ASSESSMENT OF FLASH FLOOD HAZARD POTENTIAL IN A SMALL MOUNTAINOUS CIKUNDUL WATERSHED IN CIANJUR, WEST JAVA, INDONESIA

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Abstract. Flash flood is a geomorphic hazard that can cause huge losses in a short period of time. Cianjur regency, especially Cikundul Watershed is a flash flood frequent area. Therefore, flash flood potential mapping is needed to reduce the threat that can be caused by flash flood. In the flash flood potential mapping, Flash Flood Potential Index (FFPI) method is still rarely applied in Indonesia. This study aims to see the comparison of flash flood potential areas based on models developed in the FFPI method which is Smith, Brewster, Krudzlo, and Ceru models. The four models used slope, land use, soil texture, and vegetation cover as variables. Spatial analysis and statistical test was implemented to validate the flash flood potential areas with flash flood affected locations. The research results show that the Cikundul watershed is dominated by areas with medium potential based on the Brewster, Krudzlo and Ceru models, but low potential based on the Smith model. The results also show that 65% of the 68 sub-watersheds have different potentials and 35% have the same flash flood potential. The high potential areas in the four models are spread across the Upper Cikundul watershed. The results of the Crosstab Fit Test show that the Smith model is the model that is closest to the actual event.

Keywords: *flash flood potential index, geospatial technology, Cikundul, crosstab fit test*

1 INTRODUCTION

Flash flood is a geomorphic hazard that occurs due to complex interaction between hydrological and atmosperic system in a short time (Haque et al., 2021; Deijns et al., 2022; Chowdhury et al., 2024). Globally, its one of the world's most deadly natural hazards, accounting for 85% of flooding and resulting in over 5000 casualties annually (WMO, 2016; Alam et al., 2021). In Indonesia, flash floods are a significant concern due to its complex physiography and monsoonal cycle which makes it as one of the most frequent and damaging disasters nationally (Gunawan et al., 2016; Novianti et al., 2023).

Cianjur Regency is among the epicenters of flash flood disasters in West Java and Indonesia. Characterized by its diverse physiography, Van Bemmelen (1949) classifies Cianjur into 3 physiography zone which consist of Bogor Zone in the North, Bandung Zone (West Java Central Depresion Zone) in the Middle and West Java Southern Mountain Zone in the South. This feature is associated with the existence of small-scale watersheds formed from valleys of hills or mountains with steep slopes, and the configuration that promote the convergence of water flow thus potentially increasing the possibility of flash flood disasters (Sapan et al., 2023; Ma et al., 2024). One of them is Cikundul Watershed which spans from Mount Gede Pangrango to the Cirata Reservoir. There are 3 out of 4 sub-districts in the Cikundul watershed that have a high potential for flash flooding (PVMBG, 2017). In a recent flash floods events

(March 2023), around more than 100 houses were flooded in Pacet District and caused the village bridge to break, affecting hundreds of people in Sukaresmi District (Sulthoni, 2023; Selamet, 2023). Therefore, it is necessary to develop a deeper insight into the phenomenon of flash floods in the Cikundul Watershed.

Flash flood is almost unavoidable. However, proper investigation using integrated methods can prevent more damage in the future. The significant advancement in remote sensing and GIS technology allows for analyzing large spatial data and integrating different mathematical models that have been widely used in flash floods susceptibility mapping (Yin et al., 2023; Chowdhury, 2024). To mitigate the future damage, a flash flood susceptibility map is practically plays a vital role in taking appropriate action in disaster management operations. One approach to achieve this is by applying the Flash Flood Potential Index (FPPI). The FFPI method is a method that uses physiographic condition variables that influence the hydrological response, namely slope, land use, soil texture and vegetation cover (Smith, 2003).

