Analysis of Surface Runoff and Remote Sensing Data to Identify Flood Potential in Simbang Sub-Watershed

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Abstract. Increased water runoff due to land use change phenomena has triggered flooding events. The objective is to identify flood potential in Simbang Sub-Watershed in Maros Regency using rational methods and remote sensing data. Potential flood hazards were analyzed using the weighting method with the parameters NDVI, MNDWI, NDSI, rainfall, and annual flow coefficient. The highest debit of runoff occurred in 2017, with a value of 113.36 m^3/s, while the lowest occurred in 2019, with a value of 63.91 m^3/s. The NDVI value is 0.37–1 with high vegetation covering an area of 3,089 ha, while the low-very low vegetation has value -0.03–0.25 with an area of 1,668 ha. The MNDWI value ranges from 0-0.33 with a moderate wetness level covering an area of 741 ha and an NDSI value ranging from -0.06–0.43 for bare land surrounding an area of 738 ha, which has an impact on reducing water catchment areas which can trigger an increase in surface water runoff discharge. The average rainfall is 2,965 mm/year, the area with low potential for flooding is 3,705 ha, and the area prone (moderate) to flooding is 1,450 ha. The rainfall factor is the main priority trigger for flood events with weight of 0.266, and the soil index is the lowest priority factor with weight of 0.145. Surface water runoff in the Simbang Sub-Watershed area makes a small contribution to the flood events that occurred in Maros Regency with an annual flow coefficient value of 0.23.

1 Introduction

One of the factors causing an increase in flood events in Maros Regency is the increase in population, which impacts increasing land requirements, resulting in conflicts over space use, which leads to land use that does not consider conservation principles [1–3]. Changes in vegetation cover will influence the volume of surface water runoff. An increase in runoff volume will result in flooding problems downstream in the river basin [4].

Floods are caused by surface water runoff, which cannot enter the ground because the soil is unable to absorb water [5], resulting in increased accumulation of river water discharge and can trigger erosion and flooding [6]. The amount of surface runoff is influenced by rainfall, vegetation type, and soil texture [7].

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Significant runoff due to climate change and land use can trigger flooding [8]. One of the areas that often experiences flooding events is Maros Baru and Turikale Districts. The sub-watersheds thought to impact flooding events in Maros Regency are the Simbang Sub-watershed and the Tanralili Sub-watershed. Based on data from BNBP [9], it was noted that there was an increase in river discharge in 2011-2020 by 10.22% in the Tanralili Sub-watershed so that water runoff flowing from the Tanralili Sub-watershed triggered flooding events from 2013 to 2021 in Maros Regency. Meanwhile, in the Simbang Sub-watershed, little surface runoff data is available.

Research on the role of watersheds as water suppliers in the form of surface runoff using various methods has been carried out by several researchers. One method that can be used to estimate the amount of surface water runoff is the rational method [10]. The rational method is a simple hydrological modeling method to estimate peak discharge in a watershed [11,12]. Apart from that, the development of flood event parameters can be calculated using remote sensing data, one of which is using the NDVI (Normalized Difference Vegetation Index) method. According to [13], NDVI data is the strongest predictor for explaining surface water runoff. Changes in NDVI values greatly influence the amount of surface water runoff and peak runoff discharge, which can trigger flooding events. Other parameters that can also be used as trigger factors for flood events are MNDWI (Modified Normalized Difference Water Index) and NDSI (Normalized Difference Soil Index) data. MNDWI data can be used to determine how much influence it has on the vulnerability to inundation [14]. The research results of [15], stated that the use of remote sensing data (NDVI and MNDWI) is the best explanatory variable in analyzing flood potential because it has an influence of 89 – 93% on the value of surface water runoff which triggers flooding. So, this research aims to analyze surface water runoff in the Simbang Sub-watershed, Simbang District, Maros Regency, using rational methods and remote sensing data to identify potential flooding.

2 Material and Methods

The Simbang Sub-watershed is a part of the Maros Watershed, which is located in Maros Regency, South Sulawesi. Geographically, the Simbang Sub-watershed area is located between 119° 36' 00" E – 119° 42' 00" E and 5° 00' 00" S - 5° 04' 00" S with an area of 5,156 ha or 7.05%. The Simbang Sub-watershed area includes three sub-districts: Bantimurung District, Simbang District, and Tompobulu District in Maros Regency (Figure 1).

The materials used in this research are Arc-Gis 10.8 software, Global Positioning System (GPS), Digital Elevation Model SRTM with 30 m resolution, topography map, Landsat 9 imagery of 2022, soil type data, land cover data, rainfall data, and 18 disturbed and undisturbed soil samples (Figure 2). Soil analysis used the BPSITP procedure [16]: permeability with permeameter, soil texture with a hydrometer, C-organic with Walkley and Black method, and bulk density with gravimetric.

Data analysis in this research includes estimating surface water runoff discharge using the rational method, runoff coefficient using the Hassing method, and rainfall intensity analysis. Remote sensing data are NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), and NDSI (Normalized Difference Soil Index). The Scoring and weighting methods use expert judgment methods.

