SPATIAL ANALYSIS OF HYDROMETEOROLOGICAL VULNERABILITY OF NATURAL DISASTERS IN THE BOGOR REGION

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Abstrak. Bogor Regency has a fairly large potential for natural disasters in the province of West Java, particularly hydrometeorological natural disasters, floods, and landslides. According to the Bogor Regency BPBD, there are 15 sub-districts with high potential for natural disasters. If we look at the level of damage, natural disasters, floods, and landslides have a very high level of loss due to the lack of information obtained by the community on the possibility of disasters occurring nearby. To avoid disaster losses, disaster risk management measures are needed. One way to manage disaster risk is to perform spatial data analysis in the form of maps of areas potentially prone to flooding and landslides based on the parameters that cause flooding and landslides. The method used in this study is Weighted Scoring and the analysis of disaster risk data is done spatially using a geographic information system (GIS) with the help of ArcGIS Software. This study aims to analyze and map the potential distribution of vulnerability to runoff and landslides in the district of Bogor. The results of the analysis are maps of areas prone to runoff and landslides in the regency of Bogor which can be used as a reference for mitigating natural disasters as well as for recommendations in regional land use planning.

Keywords: disaster risk, runoff, landslides, spatial data analysis, GIS

I. INTRODUCTION

Disaster is an event or series of events that threaten and disrupt people's lives and livelihoods caused, both by natural factors and/or non-natural factors as well as human factors, resulting in human casualties, environmental damage, property losses, and psychological impacts **[1]**. As a country that is in the path of the most active earthquake in the world because it is surrounded by the Pacific Ring of Fire and are on top of three continental plates colliding, namely, Indo-Australia from the south, Eurasia from the north, and the Pacific from the east, has make Indonesia is an area prone to volcanic eruptions, earthquakes and tsunamis **[2]**.

The existence of a disaster is basically not expected by any party. However, when a disaster is a possibility, then the action that can be taken is to increase preparedness when a disaster occurs and preparedness when a disaster does or has not occurred. One way of preparedness is by identifying locations that are prone to disasters. Vulnerability is closely related to vulnerability. Vulnerability is the level of possibility of a disaster object consisting of a community, structure, service or geographical area being damaged or disturbed due to the impact of a disaster or the tendency of an object or creature to be damaged by a disaster. The bigger the disaster, the greater the loss if humans, the environment, and infrastructure are more vulnerable (Himbawan **[3]**). If a hazard occurs, but the community is not vulnerable, then the community can solve the problem on its own. If the condition of the community is vulnerable, but there are no threatening events, then there will be no disaster. Vulnerability is aimed at identifying the impact of disasters in the form of casualties and economic losses in the short term, consisting of the destruction of residential infrastructure, facilities and infrastructure and other buildings, as well as long-term economic losses in the form of disruption of the economy due to trauma or damage to other natural resources. Vulnerability is a function of the magnitude of change and the impact of a situation, a vulnerable system will not be able to cope with the impact of changes that vary widely (Macchi in Pratiwi **[4]**).

Based on BNPB data **[5]**, the disasters that often occur are hydrometeorological disasters (meteorological natural disasters), especially floods and landslides, which are disasters that cause considerable damage and losses. Hydrometeorological disasters (meteorological natural disasters) are natural disasters related to climate. Hydrometeorological disasters such as floods, landslides, cyclones, tidal waves, and droughts are some examples of hydrometeorological disasters. The disaster is classified as a meteorological disaster because the above disaster is caused or influenced by meteorological factors. The number of disasters that occur cannot be separated from the geographical location of Indonesia. Indonesia is located at the confluence of active tectonic plates, active mountain paths, and tropical climates, making some of its regions vulnerable to natural disasters (Mahdia, 2013 in Rosyida, **[6]**).