Therefore, this study propose the use of Flash Flood Potential Index (FPPI) approaches to detect areas prone to flash flood in Cikundul Watershed which is still rarely applied in Indonesia. Different from previous research conducted in Indonesia (Widiyatmoko et al., 2015; Amrullah et al., 2023), this research produces four potential flash flood areas based on four FFPI models that have been developed by CBRFC and WFO of the United States, which consist of Smith, Brewster, Krudzlo, and Ceru models. Spatial analysis and Fit Test Crosstab statistical tests are used to validate potential flash flood areas with affected locations. This research is expected to provide a deeper insight into flash floods in Cikundul watershed, as well as propose the best method for flash flood susceptibility mapping for similar physiography areas in Indonesia.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

The Cikundul watershed is located in the northern part of Cianjur Regency. Geographically, the Cikundul watershed is located at 6°46'15"S - 6°44'18"S and 106°57'53"E - 107°16'26"E. The Cikundul River is the main river which has a length of 28,74 km. The upper reaches of the Cikundul River are located on Mount Pangrango and empty into the Cirata Reservoir. In this research, the Cikundul Watershed is divided into 68 sub-watersheds.

Based on its physical characteristics, the upper part of the Cikundul watershed is an area with characteristics of medium to high basin slope, dusty clay soil texture, medium vegetation cover, and land use in the form of forest; productive agricultural land; and settlement. The middle to lower parts of the Cikundul watershed are areas characterized by low basin slope, high vegetation cover, land use in the form of plantations, and clay soil texture. The upper part of the Cikundul watershed tends to consist of sub-sub watersheds with varying FFPI characteristics compared to the middle and lower parts. The physical characteristic of Cikundul Watershed is shown in Figure 2-1.

2.2 Data

This study employs various data to examine the flash flood potential of the Cikundul Watershed. Most of the data on this study relies on secondary data sources, including DEM SRTM and Landsat 8 OLI which have limited resolution in 30 x 30 m. Specifically, those satellite have a sufficient spatial resolution that is detailed enough to identify the basin slope, land use and vegetation cover in study area. Similar research using Landsat 8 OLI in determining land use and vegetation cover variables also shows good performance in the Carpathian Mountains Region of Romania (Costache et al, 2020). Overall, the data in this study are shown on Table 2-1 as follows.

Table 2-1: Data Sources

Data	Data Source	Period
Basin Slope	DEM SRTM (USGS Earth Explorer)	2014
Land Use	Geospatial Information Agency (BIG)	2016
	Ministry of Forestry and Environment (KLHK)	2016
	Landsat 8 OLI (USGS Earth Explorer)	2021
Vegetation Cover	Landsat 8 OLI (USGS Earth Explorer)	2021
Soil Texture	Field Survei and Laboratory Test	2018
Flash Flood Events	Cianjur Disaster Management Agency (BPBD Cianjur) and Field Survey	2010-2022

The Basin Slope were generated based on Zecharias & Brutsaert (1985) formula by using 30 m spatial resolution Digital Elevation Model (DEM) from SRTM (https://earthexplorer.usgs.gov). The data was then carried out in the reclassification stage of the basin slope values into the FFPI index according to Table 2-2.

The Land Use Data was obtained from processing the digital RBI (*Rupa Bumi Indonesia*) map of Java Island at a scale of 1:25,000 in 2016 which has been validated with the Ministry of Forestry's forest area map in 2016, Landsat 8 OLI imagery in 2021, and field surveys.

Vegetation cover was derived from processing Landsat 8 images in 2021 using NDVI (Normalized Difference Vegetation Index) based on Rouse et al (1974) equation and converting NDVI values into percentage vegetation cover (Widiyatmoko et al., 2015).

