MORPHOMETRY AND MORPHOTECTONIC CHARACTERISTICS OF THE CISOKAN WATERSHED CILENGKONG AND CISUKARAMA SEGMENTS, WEST JAVA, INDONESIA

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ABSTRACT

West Java has a complex geological structure characteristic due to subduction events in the south of Java Island. The control of the geological structure affects the formation of the surrounding landscape, so analysis is needed to assess its activities. The research was conducted in the Cisokan sub-watershed in the Cilengkong and Cisukarama segments in Cianjur and West Bandung districts, West Java. The purpose of this study was to determine the morphometric and morphotectonic characteristics of the Cisokan watershed in the Cilengkong and Cisukarama segments. The method used is studio analysis using applications to process digital image data into morphometric and morphotectonic analysis parameters. The parameters analyzed were the bifurcation ratio, drainage density, basin shape index, drainage basin asymmetry, and mountain front sinuosity. The results obtained are that the Cilengkong segment has an Rb value of 4 - 4.5 with a medium flow density, a BS value of 1.80, an AF value of 25.8, and an SMF value of 1.19 - 2.78. The Cisukarama 1 segment has an Rb value of 4 - 4.25, a BS value of 1.62, an AF value of 57.14, and an SMF value of 1.66 - 3.41. The Cisukarama 2 segment has a value of Rb 3 - 4.25, a BS value of 1.59, an AF value of 42.5, and an SMF value of 1.34 and 2.13. The conclusion obtained is that tectonic activity as a landscape-forming factor in the study area decreases or even stops.

Keyword: Morphometric, Morphotectonic, Watershed, Cisokan

INTRODUCTION

West Java has a relatively complex geological structure due to plate collision events in the south of Java Island (Hilmi & Haryanto, 2008). It develops folds and fault structures with high intensity, and some are regional (Haryanto, Hutabarat, Sudradjat, Ilmi, & Sunardi, 2017). Based on van Bemmelen (1949); Martodjojo (1984); Haryanto (2015) in Haryanto *et al.* (2017), there are six regional fault structures in the West Java region, namely the Cipeles Fault, Baribis Fault, Cimandiri Fault, Lembang Fault, Citanduy Fault, and Pelabuhan Ratu Fault. The existence of these faults can influence the surrounding landform.

In determining the influence of tectonic processes on the formation of landscapes, one of the developments of geomorphological studies can be used, namely morphotectonics. According to Pratama *et al.* (2019), morphotectonics can reveal tectonic activity at a location using quantitative geomorphological and spatial data. Knowledge of tectonic activity in an area is expected to provide an overview of regional development planning to minimize geological disasters.

The research area is located in the Cisokan watershed in the Cilengkong and Cisukarama segments in Cianjur Regency and West Bandung Regency, West Java. Based on the Regional Geological Map of the Cianjur Sheet (Sudjatmiko, 2003), there are geological structures in the research area, the form of faults and folds that affect the lithology of the surrounding rocks. The tectonic activity needs to be analyzed based on morphotectonic studies to know its current influence. This study aims to determine the morphometric and morphotectonic characteristics of the research area, precisely the Cisokan watershed in the Cilengkong - Cisukarama segment, to provide an overview of tectonic activity quickly and efficiently as a basis for regional planning in the research area.

REGIONAL GEOLOGY

The Cisokan watershed is located in Sukarama Village, Bojongpicung District, Cianjur Regency. Based on the Regional Geological Map of the Cianjur Sheet (Sudjatmiko, 2003), the research area has a geological structure in the form of a reverse fault with a NE-SW direction and a strike-slip fault. A more detailed geological mapping by Kurniawan (2010) proves that in the study area, there are geological structures in the form of a reverse fault with a NE-SW trend, a

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normal fault with an NW-SE direction, and folds that are parallel with the reverse fault. The geological structure is obtained from the evidence found in the field in the form of shear joints, tensional joints, brecciation, and stratigraphic positions. This geological structure is strongly influenced by the Cimandiri Fault, which is trending NE-SW, better known as the Meratus direction. According to Katili (1974) *op cit* Martodjojo (2003), the direction of the Meratus is defined as a direction that follows the general arc pattern of the Cretaceous, which continues to the Meratus Mountains in Kalimantan.

Stratigraphically, the Cisokan watershed comprises the Rajamandala Formation (Omc), consisting of clay, marl, and quartz sandstone with Oligocene age. Above it is the Citarum Formation (Mts) consisting of sandstone and siltstone consisting of a perfectly layered sandstone lithology interspersed with siltstone, claystone, graywacke, and breccias of late Oligocene age. Then the youngest layer is the volcanic product unit (Pb) in the form of tuffaceous breccia, lava, sandstone, conglomerate of Pliocene age.