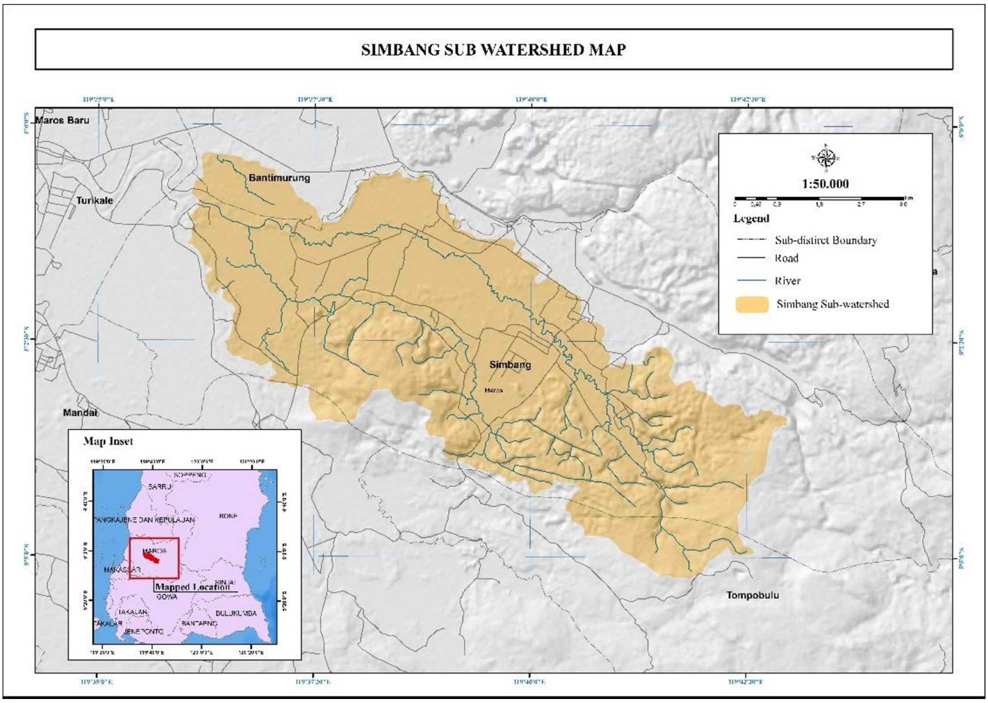

Fig. 1. The Simbang Sub-watershed area in Maros Regency

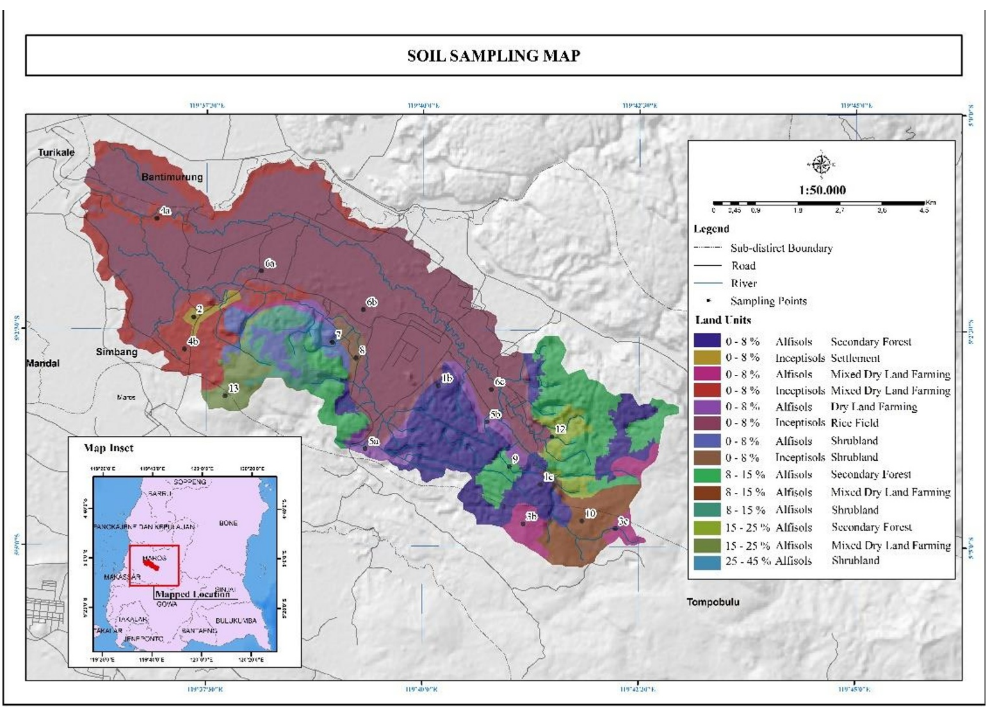

Fig. 2. Soil sampling map at Simbang Sub-watershed in Maros Regency

Estimated peak discharge (Qp) is calculated using the rational method with the following equation [12,17]:

$$Qp = 0{,}278CIA \quad (1)$$

Where Qp is the peak flow in m^3/se, C is the runoff coefficient I is average rainfall intensity (mm/hour), A is the area of study (km^2)

The intensity of rainfall (I) in each region varies due to the length of rainfall and the frequency of its occurrence, then it is calculated with the equation:

$$\mathrm{I} = \frac{R24}{24}\left(\frac{24}{Tc}\right)^{0{,}67} \quad (2)$$

Where R24 is the maximum daily rainfall (for 24 hours) (mm), Tc is a time of concentration (hours).

Meanwhile, the time of concentration can be calculated using the formula developed by the Kirpich method [18], where L is the length of the main channel (ft), S is basin slope:

$$Tc = 0.0078L^{0.77}S^{-0.385} \quad (3)$$

The runoff coefficient is determined using the Hassing method [19]. This method is obtained by combining topography, soil, and vegetation cover parameters. Each parameter is classified with different runoff coefficient values (Table 1).

Table 1. Runoff coefficient classification

Topography (Ct)	C	Soils (Cs)	C	Vegetation (Cv)	C
Very flat (< 1%)	0.03	Sand and Gravel	0.04	Forest	0.04
Undulating (1 - 10%)	0.08	Sandy Clays	0.08	Farmland	0.11
Hilly (10 -20%)	0.16	Clay and Loam	0.16	Grassland	0.21
Mountainous (> 20%)	0.26	Sheet Rock	0.26	Settlement	0.28
Runoff coefficient	C = Ct + Cs + Cv				

Normalized Difference Vegetation Index (NDVI) is a method used to compare vegetation density levels from satellite image data [20]. NDVI analysis uses Landsat 9 satellite imagery downloaded from the United States Geological Survey (USGS) with the equation;

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (4)$$

Where NIR is Near Infrared of band 5, Red is band 4.

The classification of NDVI values is carried out based on Minister of Forestry regulations [21], Table 2.

Table 2. Classification of Normalized Difference Vegetation Index (NDVI)

Class	NDVI Value	Classification
1	(-1) - (-0.03)	No vegetation
2	(-0.03) – (0.15)	Very low vegetation
3	(0.15) – (0.25)	Low vegetation
4	(0.25) – (0.35)	Moderate vegetation
5	(0.37) – (1)	High vegetation

Modified Normalized Difference Water Index is a method used to differentiate water bodies and built-up land [22,23]. MNDWI analysis uses Landsat 9 satellite imagery downloaded from the United States Geological Survey (USGS) with the equation;

$$MNDWI = \frac{Green - SWIR1}{Green + SWIR1} \quad (5)$$

Where Green is band 3, SW1R1 is short-wave infrared of band 6

The classification of MNDWI values [22] can be seen in Table 3.