Flooding is a problem that is a major concern throughout regions in many countries which is exacerbated by global climate change. Several climate projection models predict that the greenhouse effect will influence the hydrological cycle **[7].** Bogor Regency, West Java Province has several types of complex disasters, especially floods and landslides due to the biophysical condition of Bogor Regency which consists of mountains, hills and steep slopes and conditions of high land cover changes. Given these varied biophysical conditions, floods that often occur in the Bogor district are runoff floods and landslides. Runoff flooding occurs If the surface reserve capacity is exceeded, there will be surface runoff which eventually collects in the river flow as river discharge. One method to calculate flood runoff is the Cook's method. Cook's method (Cook's 1942 in Chow**[8]**) the parameters that affect runoff are (1) topographic conditions, (2) soil and rock conditions, (3) vegetation cover conditions and (4) land surface embankment conditions.

Landslides are soil movements that are directly related to various natural physical properties such as geological structures, parent materials, soil, drainage patterns, slopes/land forms, rain and dynamic non-natural properties such as land use and infrastructure (Barus **[9]**). According to Suripin **[10]** landslide is a form of erosion where the transport or movement of the soil mass occurs at one time in a relatively large volume. Wang **[11]** said that the occurrence of landslides is related to various factors such as (1) precipitation, (2) geology, (3) distance from the fault, (4) vegetation, and (5) topography.

The floods and landslides that occurred in Bogor Regency which were the most severe and resulted in large losses occurred, namely the hydrometeorological flood and landslide disaster in Cigudeg village, Sukajaya sub-district, Bogor Regency on January 1, 2020, floods and landslides in the area were caused by two The main factors are natural factors or high rainfall during or before the incident and the damage to protected areas in the upstream watershed due to changes in land use. To avoid losses due to the disaster, it is necessary to carry out disaster risk management actions. One way to be able to manage the risk of a disaster is to analyze spatial data in the form of mapping areas that are potentially prone to flooding and landslides based on the parameters that cause floods and landslides. For this reason, the main objective of this study is to analyze and map the distribution of potential flood and landslide susceptibility to runoff and landslides in Bogor district.

II. RESEARCH METHODS

Research sites. The study was conducted in all administrative areas of Bogor Regency, West Java Province, in January-April 2020. Bogor Regency is located at 6°19' North Latitude and 6°47' South Latitude, and 106°01' and 107°103' East Longitude. . With varied geographical types, from relatively low plains in the north to highlands in the south, which is about 29.28% at an altitude of 15-100 masl, 42.62% at an altitude of 100-500 masl, 19, 53% are at an altitude of 500-1,000 masl, 8.43% are at an altitude of 1,000-2,000 masl and 0.22% are at an altitude of 2,000-2,500 masl. (BPS Bogor Regency **[12]**).

Research methods. In the implementation of this research using spatial analysis and survey methods. The approach used is the administrative area approach by taking into account topographical boundaries, to estimate the potential for surface runoff and landslides. Data analysis. Data analysis used 1) Spatial Analysis. In data analysis, the spatial analysis used was the Weighted Scoring Method. In this method, the total score for each commodity is obtained by multiplying the value/score for each commodity in question by a certain weight value for each criterion (with the weight of each criterion being different), then adding up the multiplication value of the score and the weight. 2) Survey method, survey method is conducted to determine the physical condition in the field. The type of sampling technique chosen is purposive sampling. This is because the sampling was done intentionally and reasoned. The selection of sample points is done by looking at the appearance of the image, the shape of the land, and the characteristics of flood and landslide susceptibility.

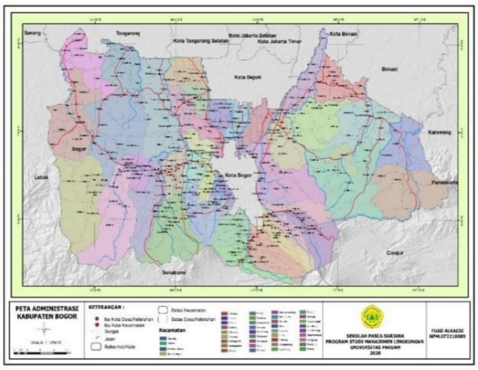

Figure 1. Research Location Map.