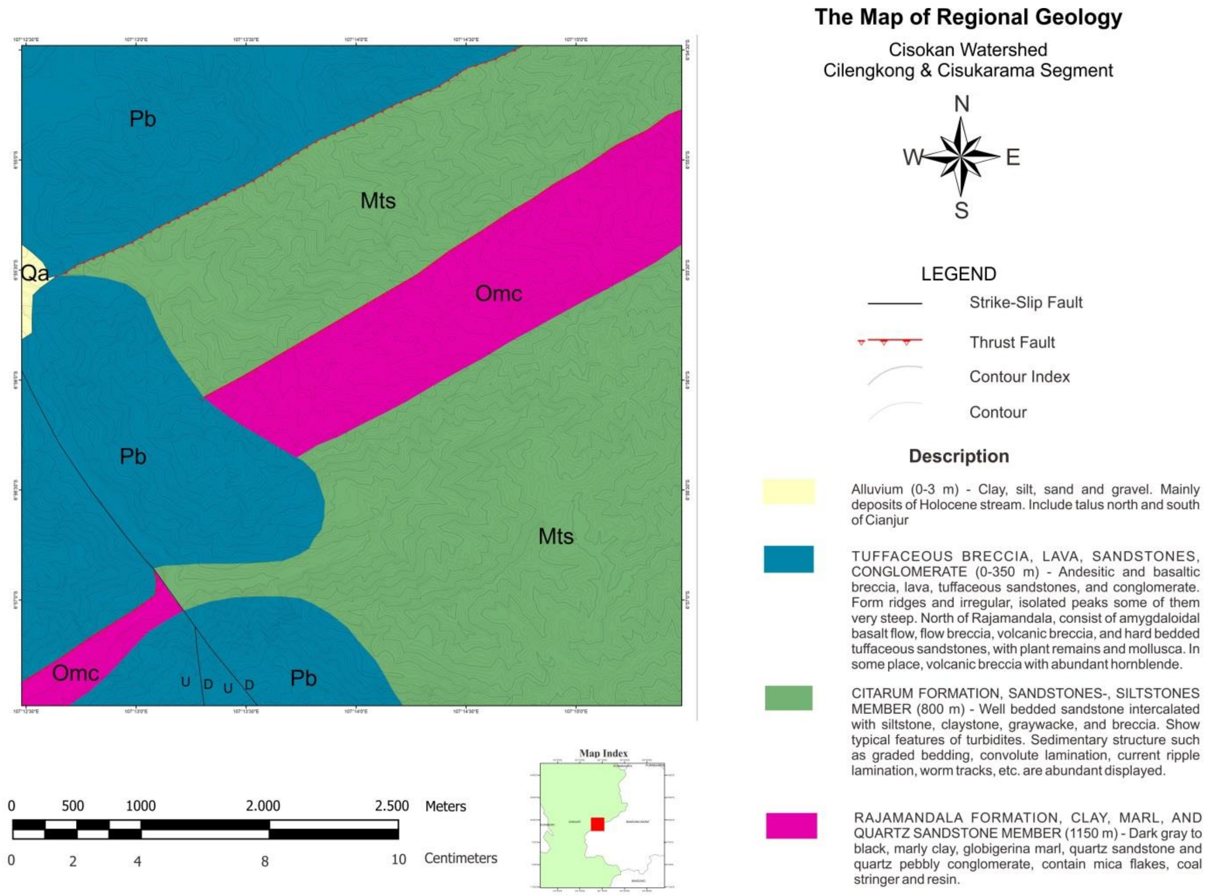

Figure 1. Regional Geological Map of the research area (modification from Sudjatmiko,2003)

RESEARCH METHOD

The research method used in this study is studio analysis using an application to process morphometric and morphotectonic parameter data based on digital data obtained from the Geospasial Information Agency. At the initial stage, watershed morphometric calculations were carried out in the area, length, width, stream order, bifurcation ratio, and drainage density. Geomorphological quantitative as an object of comparison of landforms and direct parameter calculations are very useful for identifying the character of an area and the tectonic activity level.

The area, length, and width of the watershed can be measured using measuring tools on the topographic map (Sosrodarsono and Takeda, 2003; in Sukiyah, 2017). The calculation of the area and length of this watershed is very important because it will

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be useful in the analysis that will be carried out.