Table 3. Classification of Modified Normalized Difference Water Index (MNDWI)

Class	MNDWI Value	Classification
1	(-1) - (0)	No water
2	(0) - (0.33)	Moderate wetness
3	(0.33) - (1)	High wetness

Normalized Difference Soil Index is used to determine the condition of soil cover (Table 4). NDSI analysis uses Landsat 9 satellite imagery downloaded from the United States Geological Survey (USGS) with the equation [24];

$$NDSI = \frac{SWIR1 - NIR}{SWIR1 + NIR} \quad (6)$$

Where SW1R1 is short-wave infrared of band 6, NIR is Near Infrared of band 5

Table 4. Classification of Normalized Difference Soil Index (NDSI)

Class	NDSI value	Classification
1	(-1) - (- 0.46)	water
2	(-0.46) - (-0.06)	vegetated land
3	(-0.06) - (0.43)	Bare land

The annual flow coefficient method is a method used to calculate the amount of rainwater that is a runoff (Table 5), with the equation [25];

$$AFC = \frac{k\ x\ Q}{CH\ x\ A} \quad (7)$$

Where AFC is the annual flow coefficient, k is conversion factor (365 x 86,400)/10, A is an area of watershed (ha), Q is the average annual discharge, CH is an annual average rainfall

Table 5. Classification of annual flow coefficient (AFC)

Class	AFC value	Recovery qualification
1	AFC≤ 0.2	Very low
2	0.2<AFC≤ 0.3	Low
3	0.3<AFC≤ 0.4	Moderate
4	0.4<AFC≤ 0.5	High
5	AFC>0.5	Very high

Scoring and weighting methods are done using the Expert Judgment method. Scoring and weighting values are obtained by filling out questionnaires or questionnaires based on several opinions of experts in assessing flood vulnerability. The parameters used are NDVI, MNDWI, NDSI, Rainfall Map, and Annual Flow Coefficient Map. Scoring and weighting results are combined to produce a level of flood vulnerability with the equation [26];

$$X = \sum_{i=1}^{n} (Wi \times Xi) \quad (8)$$

Where X is the susceptibility value, Wi is a weight for the i parameter, Xi is a class score in the i parameter.

The results of the scoring and weighting were classified into three potential classes following the Guidelines of the National Disaster Management Agency (BNPB) [27], namely, not prone, low, moderate, and high. The Class Classification with an equation of Kingma procedure [28]:

$$Ki = \frac{Xt - Xr}{k} \quad (9)$$

Where Ki is an interval class, Xt is high score, Xr is low score, k is the number of classes desired

Overlay the map uses the intersect method from the scoring and weighting results of each parameter to the level of potential flood vulnerability. Overlay maps are carried out to produce areas with potential flooding.

3 Results

3.1 Surface runoff analysis

The values of annual surface runoff discharge and annual rainfall for ten years (2013-2022) in the Simbang Sub-watershed are presented in Figure 3. The highest value of surface runoff occurred in 2017 with a value of 113.36 m^3/s with rainfall of 3,282 mm/year, while the lowest value of surface flow runoff occurred in 2019 with a value of 63.91 m3/s with rainfall of 2,262 mm/ year.

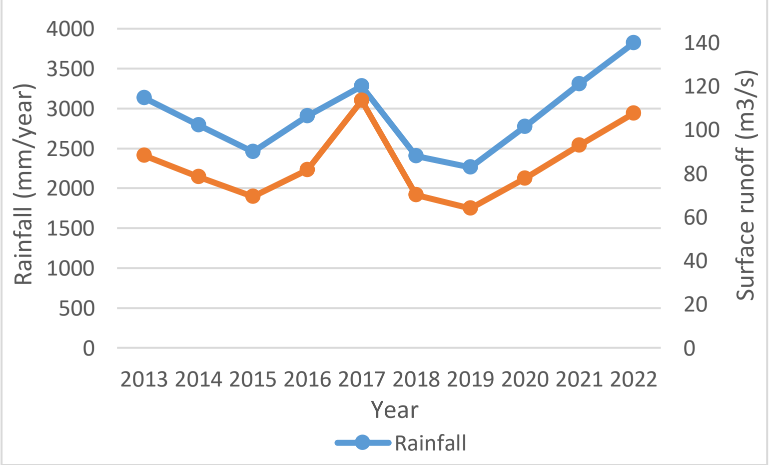

Fig 3. Surface runoff discharge with annual rainfall for ten years in the Simbang Sub-watershed (2013-2022**)**

3.2 Soil characteristics

Soil characteristics in the Simbang sub-watershed vary greatly. Soil texture in the sub-watershed consists of four texture classes: clay, silty clay, silty clay loam, and clay loam. The bulk density value ranges from 1.1 to 1.5 g/cm3. The bulk density value is related to the porosity and permeability values of the soil, where the porosity value ranges from 42.34-55.70%, while the permeability value ranges from 0.09-0.72 cm/hour in the very slow to somewhat slow category. C-organic values range from 0.98-2.27% in the low to medium category. A positive correlation exists between soil texture, infiltration, and the abundance of organic matter in the soil [29–31].

3.3 Normalized difference vegetation index (NDVI)

Most of the vegetation in the Simbang Sub-watershed area has high vegetation density (Table 6). High vegetation density values range from 0.37–1 with an area of 3,089 ha or 59.91% of the Simbang Sub-watershed area. The medium vegetation density level has an area of 396 ha or 7.69%. The low-density level has an area of 515 ha or 9.99% of the area of the Simbang Sub Watershed. The very low vegetation density level has an area of 1,155 ha or 22.40%, making it the second largest area after the high vegetation density level in the Simbang Sub-watershed (Figure 4).