Soil texture was obtained from 12 soil samples from field surveys taken using a

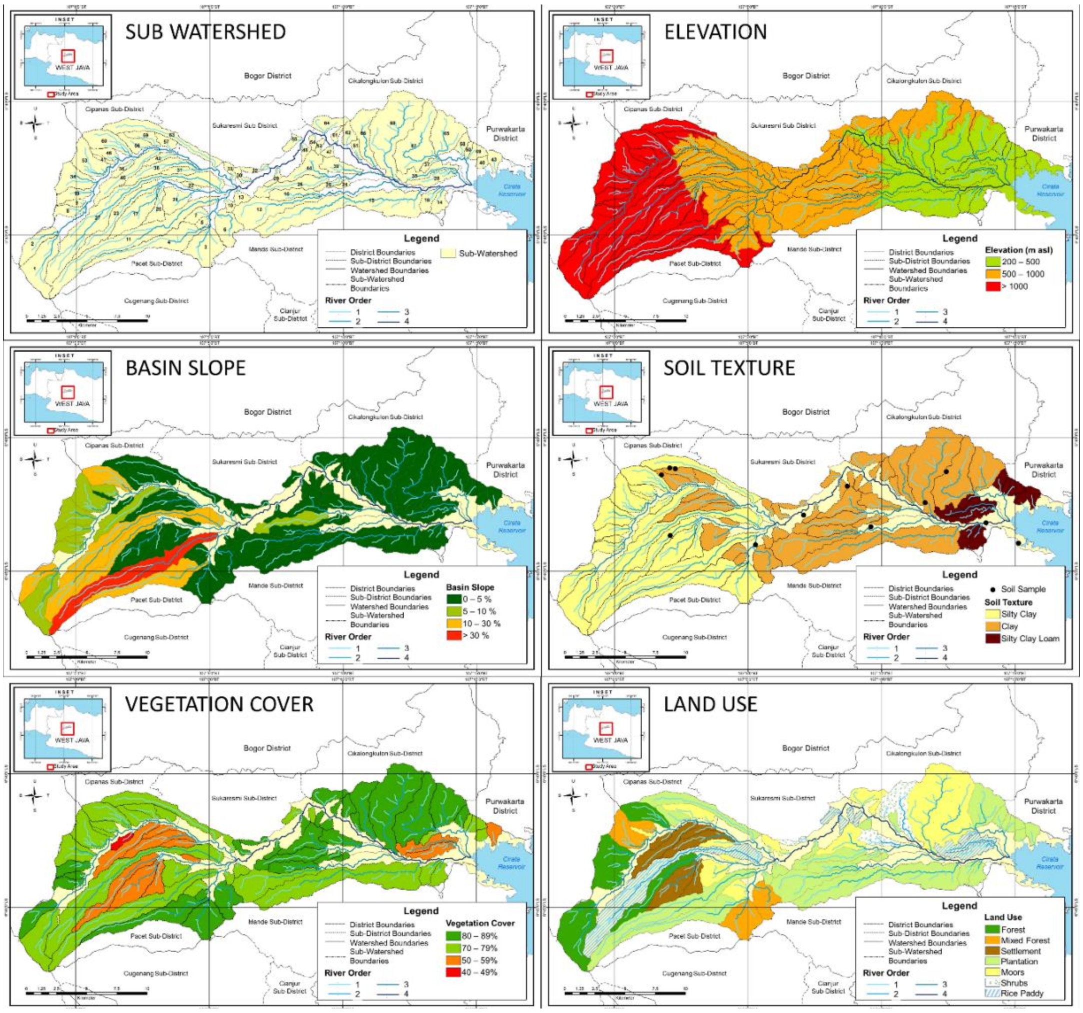

Figure 2-1: Maps of the Physical Characteristic of Cikundul Watershed, Cianjur, West Java

shovel with a soil depth of between 10-50 cm. Therefore, the location of soil sampling in field surveys is also based on the presence of outcrops in different elevation (200-500 m asl, 500 – 1000 m asl, > 1000 m asl). Soil outcrops can show the depth and horizon of the soil without having to drill the soil first. Then the soil sample are processed using grain size distribution in a soil laboratory of Ministry of Agriculture in Bogor to obtain percentage of grains of sand, silt and clay from each soil sample to determine it soil texture type.

All this data is then converted into raster format and reclassified into the FFPI index based on Table 2-2 and processed using formula from SCDF (Spatial Cumulative Distribution Function) as suggested by Suganda et al (2006) to get the cumulative index of each class in one sub-watershed.