The stream order is the position of the branching of the river in a watershed. The Strahler method is used to determine the order of the river (in Sukiyah, 2017), where the first order is a segment that has no branches. If two segments of the first order are combined, it will produce a second-order and so on.

The bifurcation ratio (Rb) compares the total length of the river segment with the number of river segments (Schumn, 1956 in Rao, 2010). Rb can be obtained based on the following equation:

$$\mathrm{RB} = \sum N_u / N_{U+1} \quad \text{.........(2)}$$

Where Rb= Bifurcation Ratio, Nu= Number of order u, Nu+1= Number of streams of order u+1. Verstappen (1983) states that if the value of Rb<3 or Rb>5, then the watershed is probably controlled by tectonic.

Drainage density compares the number of rivers and tributaries in a watershed with a specific area (Sukiyah, 2017). Drainage density can be calculated based on the following equation:

$$\mathrm{Dd} = \sum \mathrm{L}/\mathrm{A} \quad \text{.........(3)}$$

where Dd =drainage density (km/km^2), L = cumulative river length (km) and A = basin area (km^2). The results obtained were then adjusted to the classification of drainage density by Soewarno (1991) as follows:

- <0.25 (Low). The rocks that the river flows through have stiff resistance so that the sediment transported is small.
- 0.25-10 (Medium). The rocks that the river flows through have a softer resistance so that the sediment transported is large.
- 10-25 (Height). The rocks that the river flows through have soft resistance so that the sediment transported is small.
- >25 (Very High). The river flows through impermeable rocks. The rainwater that becomes the flow will be more significant when compared to an area with low Dd passing through rocks with large permeability.

Next, perform calculations on the morphotectonic parameters. This parameter consists of the basin shape index (BS), Drainage basin asymmetry (AF), and the Mountain Front Sinousity (SMF).

Basin shape index (BS) is the ratio between the basin length (Bl) or the length of the watershed measured from the highest point with the basin width (Bw) or the width of the watershed measured from the widest point (Dehbozorgi et al., 2010). The calculation of the BS value is obtained from the following equation:

$$\mathrm{BS} = \mathrm{Bl}/\mathrm{Bw} \quad \text{.........(4)}$$

The classification of tectonic classes is made based on the BS value, where class 1 is class 1 (Bs≥4), class 2 (3≤Bs<4), and class 3 (Bs≤3) (El Hamdouni et al., 2007 in Dehbozorgi et al., 2010). Class 1 will have elongated BS values that interpret more active tectonics. In classes 2 and 3, the BS value will be more circular, interpreting tectonic activity to have slowed or stopped.

Drainage basin asymmetry (AF) is a quantitative analysis to calculate the tectonic slope on a small or wide scale in a watershed (Keller & Pinter, 2002). The AF value is calculated from the following equation:

$$\mathrm{AF} = \left(\frac{\mathrm{Ar}}{\mathrm{At}}\right) \mathrm{x}\ 100 \quad \text{.........(5)}$$

Where AF = asymmetry factor, Ar = area of the right side of the sub-watershed, At = area of the entire sub-watershed. If the AF value is greater or less than 50, then there is a tectonic slope. Furthermore, the tectonic class of the AF value is based on (El Hamdouni et al., 2007 in Dehbozorgi et al., 2010). Class 1 (AF 65 ≥ or AF <35) indicating a tilting due to tectonic activity, class 2 (35≤AF<43 or 57≤AF<65) indicating a little tilting due to tectonic activity, and class 3 (43≤AF<57) indicating no deformation due to tectonic influences.

The mountain front sinuosity is the ratio between the length of the mountain front (Lmf) and the length of the projection of the front of the mountain to the flat (Ls) (Bull and McFadden, 1977, in Doornkamp, 1986). The following equation can calculate the SMF value:

$$\mathrm{Smf} = \mathrm{Lmf}/\mathrm{Ls} \quad \text{.........(6)}$$

Where Lmf = the length of mountain front along the bottom/valley, Ls = the straight length of the mountain front.

Based on El Hamdouni et al. (2007) in Dehbozorgi et al. (2010), The tectonic classes from the SMF value are divided into three classes, namely class 1 (Smf<1.1), class 2 (1.1≤ Smf<1,5), and class 3 (Smf≥1,5). SMF class 1 indicates that tectonic activity dominates the mountain front formation, SMF class 2 indicates a balance of tectonic and erosional activities, and SMF class 3 indicates erosion activity

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dominates the mountain front formation. The calculated watershed morphometric and morphotectonic aspects were then compared to obtain tectonic activity in the study area.