Table 6. NDVI value in Simbang Sub-watershed

Class	NDVI value	Classification	Area (ha)	Percentage (%)
1	(-0.03) – (0.15)	Very low vegetation	1155	22.41
2	(0.15) – (0.25)	Low vegetation	515	9.99
3	(0.25) – (0.35)	Moderate vegetation	396	7.69
4	(0.37) – (1)	High vegetation	3089	59.91
		Total	**5156**	**100**

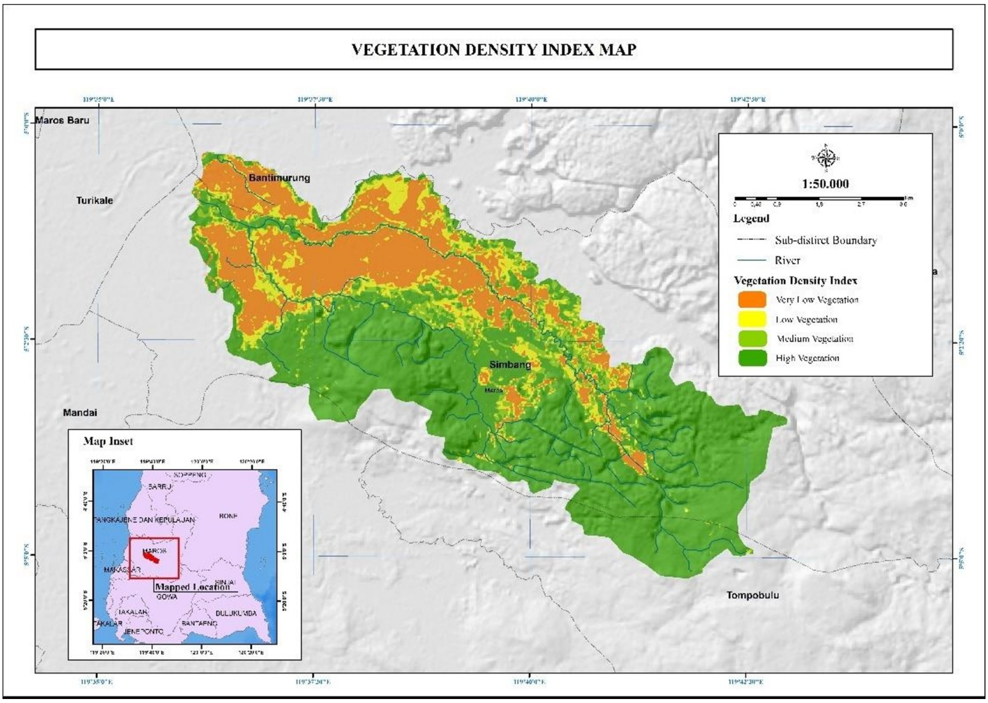

Fig. 4. Distribution of vegetation in Simbang Sub-watershed in Maros Regency

3.4 Modified normalized difference water index (MNDWI) and normalized difference soil index (NDSI)

The no-water body classification ranges from -1–0 and has an area of 4,415 ha or 85.62% of the Simbang Sub-watershed area. The next wetness level value obtained is a moderate wetness level, which covers an area of 741 ha or 14.38% of the Simbang Sub-watershed area (Figure 5).

The NDSI value shows that some areas of the Simbang Sub-Watershed still have vegetated land. The Soil Index value of vegetated land ranges from -0.46–(-0.06), which has an area of 4,418 ha or 85.68% of the Simbang Sub-watershed area. The bare land has an area of 738 ha or 14.32% of the Simbang sub-watershed area. The Soil Index map can be seen in Figure 6.

3.5 Rainfall data

The rainfall value in the Simbang Sub-watershed in the last ten years has been 2,965 mm/year with an area of 5,156 ha or 100% at the upstream of the sub-watershed, while rainfall continues to gradually decrease towards the downstream of the sub-watershed with rainfall of 2,857 mm/year. The rainfall value is included in the high rainfall classification, with rainfall values ranging from 2,500 mm/year to 3,000 mm/year (Figure 7). Rainfall is a trigger factor for induced flood in a watershed [32].