In carrying out the analysis of flood and landslide susceptibility/vulnerability, the methods used are 1) Cook's method is used for runoff flood analysis, 2) the method of estimating landslide-prone areas with the method of the Directorate of Volcanology and Geological Hazard Mitigation/DVMBG **[13]**.

1. Analysis of Flood Runoff (run off).

In the analysis of flood runoff the analysis used was Cook's method. Cook's developed an empirical method for the relationship between physical environmental characteristics of the watershed and hydrological processes, including: land slope/topography parameters, land cover (vegetation), soil infiltration, and surface embankment. Of the four variables, the area is calculated and given a value (score) for each character based on Cook's table. Area and Score are then multiplied to produce a weighted score. The total weighted value divided by the total area produces the variable coefficient value.

After the results of the total scoring of the parameters determining the flood runoff with the Cook's model are obtained, it is then classified into five classifications of flood runoff, namely low, normal, high and extreme. After the runoff flood classification is obtained, the next step is to calculate the peak discharge. From the results of the calculation of peak discharge using the rational method by dividing per catchment according to the surface embankment. The method used for the calculation of peak discharge (Qp) using the rational method,

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2. Landslide Analysis

Determination of the level of vulnerability to landslides in the study area is based on the estimation model of landslide-prone areas by the Directorate of Volcanology and Geological Hazard Mitigation/DVMBG **[13]**. In the analysis, the data analysis technique for determining the level of landslide hazard is carried out by a scoring technique, namely by provide an assessment and weighting of the determinants of landslides.

The results of the total scoring of the parameters determining landslides are classified according to the level of landslide hazard, namely Safe (A), Low (R), Medium (S), and High (T).

Accuracy Test.

The suitability of the results on the model to the existing conditions was validated by calculating the results in the field (ground check) and the location of the disaster incident with an accuracy of kappa values. The equation for the kappa accuracy value and the level of accuracy used is as follows (Foody, **[14]**).

III. RESULTS AND DISCUSSION

A. Flood Vulnerability Runoff

Based on the results of the analysis using the Cook's model in the research area, it shows that the broad coverage of runoff flood vulnerability levels in Bogor district obtained three criteria, namely the Normal, High, and Extreme categories. The extreme runoff flood category shows that in the Bogor district area, more than 76% of the rainwater that falls will become runoff. The factors that affect the amount of water that becomes runoff are highly dependent on the amount of rainwater per unit time (intensity), the state of land cover, topography (especially the slope), and the type of soil. Istiadi & Priatna **[7]** found that determinant factors of hydro-climatological disasters can be divided into two factors, i.e. land characteristics factor and ecological maintenance of rainfall factor. The results of the research on the level of runoff flood susceptibility can be seen in table 1.

Table 1. Results of the analysis of the level of flood susceptibility to runoff.

No	Vulnerability Flood Runoff	Score	Area (Ha)	Percentage (%)
1	Normal	26 - 50	51.089,74	17
2	Height	51 - 75	198.381,05	66
3	Extreme	> 76	49.247,61	16
Total			**298.718,40**	**100**

Source: Spatial Analysis

Based on the results of research from the entire area in Bogor district, 51,089.74 hectares or 17% have a normal level of flood vulnerability to runoff. Meanwhile, areas that have a high runoff category for flood disasters reach 198,381.05 hectares or 66%. The remaining 49,247.61 Ha or 16% have extreme levels of runoff flood vulnerability. From the results of the study in the form of a flood runoff distribution map, it shows that the distribution of runoff flood susceptibility maps is almost evenly distributed in the Bogor district. For the extreme class, it shows that the East and West areas of Bogor Regency have greater potential for flooding than other areas. From the results of the study to the site level in Bogor district, namely the sub-district level as shown in table 2.