RESULT AND DISCUSSION

Watershed Area and Length

From the results of studio analysis using a data processing application, it was found that the boundaries of the Cisokan watershed in the Cilengkong segment are divided into 15 sub-watersheds. The Cisukarama 1 segment is divided into ten sub-watershed, and the Cisukarama 2 segment is divided into ten sub-watershed. Based on the broad aspects of the calculation done on each segment in the Cisokan watershed, Cilengkong segment has an area of 7.75 km^2 with a total river length of 47.02 km. The Cisukarama 1 segment has an area of 5.25 Km^2 with a total river length of 32.14 Km. The Cisukarama 2 segment has an area of 4.7 km^2 with a total river length of 25.09 km. The value of the area and length of the river segment is needed to calculate and analyze the drainage density value (Dd) to support the broad aspect in determining the level of permeability and rock types.

Order and Level of Bifurcation Ratio

The stream order is one of the main variables to determine the bifurcation ratio. In this study, the method used to determine the stream order is the Strahler Method. Furthermore, the stream order is used to determine the bifurcation ratio. If the value of the bifurcation ratio is <3 and 5>, This indicates that the area is affected by tectonic activity, which causes the deformation process (Strahler, 1964; in Verstappen 1983).

According to their respective orders in the research area, the results of river classification can be seen in the stream Order Map (Figure 2). After performing studio measurements using software, the results can be seen in Table 1.

The Cilengkong segment from order 1 to order 4 has 103 river segments, and the bifurcation ratio of the Cilengkong segment has a value range of 4 to 4,5. The values obtained indicate that there is no deformation due to tectonic influences. The Cisukarama 1 segment from orders 1 to 4 has 93 river segments. The bifurcation ratio of the Cisukarama 1 segment has a value range of 4 to 4,25. The values obtained indicate that there is no deformation due to tectonic influences. In the Cisukarama 2 segment from orders 1 to 4 has 68 river segments. The bifurcation ratio of the Cisukarama 2 segment has a value range of 3 to 4.25. The values obtained indicate that there is no deformation due to tectonic influences.

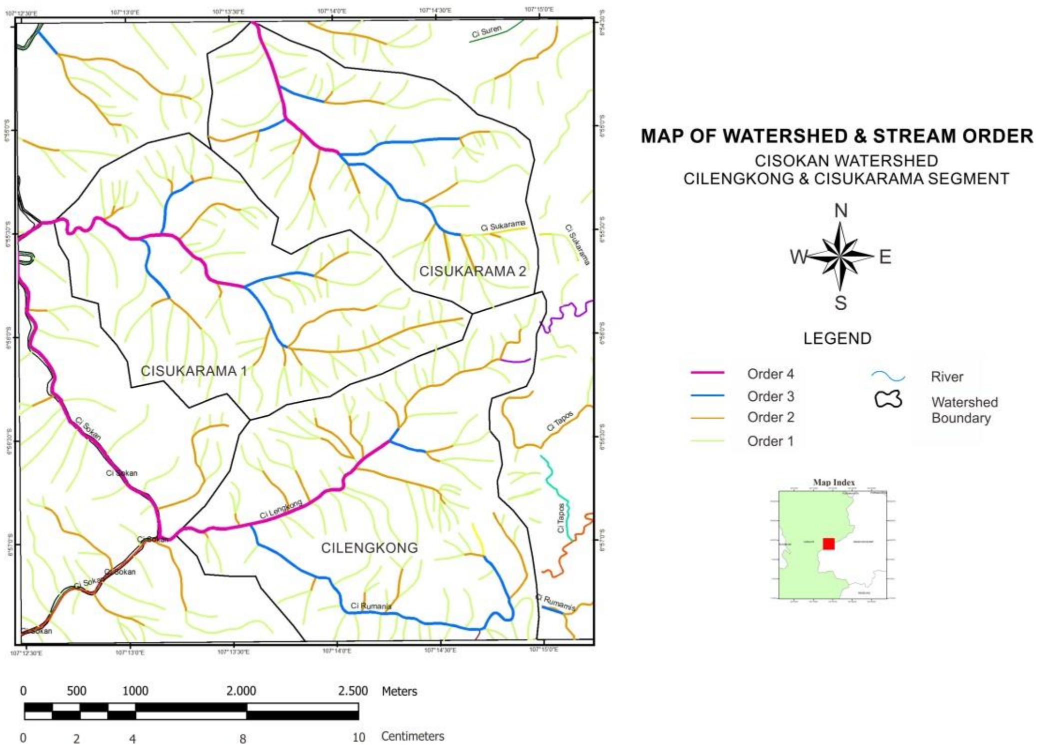

Figure 2. Map of the stream order of the research area

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Table 1. The value of the bifurcation ratio of the Cisokan sub-watershed