Table 2-2: FFPI Variable Weighting Classification

FFPI Index	Basin Slope	Land Use	Vegetation Cover	Soil Texture
1	< 2%	Water Bodies	90% - 100%	Water/Alluvial
2	2% -5%	Swamp	80% - 89%	Sandy
3	5% - 7%	Forest	70% - 79%	Sandy Loam
4	7% - 10%	Mixed Forest	60% - 69%	Silty Loam / Loam Sandy
5	10% - 14%	Plantation, Moors, Rice Paddy Fields	50% - 59%	Silt / Organic Matter
6	14%- 18%	Shrubs	40% - 49%	Loam
7	18% - 22%	Open Area	30% - 39%	Sandy Clay Loam / Sandy Silt Loam
8	22% - 26%	Low Density Settlement	20% - 29%	Clay Loam / Sandy Clay
9	26% - 30%	Medium Density Settlement	10% - 19%	Clay
10	≥ 30%	High Density Settlement	0 – 9%	Bedrock

Meanwhile, the flash flood events data that obtained from Cianjur Disaster Management Agency (BPBD Cianjur) is data in the form of a table of disaster events that does not include the geographic coordinates. Therefore,

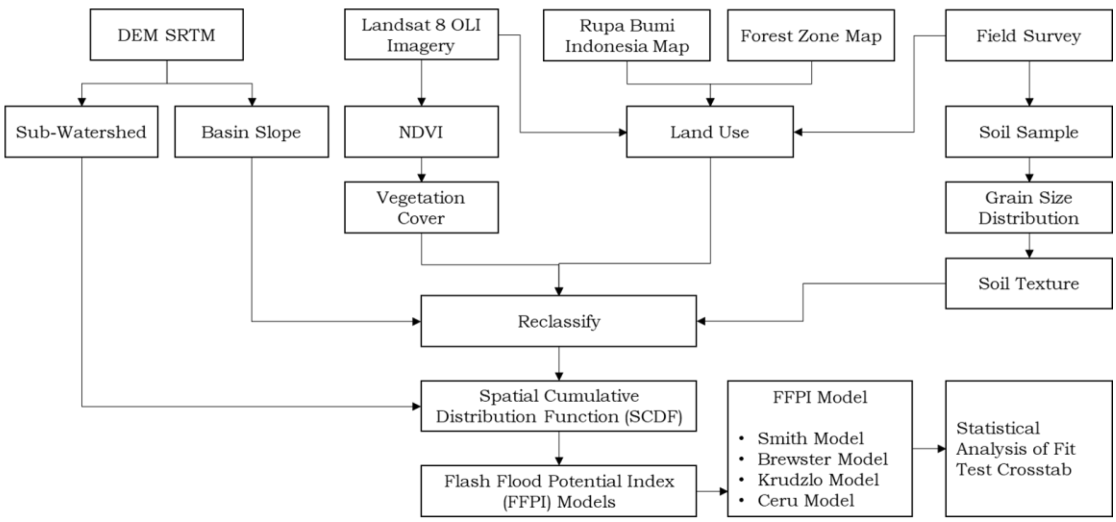

Figure 2-2: Research Workflow

further field survey activities were carried out to obtain data on coordinates/ locations affected by flash floods accompanied by the local communities to the past flash flood site along with coordinate tagging and found 12 past flash flood site. This data can be utilized in FFPI model evaluation to determine the fittest model in Cikundul Watershed.

2.3 Methods

The raster maps of basin slope, land use, vegetation cover and soil texture that have been generated are then integrated using raster calculator in ArcMap 10.1 based on the equation in each FFPI model as shown on Table 2-3 and Figure 2-2. The FFPI model is considered a reliable method for estimating flash flood potential hazard in small mountainious catchments due to its comprehensive approach which integrates various physical and environmental factors with feasible to integrating it into GIS technology (Smith, 2003; Zulhisham & Sadek, 2023).

Table 2-3: FFPI Model Equation

No	Model	Weighted Formula	Description
1.	Smith (2003)	FFPI = $\frac{2M+L+S+V}{N}$	M = Basin slope, L = Land Use, S = Soil Texture, V = Vegetation Cover, N = Total Weight (N>4)
2.	Brewster (2009)	FFPI = $\frac{1.5\,M+L+S+0.5\,V}{4}$	M = Basin slope, L = Land Use, S = Soil Texture, V = Vegetation Cover, N = Total Weight (N=4)
3.	Krudzlo (2010)	FFPI = $\frac{M+L+S+V}{4}$	M = Basin slope, L = Land Use, S = Soil Texture, V = Vegetation Cover, N = Total Weight (N=4)
4.	Ceru (2012)	FFPI = $\frac{2M+L+2S+V}{N}$	M = Basin slope, L = Land Use, S = Soil Texture, V = Vegetation Cover, N = Total Weight (N>4)

In this research, the weighting model of Smith (2003) and Ceru (2012) was modified by weighting where the variables of slope and land use were given a weight of 2 referring to research conducted by Widiyatmoko et al. (2015). After the maps from each four models generated, the FFPI index was reclassified into high, medium and low potential level classes based on Table 2-4.