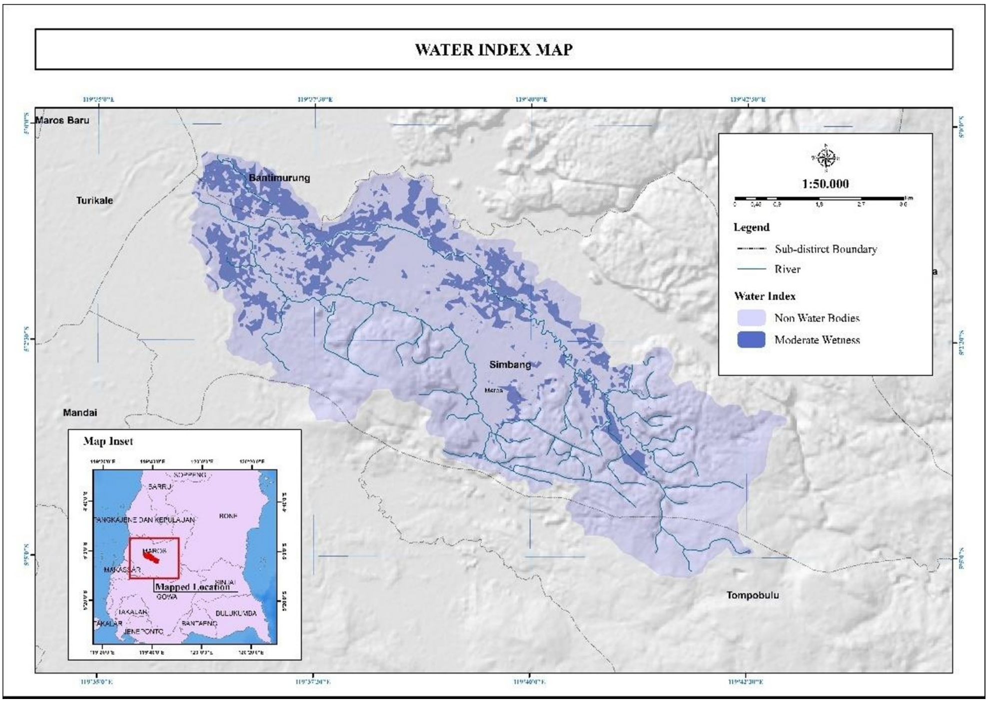

Fig. 5. Distribution of water in Simbang Sub-watershed in Maros Regency

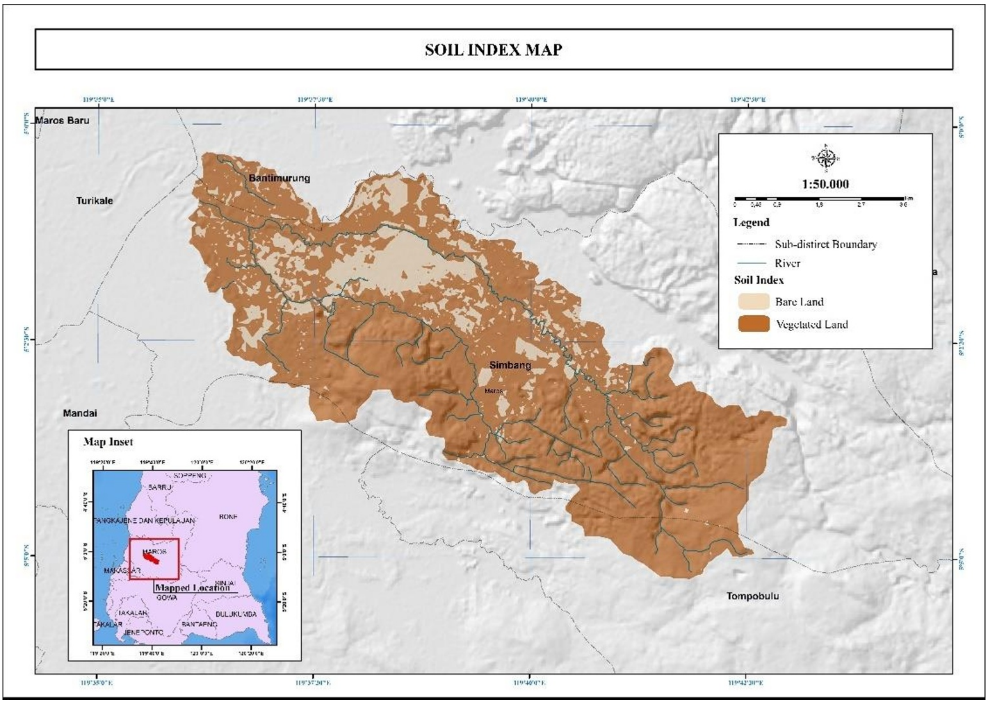

Fig. 6. Distribution of vegetated and bare land in Simbang Sub-watershed in Maros Regency

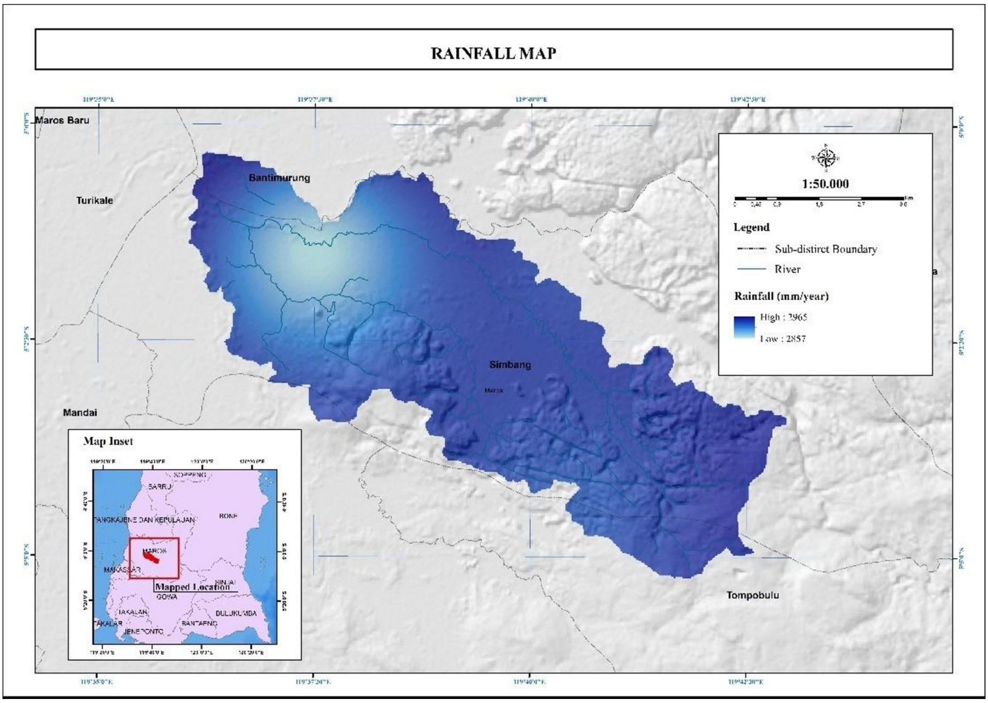

Fig. 7. Distribution of rainfall in Simbang Sub-watershed in Maros Regency

3.6 Annual flow coefficient (AFC), scoring and weighting

The annual flow coefficient value of the Simbang Sub-watershed is in the low category with an AFC value of 0.23 and has an area of 5156 ha or 100% of the sub-watershed area in this category. The weight value can determine a priority parameter for triggering floods. The highest parameter weight value is found in the rainfall parameter with a weight of 0.266, thus making the rainfall parameter the main priority. The weight value of parameters with a low priority level is found in the NDSI parameter with a weight of 0.145.

Table 7. The weight of flood parameter

No.	Parameter	Weight
1	Normalized Difference Vegetation Index (NDVI)	0.186
2	Modified Normalized Difference Water Index (MNDWI)	0.175
3	Normalized Difference Soil Index (NDSI)	0.145
4	Average rainfall (mm/year)	0.266
5	Annual flow coefficient	0.228
	Consistency Ratio	0.000

The scoring value determines the level of influence of the sub-parameters on each parameter. The higher the scoring value for each sub-parameter, the more impact it will have on flood events (Table 8). The highest scoring value for the NDVI parameter was obtained for the non-vegetated land sub-parameter with a score of 39.0 and the lowest score for the high vegetation sub-parameter with a score of 6.2. The score value for the MNDWI parameter obtained the highest score for the high wetness sub-parameter with a score of 46.9, and the lowest score for the non-water body sub-parameter, namely 19.4. The highest NDSI parameter scoring value was in the open land sub-parameter, with a value of 46.7, and the lowest score was in the vegetated land sub-parameter, with a value of 15.3. The scoring value for the rainfall parameter is highest for the sub-parameter for rainfall >3,000 mm/year, namely 34.7, and the lowest score for the sub-parameter for rainfall <1,500 mm/year, namely 5.9. The highest annual flow coefficient parameter scoring value in the very high sub-parameter is 27.2, and the lowest score in the very low sub-parameter is 11.9.