No	Sub-Watershed	Number of River Segments				Rb 1_2	Rb 2_3	Rb 3_4
		Order 1	Order 2	Order 3	Order 4			
1	Cilengkong	80	18	4	1	4.44	4.5	4
2	Cisukarama 1	71	17	4	1	4.17	4.25	4
3	Cisukarama 2	51	12	4	1	4.25	3	4

Drainage Density

From the analysis results of the calculation of the drainage density formula (Priyono and Savitri, 1997), the results obtained the Cilengkong segment show that the drainage density value is 6.07. The drainage density value is included in group of 0.25 - 10, so according to Soewarno (1991), indicates that in general, the river flows through rocks with medium to hard resistance, so that the intensity of the drainage density is not too dense or moderate.

In the Cisukarama 1 segment, the density value is 6.12. This value is classified as having a drainage density of 0.25-10, which includes a moderate drainage density (Soewarno, 1991). The medium drainage density level indicates that, in general, the river channel in the watershed passes through rocks with medium to stiff resistance so that the intensity of the drainage density is not too dense.

In the Cisukarama 2 segment, the drainage density value is 5.34. This value is classified as having a drainage density of 0.25-10, which includes a moderate drainage density (Soewarno, 1991). The medium drainage density level indicates that the river channel in the watershed passes through rocks with medium to stiff resistance so that the intensity of the drainage density is not too dense. The drainage density (Dd) values are attached in Table 2.

Table 2. Cisokan sub-watershed drainage density value

No	Sub-Watershed	Area (km^2)	Length (km)	Dd (km/km^2)
1	Cilengkong	7.75	47.02	6.07
2	Cisukarama 1	5.25	32.14	6.12
3	Cisukarama 2	4.7	25.09	5.34

Basin Shapes Index (BS)

Basin shape index is the ratio between basin length (Bl) and basin width (Bw) in each segment. The Basin shape index is used to determine the shape tendency of a watershed to determine tectonic activity. Identification of basin length and basin width can be seen in Figure 3.

From the analysis results, the Cilengkong segment has a basin length value of 3797 m and a basin width value of 2101 m, so that a BS value of 1.80 is obtained. This value is included in class 3, which indicates tectonic activity in the area has slowed or stopped so that the formation of the sub-watershed becomes circular.

The Cisukarama 1 segment has a basin length value of 3389 m and a basin width value of 2086 m, so that the BS value is 1.62. This value is included in class 3, which indicates tectonic activity in the area has slowed or stopped so that the formation of the sub-watershed becomes circular.

The Cisukarama 2 segment has a basin length value of 3921 m and a basin width value of 2463 m, so that the BS value is 1.59. This value is included in class 3, which indicates tectonic activity in the area has slowed or stopped so that the formation of the sub-watershed is getting circular

In general, the BS value in the Cisokan watershed is included in class 3 with a circular shape. The class interprets that tectonic activity in the study area tends to decrease or even stop.