Table 2-4. FFPI Classification

FFPI	Flash Flood Potential Level
2 – 3,5	Low
3,5 - 5	Medium
> 5	High

(Source : Modifications refer to Minea, 2013)

In order to obtain the fittest model to identify the flash flood susceptibility area based on watershed, this study compares the spatial distribution of FFPI model with overlay analysis and statistical analysis with fit test crosstab with PSS (Pierce Skill Score) and ePSS (error rate) values. The fit test crosstab is chosen to analyze the FFPI because it's a robust statistical method for evaluationg the association in categorical variable, particularly when the variable are nominal or ordinal and it helps determine whether the observed frequencies differ significantly from the expected frequencies based on the independence assumption (Moore, 2013). In this study, the FFPI is likely categorized into different levels (e.g., low, moderate, high), the fit test crosstab is suitable for such nominal and ordinal variables.

3 RESULTS AND DISCUSSION

The FFPI value represent the likelihood of flash flood occurrence. A larger relative value suggests a stronger impact on the occurrence of flash flood disasters. (Li et al., 2024). Based on the 4 different model of FFPI calculation as shown in Table 2-3, the result shows a diversed FFPI classification distribution in Cikundul Watershed as shown in Figure 3-1.

The Smith model shows the Cikundul watershed is dominated by low potential areas. Low potential areas tend to dominate the lower part of the Cikundul watershed, which is an area with a basin slope of <5% with a low F FPI index. Medium and high potential areas tend to dominate the Upstream section, which is an area with a basin slope of >5%. This is because in the Smith weighting model, the slope variable is considered to play a more important role than other variables (Smith, 2003), so that areas with a low basin slope will have low potential, as well as areas with a maximum basin slope will have high potential. Locations affected by flash floods tend to be spread across high potential areas, which is in the upper reaches.