The results of the analysis show that almost all areas in the Bogor area have the potential for high to extreme runoff flooding, the area in Bogor district which is quite large in extreme runoff values is covering the Nanggung sub-district area of 8,994.12 hectares or 18.26%, Sukayaja sub-district, covering an area of 5,894.82 Ha or 11.97%, Sukamakmur sub-district covering an area of 3,508.95 Ha or 7.13%, Tanjungsari sub-district covering an area of 4,412.86 Ha or 8.96%, Cigudeg sub-district covering an area of 6600.96 Ha or 13.40%, Megamendung sub-district covering an area of 1,865.96 ha or 3.79%, and Babakanmadang sub-district covering an area of 3,103.82 ha or 6.30%. The potential for high runoff flood prone areas includes Cigudeg sub-district covering an area of 10,127.93 ha or 5.11%, Pamijahan sub-district covering an area of 9,745.41 ha or 4.91%, Sukajaya sub-district covering an area of 10,143.47 ha or 5.11%, Sukamakmur sub-district covering an area of 10.143.47 ha or 5.11%. 13,295.58 Ha or 6.70%. For areas that are not vulnerable, it means that the potential for flooding is low or normal, namely Jasinga District covering an area of 4,003.08 Ha or 9.88%, Rumpin District covering an area of 3,866.66 Ha or 7.57%, Tejo Panjang District covering an area of 2,513.70 Ha or 4, 92%. Based on the results of the analysis that has been carried out for each parameter, it shows that land cover and land slope factors have more influence on the level of runoff flood vulnerability in Bogor district. Based on the analysis of land cover from 2009 to 2019 (figure 2), it shows that there is a trend of land subsidence from densely vegetated land to low vegetated land, this shows that rainwater that falls directly to the ground shows that it will go directly to the ground and flow directly into rivers without retained by vegetation.

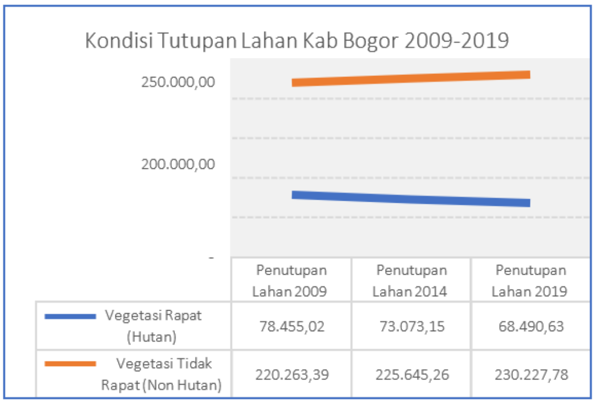

Figure 2. Conditions of Land Cover Change in 2009 to 2019.

Based on the results of the land cover analysis, it can be seen that the condition of land that has changed functions is still quite massive, amounting to 9,964.39 ha for 10 years

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from permanent vegetation (forest) to non-tense vegetation (non-forest). From the results of the analysis, it shows that the largest change in land cover in the research area on average turns into residential areas, agriculture and rice fields. Although the change in land cover in the Bogor district is only 3.34% so that the research area is still classified as a pervious area, it is necessary to pay attention to the possibility of an increase in runoff height from year to year. This shows that the high value of surface runoff is directly proportional to changes in land use which converts water catchment areas into non-water catchment areas. Besides that, the condition of land cover factors, topographical factors are also more influential as well. Based on the results of the analysis of the Bogor district area of 47% hilly and 20% steep, it shows that the Bogor district has the potential for high runoff flooding.

a. Peak Discharge.

In calculating the peak discharge there are several parameters that need to be known before calculating the discharge, namely first calculating the runoff coefficient value, second calculating the distribution of the maximum rain distribution in the area. After calculating the rain distribution, and the flood runoff classification value (runoff coefficient) is obtained, then calculate the peak discharge. The results of the calculation of the runoff coefficient value of the research location can be seen in table 2.

Table 2. Value of Runoff Coefficient (%) Weighted Persegment di

NO	SEGMENTASI	COOEFISIEN LIMPASAN (%) KELAS LERENG	PENUTUPAN LAHAN	TIMBUAN PERMUKAAN	INFILTRASI TANAH	TOTAL
1	SEGMENTASI I	35,10	7,25	5,47	15,73	63,55
2	SEGMENTASI II	26,55	12,48	1,88	10,50	51,40
3	SEGMENTASI III	29,66	11,14	2,69	14,39	57,88
4	SEGMENTASI IV	18,79	13,81	1,80	17,60	52,00

Based on the results of the analysis, it was found that the research location was divided into four segments based on the surface embankment flow in the area. From the results of the analysis as shown in table 9, it can be we know that the potential for surface water in the study area per segmentation shows a fairly high value. All segmented areas have a weighted runoff coefficient value of almost more than 50%. The highest surface water potential is in segment I with a Co value of 63.55% and the lowest is in segmentation II with a total Co of 51.40%.