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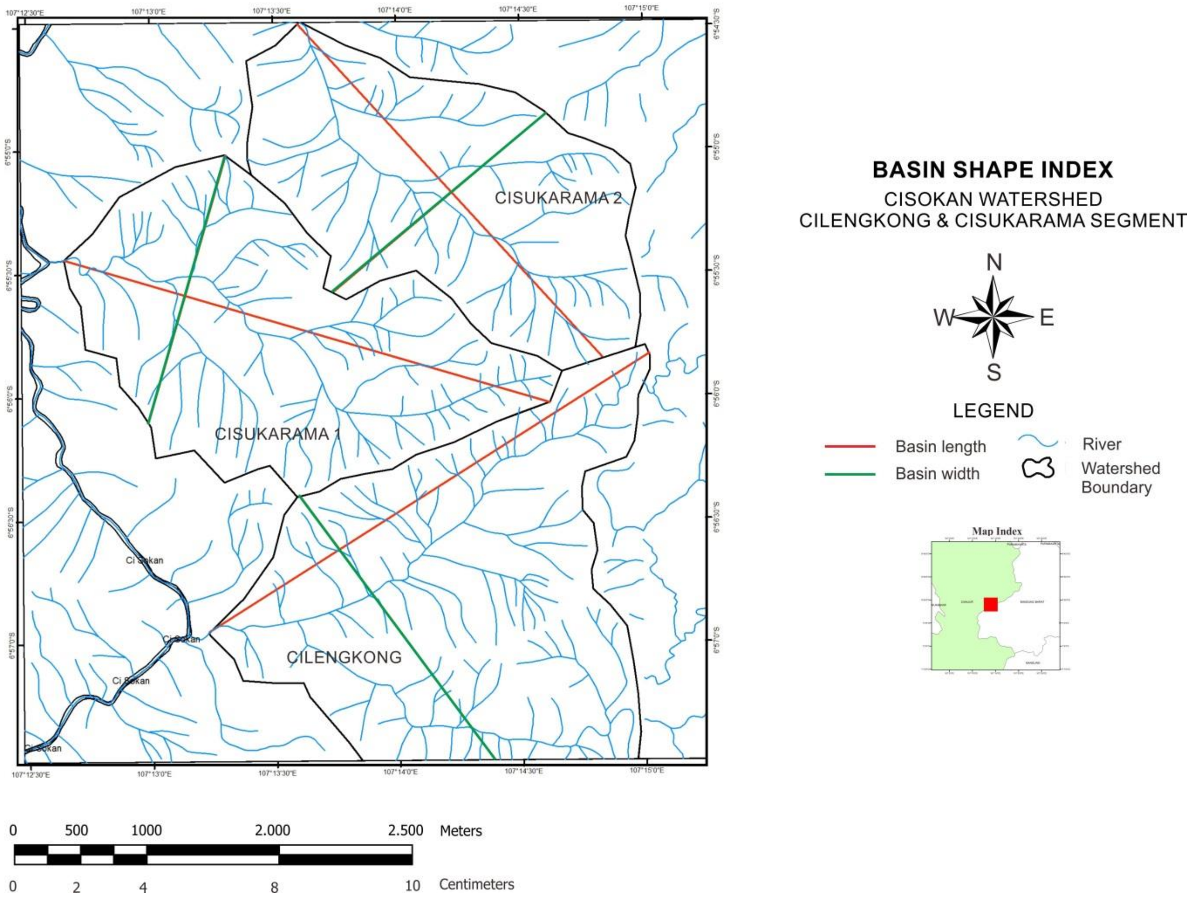

Figure 3. Map of the basin shape index of the research area

Drainage Basin Asymmetry (AF)

Drainage Basin Asymmetry is obtained based on the comparison between the area of the right side of the sub-watershed (Ar) and the sub-watershed (At) total area multiplied by 100. This calculation aims to determine the tectonic slope that occurs in the watershed. Af value is close to 50 if there is no or little tilting perpendicular to the direction of the master stream (El Hamdouni et al., 2007 in Dehbozorgi et al., 2010). Figure 4 shows the identification of drainage basin asymmetry (AF) in the study area.

The study results found that the Cilengkong segment has an Ar value of 2 Km^2 and an At value of 7.75 Km^2, so that the AF value is 25.8. This value is included in class 1, indicating a tilting due to tectonic activity in this segment.

The Cisukarama 1 segment has an Ar value of 3 Km^2 and an At value of 5.25 Km^2, so that the result is an AF value of 57.14. This value is included in class 2, indicating a little tilting due to tectonic activity in this segment.

The Cisukarama 2 segment has an Ar value of 2 Km^2 and an At value of 4.7 Km^2, so that the result is an AF value of 42.5. This value is included in class 2, indicating a little tilting due to tectonic activity in this segment.