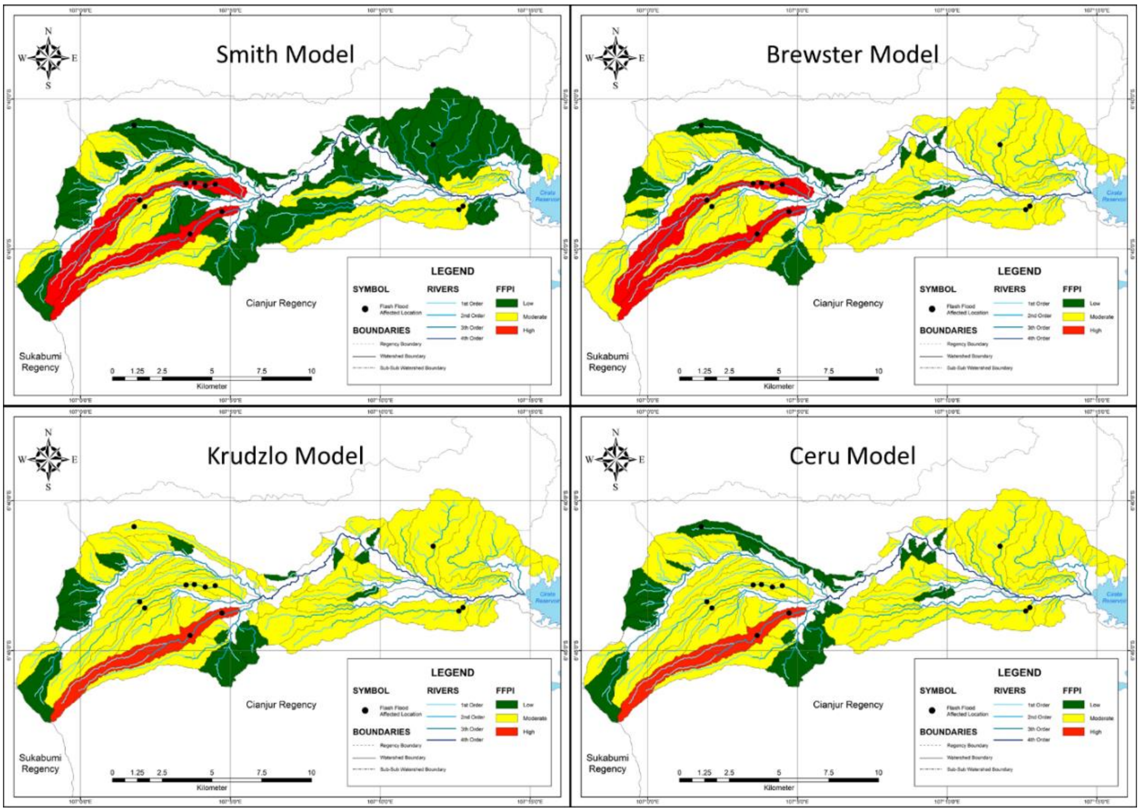

Figure 3-1: Flash Flood Potential Index maps in the Cikundul watershed based on the Smith, Brewster, Krudzlo and Ceru models

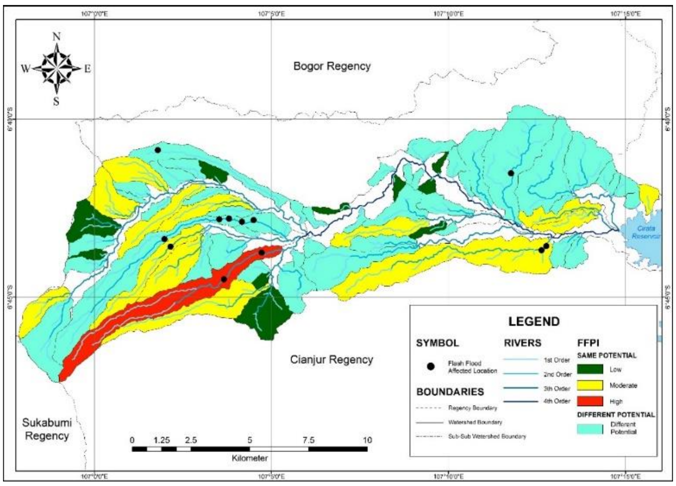

Figure 3-2: A classification map of potential flash floods in the Cikundul watershed derived from the overlay results of the Smith, Brewster, Krudzlo, and Ceru FPPI maps

In the Brewster model, the Cikundul watershed is dominated by medium potential areas. Low potential areas tend to dominate the lower part of the Cikundul watershed, which is an area with a basin slope of <5%, vegetation cover of >80% and plantation land use with a low FFPI index. However, areas of low potential can still be found in areas with vegetation cover <60% which have a high FFPI index, and conversely, areas of medium and high potential are located in areas with high vegetation cover which have a low FFPI index. This discrepancy occurs because in the Brewster weighting model (Brewster, 2009), vegetation cover is given the least weight because it is considered not to play a significant role in determining potential flash flood areas. Locations affected by flash floods tend to be spread across high potential areas, namely in the upper reaches.

Meanwhile in the Krudzlo model, the Cikundul watershed is still dominated by medium potential areas. Areas of low and medium potential are spread throughout almost the entire Cikundul watershed, namely from upstream to downstream. In the Krudzlo model (Krodzlo, 2010), all variables are assessed as having the same role so that it is found that areas with high basin slopes have moderate potential and conversely areas with low basin slopes have medium potential. This is due to there are other variables that also have the same influence, such vegetation cover, land use and soil texture. Locations affected by flash floods tend to be spread across medium potential areas, which is in the upper reaches.

Lastly in the Ceru model, the Cikundul watershed also dominated by medium potential areas. Areas of low and medium potential are spread throughout almost the entire Cikundul watershed, namely from the upstream to the downstream of the Cikundul watershed. In the Ceru model (Ceru, 2012), basin slope and land use are considered to play a greater role in determining the potential for flash floods. Areas with high basin slopes should have high potential but have low potential due to land use which is generally forest or plantations, and vice versa. Based on this, it can be seen that in the Ceru weighting model, the two factors, namely slope slope and land use, have an equally large role in determining the potential flash flood area compared to other variables, namely vegetation cover and soil texture. Locations affected by flash floods tend to be spread across medium potential areas, namely in the upper reaches.