The second analysis that must be known in calculating peak discharge is the distribution of maximum rainfall in the research area, based on the results of data analysis, the data for determining the distribution of rainfall taken by each station is the annual average data for 3 years from 2018-2020, rainfall the maximum is only calculated for 3 years, namely to see the latest potential for flooding at this time. From the results of the analysis of data processing, it shows that during 2018 to February 2020, it shows that the maximum rain value that has ever occurred is 242.02 mm/day. The results of the intensity and distribution of rainfall in the research area can be seen in Figure 3.

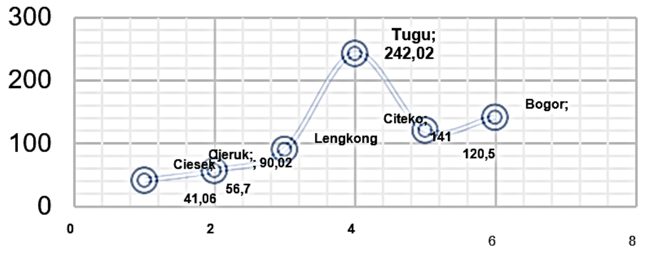

Figure 3. Maximum Daily Rain

Based on the results of the analysis carried out on the peak discharge, the discharge value is obtained as table 3.

Table 3. Calculation of discharge in each segmentation in the district Bogor.

No	Segmentasi	Debit (m3/detik)	Area (Ha)
1	SEGMENT I	1.050,18	81.714,09
2	SEGMENT II	584,28	56.207,24
3	SEGMENT III	626,01	53.481,58
4	SEGMENT IV	1.128,40	107.315,49
Total			**298.718,40**

Source: Spatial Analysis Results

Figure 4. Distribution Map of Peak Discharge Areas in Bogor Regency.

The results of the analysis show that the largest maximum discharge is in segmentation I, which is 1,050.18 m3/second, while the lowest peak discharge is 584.28 m3/second, if we look at the peak discharge value, the value is directly proportional to the runoff coefficient value. If the coefficient is high, then the peak discharge value is also high, if it is low, the peak discharge value is also low. The distribution of the peak discharge area in each segmentation can be seen in Figure 5.

B. Landslide Vulnerability.

In analyzing landslide-prone areas, the determination of landslide-prone areas is based on the total number of cumulative scores obtained from all parameters, the results are converted at several levels according to the number of these scores. Based on the results of the calculation of the

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landslide hazard class area based on the landslide hazard assessment criteria method (Directorate of Volcanology and Geological Hazard Mitigation), it shows that Bogor district is an area that has 3 classes of landslide hazard that vary from very low to high. The results of the landslide susceptibility analysis can be seen in table 11. The results of the analysis at the research location show that the average research location is in the moderate or landslide hazard class prone to 32,663.16 Ha or 64.26%, in the second position, namely high or very vulnerable landslide vulnerability of 74.100.93 Ha or 24.81% and low vulnerability of 32.663.16 Ha or 10.93%, from the results of the analysis. , almost all areas of Bogor district are not in a safe or landslide-free class category position, but all areas of Bogor district have the potential for landslides even though on a low scale.

Table 4. Results of Soil Vulnerability Analysis Landslide in Bogor Regency

No	Landslide Hazard	Score	Area (Ha)	rcentage (%)
1	Vulnerability Low	≥ 1,5 – ≤ 2,6	32.663,16	10,93
2	Vulnerability Medium	>2,6 – ≤ 3,6	191.954,32	64,26
3	High Vulnerability	≥ 3,7	74.100,93	24,81
	Total		**298.718,40**	**100,00**

The results of the analysis of the distribution of areas according to the level of landslide susceptibility in the Bogor district show that landslide-prone areas are spread in areas with high slopes. The distribution of landslide-prone areas in the Bogor district is visually presented in Figure 4.