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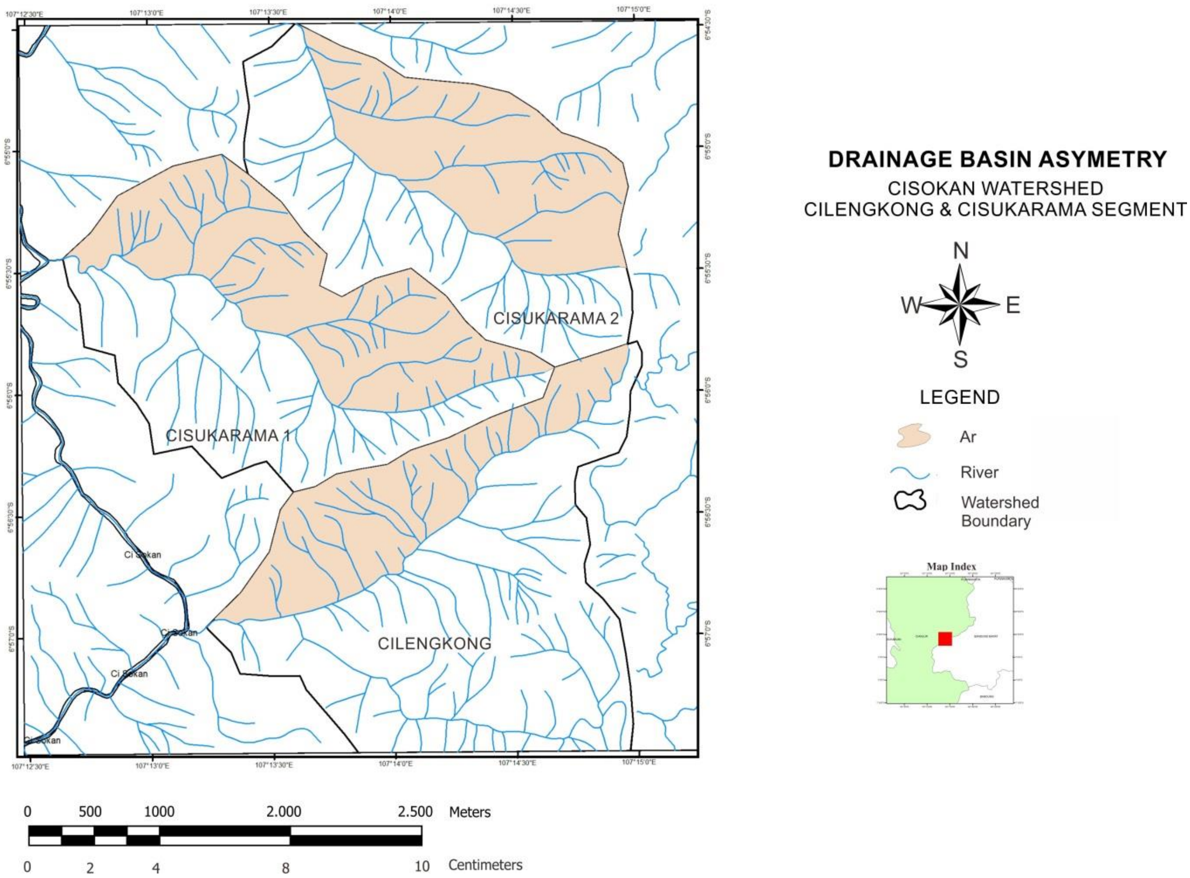

Figure 4. Map of the drainage basin asymmetry of the research area

Mountain Front Sinuosity (SMF)

Calculation of mountain front sinuosity (SMF) is carried out using a data processing application at a location shown in Figure 5. The data processing results are then categorized according to each class based on the classification of the degree of tectonic activity based on SMF (El Hamdouni dkk., 2007 dalam Dehbozorgi dkk., 2010).

The results of data processing in the research area can be seen in table 3. In the Cilengkong segment, the SMF values are 1.19 - 2.78, which are included in class 2 and 3. In the Cisukarama 1 segment, the SMF values are 1,66 - 3.41, which are included in class 3. Furthermore, the Cisukarama 2 segment has a value of 1.34 and 2.13, which are included in class 2 and 3. So from these results, it is found that the influence of erosion activity dominates the formation of the mountain front in the Cisokan watershed compared to tectonic activity.