Table 8. Flood potential sub-parameter scoring

No.	Parameter	Sub Parameter	Score
1	Normalized Difference Vegetation Index (NDVI)	High vegetation	6.2
		Moderate vegetation	9.0
		Low vegetation	19.3
		Very low vegetation	26.5
		No vegetation	39.0
2	Modified Normalized Difference Water Index (MNDWI)	No water	19.4
		Moderate wetness	33.6
		High wetness	46.9
3	Normalized Difference Soil Index (NDSI)	water	37.9
		Vegetated land	15.3
		Bare land	46.7
4	Average of Rainfall (mm/year)	0 – 1,500	5.9
		1,500 – 2,000	13.0
		2,000 – 2,500	20.3
		2,500 – 3,000	26.1
		>3,000	34.7
5	Annual flow coefficient	Very low	11.9
		Low	17.3
		Moderate	19.9
		High	23.8
		Very high	27.2

3.7 Potential flood-prone areas in the Simbang Sub-watershed

The flood susceptibility level value in the Simbang Sub-watershed is dominated by areas not prone to flooding, with an area of 3,705 ha or 71.86%. The value of the potential level of flood risk in the Simbang Sub-watershed is 1,450 or 28.14% of the total area of the Simbang Sub-watershed (Table 9 and Figure 8). Vegetated land determines the amount of surface runoff; the more vegetation, the smaller the surface runoff [32].

Table 9. Level of flood susceptibility in the Simbang Sub-watershed

Class	Interval	Prone level	Area (ha)	Percentage (%)
1	17.65 – 22.03	Tidak Rawan	3,705	71.86
2	22.04 – 26.41	Rawan	1,451	28.14
Total			**5,156**	**100**

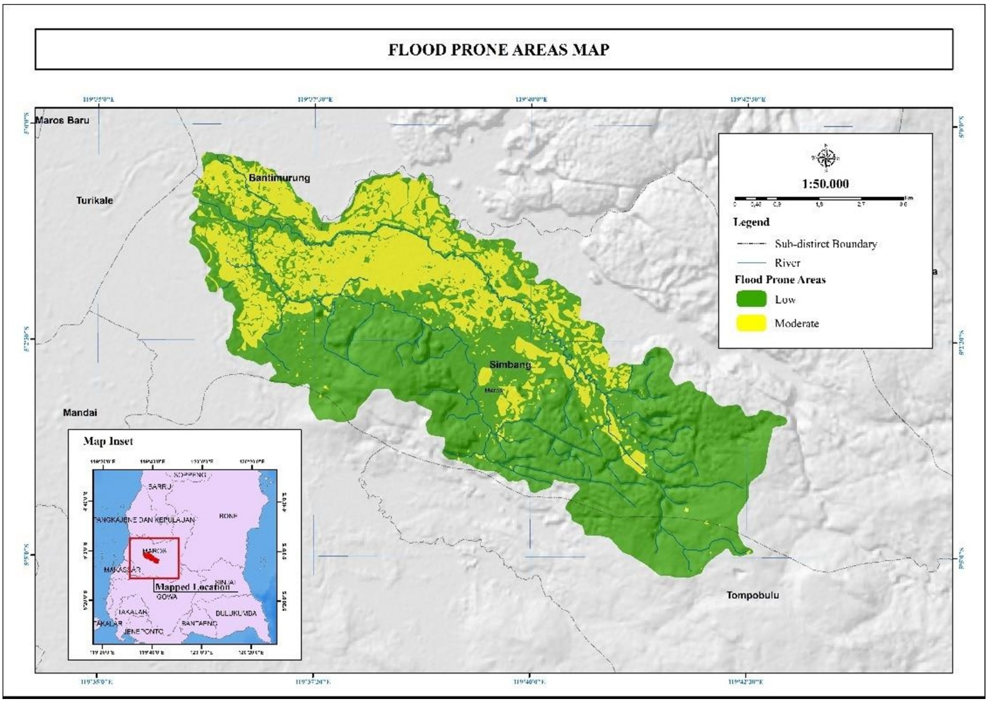

Fig. 8. Distribution of potential flood-prone areas in the Simbang Sub-watershed

4 Discussion

The research area has an average rainfall of 2,965 mm/year. High rainfall is a very influential factor in triggering flooding in an area [33]. The soil texture in the research area dominated by the clay texture class, influences the soil's ability to pass water. Clay texture is one factor that influences soil porosity and permeability [34]. High rainfall intensity, rainfall duration, low vegetation density, and a texture dominated by the clay fraction trigger an increase in surface flow, which can trigger flooding events [35]. [36] added that rainfall with an average of 2,840 mm/year, clay texture, and land cover conditions greatly influence the amount of surface runoff, which causes flooding in the downstream areas of the Beringin River, Semarang.

Surface runoff that occurs in the Simbang Sub-watershed is 113.36 m3/s. The increase in runoff discharge at the research location only occurred in areas with very low vegetation density with NDVI values of 0.03–0.15, while most of the Simbang Sub-watershed area was dominated by high vegetation density with values of 0.37-1. The water index value ranges from -1-0 or no-water body, and the soil index value ranges from -0.46-(-0.06). According to [37], vegetated land greatly influences soil infiltration, as well as research results from [35], areas that have low levels of vegetation density have lower levels of infiltration compared to areas that have high levels of vegetation density, due to surface runoff. The roots and stems of vegetation will support the surface. Changes in land use area and rainfall intensity have the impact of increasing the value of surface runoff [38].

The surface runoff has an impact on the AFC value of the Simbang Sub-Watershed, which is in the low category with a value of 0.23, so the contribution of the Simbang Sub-watershed as a trigger for flood events in the cities of Maros and Turikale is very small. Annual flow coefficient values ranging from 0.40 - > 0.5 indicate that the watershed response is classified as critical, which can cause an increase in surface flow, thus triggering flood events [39]. Research results from [40] in the Tanralili Sub-watershed show data on the increase in discharge from 113.81 m3/s to 186 m3/s, so the increase in flow discharge in the Tanralili Sub-watershed is one of the factors triggering flood events in the cities of Maros and Turikale. The same thing also happened in Sorong City, where the increase in surface runoff discharge from 0.448 m3/s to 1,200 m3/s due to an increase in rain intensity from 12.57 mm/hour to 33.69 mm/resulting in flooding and waterlogging [41].

The increase in annual flow coefficient is strongly influenced by rainfall and river discharge. [42] in their research stated that the increase in the annual flow coefficient value from 0.34 to 0.42 in the Cicatih sub-watershed was due to an increase in river discharge and rainfall from 2,603 mm/year to 2,956 mm/year. The annual flow coefficient of the Simbang Sub-Watershed is relatively low, influenced by the soil's organic C content, which is in the medium category. The organic C content of the soil in the research area, with an average value of 2.31% and a bulk density value of 1.24 g/cm^3, affects the soil water-holding capacity, reducing the increase in surface water runoff. [43] concluded that high organic C content affects the soil's ability to store water to inhibit erosion and surface water runoff. Even though the AFC value is still in the low category, the soil characteristics show a high clay content with a soil carbon value in the medium category, which can trigger landslides in Maros City in the future. Hence, the Simbang Sub-watershed area requires applying soil processing by considering conservation principles.