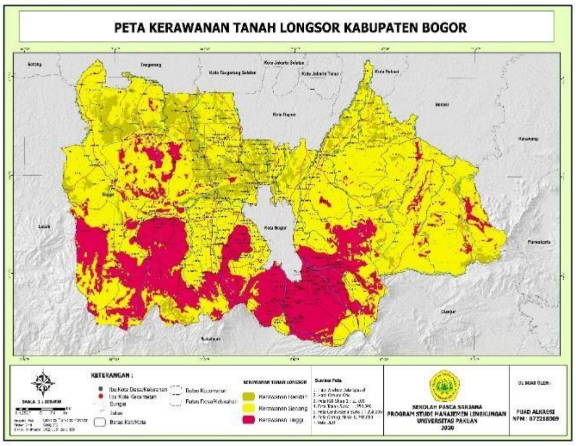

Figure 4. Flood Vulnerability Map of Runoff in Bogor Regency.

Based on the results of the analysis as shown in table 12, it can be seen that several sub-districts that fall into the category of moderate or vulnerable vulnerability are Cigudeg sub-district with an area of 13,224.35 Ha, Jasinga District with an area of 11,599.87 Ha, Jonggol District covers an area of 12,043.99 Ha, Tanjungsari District covers an area of 13,131.89 Ha, and Sukamakmur District covers an area of 14,160.18 Ha. For sub-districts with a high vulnerability category, namely Caringin sub-district covering an area of 6,620.57 Ha, Leuwiliang sub-district covering an area of 5,967.68 Ha, Pamijahan sub-district 4,719.28 Ha, Sukajaya sub-district 6,891.79 Ha, and the most widespread vulnerability is Nanggung sub-district covering an area of 10,097.47 Ha.

Based on the results of the analysis of the sub-districts in the research area found in the survey area, there are several dominant factors that may cause landslides, namely: slope, soil depth and changes land cover, and rainfall as trigger factors. Steep slopes tend to be prone to landslides, especially with unstable slope conditions. The topographical conditions in the study area vary widely, and although it is dominated by low slopes, the upstream area of the study area is dominated by hills with a soil thickness of 2-5 m. In addition to the slope factor and soil depth, land use factors are very influential, based on the results of the land cover analysis in the slope area, it shows that in the research area for slope class 15-25% is dominated by dry land agriculture and shrubs, as well as with a slope of 45-65% dominated by dry land agriculture, for a slope of > 65% if we look at the data, it shows that land cover in the steep slope area is dominated by a pattern of agricultural land cover and shrubs, this shows that the potential for landslides in the research area is quite high. Changes in land cover to agriculture and settlements (population density) on steep slopes will disrupt slope stability due to various human activities on it which increase the potential for landslides (figure 5).

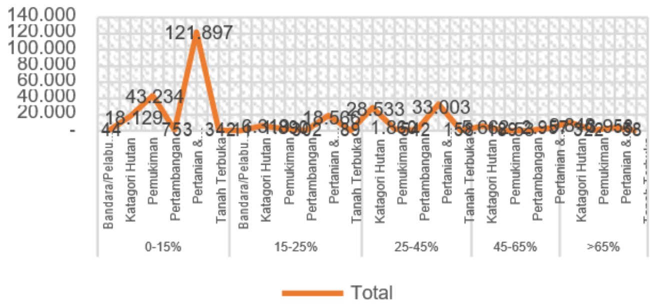

Figure 5. Land Cover Patterns across different slope classes

In addition to the dominant factor of slope, soil depth and land cover change, there is also a very important trigger factor to consider, namely rainfall. Based on the results of the analysis of the Bogor district on average have a high intensity of >300 mm per 3 days covering an area of 127,134.08 Ha or 42.56%, while the intensity is rather high with a rainfall intensity of 200-300 mm 3 days of 170.404.29 Ha or 57%, and only 0.40% or 1,180.04 Ha with moderate intensity of 100-199 mm. From the results of the data analysis, it shows that rainfall is a trigger factor that greatly influences the occurrence of landslides. According to Pamin et al (2012) rainfall >300 mm for 3 consecutive days in areas with steep and unstable slopes can trigger landslides.