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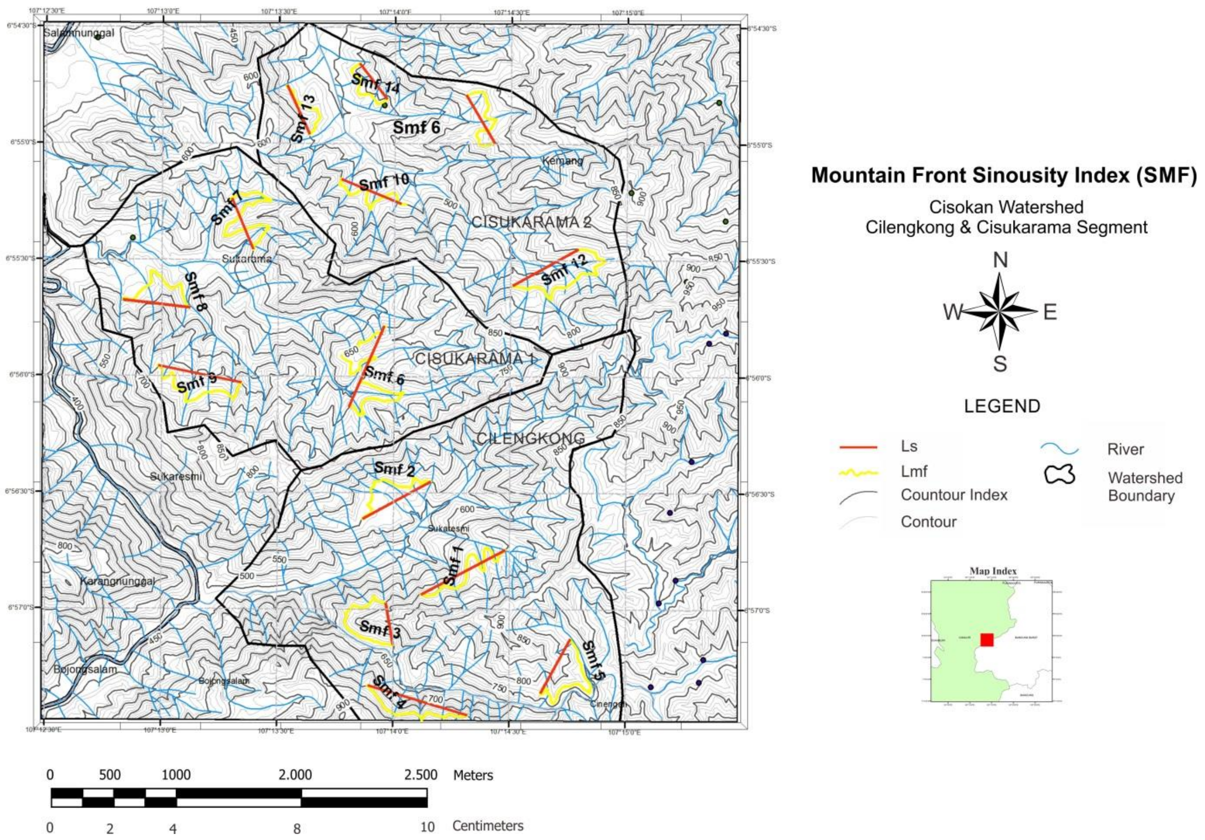

Figure 5. Map of Mountain Front Sinousity (SMF)

Table 3. Calculation of the mountain front sinuosity index

NO	Sub-Watershed	CODE	Lmf	Ls	Smf	Class
1	Cilengkong	Smf 1	1295,65	757,72	1,71	3
		Smf 2	950,82	620,95	1,53	3
		Smf 3	942,63	338,5	2,78	3
		Smf 4	1086,19	494,03	2,19	3
		Smf 5	992,9	828,8	1,19	2
2	Cisukarama 1	Smf 6	2222,96	700,1	3,18	3
		Smf 7	1504,14	441,24	3,41	3
		Smf 8	899,96	540,13	1,66	3
		Smf 9	1127	676,65	1,66	3
3	Cisukarama 2	Smf 10	923,34	514,92	1,79	3
		Smf 11	891,2	448,32	1,99	3
		Smf 12	1276,99	598,65	2,13	3
		Smf 13	581,58	431,59	1.34	2
		Smf 14	598,73	359,58	1.66	3

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CONCLUSION

Based on the morphometric and morphotectonic analysis carried out in this study, the research area is composed of rocks with moderate to stiff resistance from the value of drainage density so that the intensity of river density is not too dense. The bifurcation ratio in the Cisokan watershed shows no deformation due to tectonic influences. The basin shape index proves that in the Cisokan watershed, tectonic activity tends to decrease or even stop. It can be seen from the watershed, which tends to be circular. The asymmetry of the drainage basin indicates a little tilting due to tectonic activity in this segment. From the mountain front sinuosity, it can also be seen that the erosion activity in the Cisokan watershed dominates compared to tectonic activity.

The Regional geological map of the Cianjur sheet (Sudjatmiko, 2003) in the study area shows a relatively complex geological structure. However, the watershed morphotectonic analysis results do not show any symptoms of significant tectonic activity seen from the morphotectonic parameters and watershed morphometry. These results interpret that tectonic activity as a landscape-forming factor in the study area tends to decrease or even stop. This influence is replaced by erosion activity which is more dominant as a controlling factor for landforms in the study area. The geological structure in the study area has a NE-SW direction following the Meratus pattern formed during the subduction process in the Cretaceous period. Then the research area is covered by quaternary volcanic products, which tend to be unconsolidated. This makes the current geological structure less dominant and has been replaced by a high erosion process.

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