5 Conclusions

The surface runoff value in the Simbang sub-watershed ranges from 63.91 m^3/s to 113.36 m3/s, and the AFC value is 0.23 (low category). This is in accordance with the level of the flood-prone area in the Simbang Sub-Watershed, which is dominated by the no-prone class covering an area of 3,705 ha (71.86%) found in the regions that have NDVI values ranging from 0.37-1 or high levels of vegetation density, water index values ranging from -1-0, and soil index values ranging from -0.46-(-0.06) in the vegetated land category, while in the prone class of 1,450 ha (28.14%) is found in areas with NDVI values ranging from -0.03–0.15 or very low vegetation density, MNDWI value 0-0.33 (medium category) and NDSI -0.06–0.43 (bare land). Overall, surface water runoff in the Simbang Sub-Watershed makes a small contribution to the flood events that occur in Maros Regency, and soil conservation must begin to be implemented to prevent the potential for the Simbang Sub-Watershed to trigger future flood events.

References

1. M. Fadhil, Y. Ristya, N. Oktaviani, and E. Kusratmoko, Flood Vulnerability Mapping Using the Spatial Multi-Criteria Evaluation (SMCE) Method in the Minraleng Watershed , Maros Regency , South Sulawesi, E3S Web Conf. **153**, 1 (2020).
2. Wahyunto and A. Dariah, Degradasi Lahan Di Indonesia: Kkondisi Existing, Karakteristik, Dan Penyeragaman Definisi Mendukung Gerakan Menuju Satu Ppeta, J. Sumberd. Lahan **8**, 81 (2014).

3. BNPB, *Data Informasi Bencana Indonesia (DIBI)*, https://bnpb.cloud/dibi/laporan5.
4. M. Farid, M. I. Pratama, A. A. Kuntoro, M. B. Adityawan, F. I. W. Rohmat, and I. R. Moe, Flood Prediction Due to Land Cover Change in the Ciliwung River Basin, Int. J. Technol. **13**, 356 (2022).
5. P. Zhang, W. Sun, P. Xiao, W. Yao, and G. Liu, Driving Factors of Heavy Rainfall Causing Flash Floods in the Middle Reaches of the Yellow River: A Case Study in the Wuding River Basin, China, Sustain. **14**, 1 (2022).
6. Mahmud, A. Kusumandari, Sudarmadji, and N. Supriyatno, A Study of Flood Causal Priority in Arui Watershed, Manokwari Regency, Indonesia, J. Manaj. Hutan Trop. **24**, 81 (2018).
7. S. Rohyanti, I. Ridwan, and Nurlina., Analisis Limpasan Permukaan Dan Pemaksimalan Resapan Air Hujan Di Daerah Tangkapan Air (Dta) Sungai Besar Kota Banjarbaru Untuk Pencegahan Banjir, J. Fis. FLUX **12**, 128 (2015).
8. M. Ardiansyah, R. A. Nugraha, L. O. S. Iman, and S. D. Djatmiko, Impact of Land Use and Climate Changes on Flood Inundation Areas in the Lower Cimanuk Watershed, West Java Province, J. Ilmu Tanah Dan Lingkung. **23**, 53 (2021).
9. BNPB (Badan Nasioanal Penanggulangan Bencana/National Agency for Disaster Management) Indonesia), Indeks Risiko Bencana Indonesia (IRBI), Vol. 01 (Badan Nasional Penanggulangan Bencana, 2023).
10. G. Baiamonte, A Rational Runoff Coefficient for a Revisited Rational Formula, Hydrol. Sci. J. **65**, 112 (2020).
11. A. Herison, Y. Romdania, O. T. Purwadi, and R. Effendi, Kajian Penggunaan Metode Empiris Dalam Menentukan Debit Banjir Rancangan Pada Perencanaan Drainase (Review), J. Apl. Tek. Sipil **16**, 77 (2018).
12. A. Suheri, C. Kusmana, M. Purwanto, and Y. Setiawan, The Peak Runoff Model Based on Existing Land Use and Masterplan in Sentul City Area , Bogor, IOP Conf. Ser. Earth Environ. Sci. **399**, 1 (2019).
13. H. W. Kim, J. H. Kim, W. Li, P. Yang, and Y. Cao, Exploring the Impact of Green Space Health on Runoff Reduction Using NDVI, Urban For. Urban Green. **28**, 81 (2017).
14. I. K. B. Ramadhan and C. Susetyo, Prediksi Debit Limpasan Air Permukaan Pada Daerah Rawan Banjir Di Kabupaten Jombang Berdasarkan Pemodelan Penggunaan Lahan, J. Tek. ITS **9**, 2301 (2021).
15. N. Ohana-Levi, A. Karnieli, R. Egozi, A. Givati, and A. Peeters, Modeling the Effects of Land-Cover Change on Rainfall-Runoff Relationships in a Semiarid, Eastern Mediterranean Watershed, Adv. Meteorol. **2015**, 1 (2015).
16. BPSITP (Balai Pengujian Standar Instrumen Tanah dan Pupuk), Petunjuk Teknis Edisi 3: Analisis Kimia Tanah, Tanaman, Air, Dan Pupuk (Technical Instructions Edition 3: Chemical Analysis of Soil, Plants, Water and Fertilizer) (Kementerian Pertanian Republik Indonesia, 2023).
17. D. C. Hayes and R. L. Young, Comparison of Peak Discharge and Runoff Characteristic Estimates from the Rational Method to Field Observations for Small Basins in Central Virginia Scientific Investigations Report 2005-5254 (2006).
18. S. Grimaldi, A. Petroselli, F. Tauro, and M. Porfiri, Time of Concentration: A Paradox in Modern Hyrdology, Hydrol. Sci. J. **57**, 217 (2012).
19. M. H. Z. Nurrachman, I. Sumardi, and T. Lastini, Land Cover and Groundwater Recharge Changes Study Using Conservation Index in the Highland Ciburial Village, Bandung Regency, IOP Conf. Ser. Earth Environ. Sci. **166**, 1 (2018).
20. I. G. Sudarman and A. Ahmad, Mapping of Landslide-Prone Areas in the Lisu River Basin Barru Regency Based on Binary Logistic Regression, IOP Conf. Ser. Earth Environ. Sci. **807**, 0 (2021).