C. Accuracy Test

a. Test the Accuracy of the Flood Overflow Vulnerability Map

Accuracy is carried out directly by taking several samples and using data on flooded areas that have occurred in the study area (figure 6).

From 34 sample points of validation data using the runoff flood-prone map model, 20 data or 58.8% were obtained according to the model analysis criteria and 14 data or 41.2% location data did not match the existing model. To test the accuracy of these data, from the validation data, the accuracy test is carried out using the kappa value model

Figure 6. Map of Distribution of Locations of Accuracy Points for Flood Overflow Hazard Map.

Based on the results of statistical analysis using kappa value modeling, it shows that the criterion value of the kappa value coefficient (K) shows that it is at 0.940. Based on Foody's 2002 theory **[14]**, the conclusions that can be drawn from the results of the accuracy of the runoff flood vulnerability map using Cook's method are in this study. able to produce a very good level of truth, namely with a kappa value of 0.940 which is in the Kappa value class = 0.81 < K< 1.00. Thus, the level of validity of the validation process is quite accurate and the results of this spatial analysis can be used in mapping the level of flood vulnerability in Bogor district.

b. Landslide Hazard Map Accuracy Test.

For the Accuracy Test on the Landslide Prone Map, it is almost the same as the Accuracy on the Flood Runoff Map, which is carried out directly by taking several samples and using data on landslides that have occurred in the study area (figure 9). From the 31 sample points of validation data using the landslide hazard map model, 20 data or 64.5% were obtained according to the model analysis criteria and 11 data or 35.5% location data did not match the existing model. To test the accuracy of these data, from the validation data, the accuracy test is carried out using the kappa value model.

Based on the results of statistical analysis using kappa value modeling, it shows that the criterion value of the kappa value coefficient (K) shows that it is at 0.845, so the conclusions that can be drawn from the results of the accuracy of the landslide hazard map in this study are able to produce a very good level of truth, namely by the kappa value is 0.845 which is in the kappa value class = 0.81 < K < 1.00. Thus, the level of validity of the validation process is quite accurate and the results of this spatial analysis can be used in mapping the level of landslide hazard in Bogor Regency.

IV. CONCLUSION

Based on the results of the study, it can be concluded as follows The potential for flood-prone areas in Bogor district is 247,628.66 ha, consisting of 49,247.61 Ha or 16% has a level of extreme runoff flood vulnerability, 198,381.05 Ha or 66% in the high runoff flood category, the largest vulnerable areas include Sukamakmur District covering an area of 3,508.95 Ha or 7.13%, Tanjungsari District area of 4,412.86 Ha or 8.96%, Kec Sukajaya 5,894.82 Ha or 11.97%, Cigudeg District covering an area of 6600.96 Ha or 13.4% and Nanggung District covering an area of 8,994.12 or 18.26%, with the dominant factors causing runoff flooding, namely: land slope and changes in land cover. Potential landslide-prone areas in Bogor district covering an area of 266,055.24 ha, consisting of 74,100.93 ha or 24.81% having a high landslide susceptibility level, 191,954.32 ha or 64.26% in the medium vulnerability category, The largest vulnerable areas include Caringin District covering an area of 6,620.57 Ha or 8.93%, Leuwiliang District covering an area of 5,967.68 Ha or 8.05%, Pamijahan District 4,719.28 Ha or 6.37%, Sukajaya District 6,891.79 Ha or 9 ,30, and Kec Nanggung covering an area of 10,097.47 Ha or 13.63%, with the dominant factors causing landslides, namely: land slope, land cover changes, soil depth and rainfall as trigger factors. Based on the results of the study show that the greater the intensity of the rain that occurs, the potential for vulnerabilities will be higher.

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