prone zones, 23% is in the moderate zone, and 63% is in the safe zone. The appropriate mitigation strategy based on the highest FR value is to create drainage networks, green open spaces, and normalize rivers in residential areas. In addition, the implementation of selective logging and reforestation programs needs to be carried out to increase the NDVI value. The results of this study are used to reduce the impact and risk of future flood disasters.

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