21. Peraturan menteri Kehutanan Republik Indonesia (Regulation of the Minister of Forestry of the Republic of Indonesia), *Tata Cara Penyusunan Rencana Teknik Rehabilitasi Hutan Dan Lahan Daerah Aliran Sungai (RTk RH-DAS)*, Menteri Kehutanan Republik Indonesia.
22. H. Xu, Modification of Normalised Difference Water Index (NDWI) to Enhance Open Water Features in Remotely Sensed Imagery, Int. J. Remote Sens. **27**, 3025 (2006).
23. J. Laonamsai, P. Julphunthong, T. Saprathet, B. Kimmany, T. Ganchanasuragit, P. Chomcheawchan, and N. Tomun, Utilizing NDWI, MNDWI, SAVI, WRI, and AWEI for Estimating Erosion and Deposition in Ping River in Thailand, Hydrology **10**, 1 (2023).
24. Indrayani, E. Buchari, D. Putranto, and E. Saleh, Spatial Analysis of Soil Texture and Peat Soil by NDSI Method at Swamp Area of Banyuasin District, Indonesia, Ecol. Environ. Conserv. **24**, 673 (2018).
25. P. M. K. R. (Regulation of the M. of F. of the R. of I. Indonesia, *Kriteria Penetapan Klasifikasi Daerah Aliran Sungai (Criteria for Determining Watershed Classification)*, The Minister of Forestry of the Republic of Indonesia.
26. T. L. Saaty, Decision Making with the Analytic Hierarchy Process, Int. J. Serv. Sci. **1**, 83 (2008).
27. BNPB, Risiko Bencana Indonesia (BNPB, Jakarta, 2016).
28. T. Purwandari, M. P. Hadi, and N. C. Kingma, A Gis Modelling Approach for Flood Hazard Assessment in Part of Surakarta City, Indonesia, Indones. J. Geogr. **43**, 63 (2011).
29. D. Mey, J. Sartohadi, D. Mardianto, and M. Marfai, Prediction of Soil Organic Carbon Loss Due to Erosion in the Girindulu Watershed of Central Java, Degrad. Andmining Landsmanagement **2**, 361 (2015).
30. N. E. Saputra, C. Wibowo, and Y. Lisnawati, Analysis of Soil Physical Properties and Infiltration Rates for Various Landuses at Gunung Dahu Research Forest, Bogor District, West Java Province, IOP Conf. Ser. Earth Environ. Sci. **713**, 1 (2021).
31. Z. He, H. Xu, S. He, X. Liang, Z. Zheng, Z. Luo, Y. Wang, Y. Zhang, and B. Tan, Characteristics of Soil Organic Carbon (SOC) Loss with Water Erosion in Sloping Farmland of Southwestern China during Maize (Zea Mays L.) Growth Stages, Agronomy **13**, 1 (2023).
32. X. Zhang, F. Mao, Z. Gong, D. M. Hannah, Y. Cai, and J. Wu, A Disaster-Damage-Based Framework for Assessing Urban Resilience to Intense Rainfall-Induced Flooding, Urban Clim. **48**, 101402 (2023).
33. D. Prabawadhani, B. Harsoyo, T. Seto, and M. Prayoga, Karakteristik Temporal Dan Spasial Curah Hujan Penyebab Banjir Di Wilayah DKI Jakarta Dan Sekitarnya, J. Sains Teknol. Modif. Cuaca **17**, 21 (2016).
34. A. Ahmad, M. Farida, N. Juita, and M. Jayadi, Soil Micromorphology for Modeling Spatial on Landslide Susceptibility Mapping: A Case Study in Kelara Subwatershed, Jeneponto Regency of South Sulawesi, Indonesia, Nat. Hazards **118**, 1445 (2023).
35. P. Kusumo and E. Nursari, Zonasi Tingkat Kerawanan Banjir Dengan Sistem Informasi Geografis Pada DAS Cidurian Kab. Serang, Banten, STRING (Satuan Tulisan Ris. Dan Inov. Teknol. **1**, 29 (2016).
36. D. A. Nugroho and W. Handayani, Kajian Faktor Penyebab Banjir Dalam Perspektif Wilayah Sungai: Pembelajaran Dari Sub Sistem Drainase Sungai Beringin, J. Pembang. Wil. Dan Kota **17**, 119 (2021).
37. A. D. Rahma, M. Rosidi, R. Zapariza, E. Sulaeman, and I. Ridwan, Infiltration Ability in the Area of Land Use Change, Bogor, West Java, Appl. Water Sci. **13**, 1 (2023).
38. U. Izzati, H. S. Hasibuan, and T. L. Indra, Land Use Change of Cisadane River Buffer Strips, South Tangerang City, Indonesia, IOP Conf. Ser. Earth Environ. Sci. **338**, 1

(2019).
39. R. Rahman, S. Kadir, and B. Badaruddin, Studi Tata Air Di Sub Das Bati-Bati Das Maluka Kalimantan Selatan (Water System Study in Sub-Water Bati-Bati Maluka Watershed South Kalimantan), J. Sylva Sci. **3**, 568 (2020).
40. Nurhidayat, *Pengaruh Perubahan Penggunaan Lahan Terhadap Debit Puncak Sungai Di Sub DAS Tanralili*.
41. A. Farida and V. Aryuni, Analisis Limpasan Permukaan Di Sekitar Kampus Universitas Muhammadiyah Sorong Kota Sorong, J. Sains Dan Teknol. Lingkung. **12**, 146 (2020).
42. S. P. Nugroho, S. D. Tarigan, and Y. Hidayat, Analisis Perubahan Penggunaan Lahan Dan Debit Aliran Di Sub Das Cicatih, J. Pengelolaan Sumberd. Alam Dan Lingkung. (Journal Nat. Resour. Environ. Manag. **8**, 258 (2018).
43. M. K. Rugendo, B. M. Gichimu, J. N. Mugwe, M. Mucheru-Muna, and D. N. Mugendi, Surface Runoff and Soil Erosion from Nitisols and Ferralsols as Influenced by Different Soil Organic Carbon Levels under Simulated Rainfall Conditions, Heliyon **9**, 1 (2023).