Overall, The Cikundul watershed is dominated by medium potential areas according to the Brewster, Krudzlo, and Ceru models, but is dominated by low potential areas in the Smith model. The potential areas that dominate in the four models tend to be in the middle to lower reaches of the Cikundul watershed. This is due to the characteristics of the Middle to Downstream parts of the watershed which tend not to vary compared to the Upstream parts.

The medium and high potential areas tend to be found in areas with all four variables having a high FFPI index. Low potential areas tend to be found in areas where the four variables also have a low FFPI index. Based on this condition, it shows that there is a match between the level of potential and the characteristics of each region. In different potential areas, many differences are produced by the Smith model where the Smith model shows low potential, not medium potential as produced by other models.

Based on the overlay analysis as shown in Figure 3-2, locations affected by flash floods were found in the same and different potential areas in the four models. In the same potential area, no affected locations were found in the low potential area. This is because low potential areas tend to have characteristics of slope, land use, and vegetation cover that are in accordance with a low FFPI index. In different potential areas, affected locations were found in the low potential areas produced by the Smith model. The low potential areas produced by the Smith model are in the Middle to Lower parts which are areas with high potential characteristics in almost all characteristics but low in the basin slope. This shows that the Smith model has shortcomings, namely in assessing potential areas in watersheds with basin slope characteristics that do not vary.

The findings of this research indicate that high potential areas are primarily in the upstream of Cikundul watershed that have steeper basin slope which generate more runoff due to increased kinetic energy of water flowing downhill. The accumulation of this runoff within complex slope configuration from torrential rainfall increases the potential for flash flood. Similar trends in the upstream also occurs in the upstream of Carpathians Mountain (Popa et al., 2020; Kocsis et al., 2022).

Table 3-1: Fit Test Crosstab Analysis

Model	Hit Rate	False Alarm	Miss	Cnull	PSS	ePSS
Smith	4	11	2	51	**0,4892**	**0,2054**
Brewster	5	45	1	17	0,1532	0,2130
Krudzlo	6	47	0	15	0,2419	0,2118
Ceru	5	42	1	20	0,1559	0,2129

The Fit Test Crosstab test as shown in Table 3-1, resulting that the Krudzlo model has a higher Hit Rate value than the other three models. The Hit Rate value indicates the suitability between predictions from the model and actual events. However, the Krudzlo model also has the highest False Alarm (47). False Alarm is a value that indicates a link between errors in predictions where the model predictions do not exist in actual events. This is inversely proportional to the Smith model where the Smith model has the smallest Hit Rate and False Alarm values among the three other models. Paralelly, the PSS value obtained by each model shows that the Smith model has a PSS value that is closest to 1 with the smallest ePSS as shown in Table 3-1. The potential flash flood area produced by the Smith model best matches the actual event in the Cikundul watershed and prospective to be duplicated in the similar physiography area in Indonesia.

4 CONCLUSION

The Cikundul watershed is dominated by a moderate flash flood potential area based on the Brewster, Krudzlo, and Ceru models, and a low potential area based on the Smith model. Analysis of the four models shows that there are more areas of different potential than areas of the same potential. The upper part of the Cikundul watershed is dominated by areas with different levels of potential, which are areas with varying FFPI characteristics, while the lower part is dominated by areas with the same level of potential, which are areas whose FFPI characteristics tend to be the same.

Based on statistical tests carried out on the four models, both the PSS and ePSS values of the Smith model show the highest results with the smallest error rates. The Smith model is the FFPI model that is most suitable for assessing potential flash flood areas in the Cikundul watershed. Among the four variables, slope is the most influential variable in assessing flash flood potential areas based on the Smith model.

Overall, this study highlighted the practical implications of FFPI application in Cikundul Watershed to identify areas with high flash flood potential, planning a sub-watershed-based mitigation strategies to reduce the impact and intensity of flash flood hazard in the future. Generally, the methodology proposed in this study has a wide range of applicability and it can be adapted to region or watershed with similar physiography on national level.

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