ANALYSIS OF TECTONIC CONTROL OF CIHEA AND KEMANG VILLAGE, HAWURWANGI AND BOJONGPICUNG SUBDISTRICT, CIANJUR REGENCY, WEST JAVA PROVINCE

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ABSTRACT

Quantitative geomorphological can be analyzed using watersheds morphometric aspect. Morphometry can be interpreted as a quantitative aspect of watersheds or parameters of watershed characteristics that can be measured and calculated. This research was shown to determine the tectonic control of the research area with the approach of the morphometric aspect of watershed. Aspect of watershed morphometry used in this research consist of river order and bifurcation ratio (Rb), drainage density (Dd), asymmetry factor (Af), mountain front sinuosity (Smf) and watershed shape index (Bs). The method used in this research is the studio method by processing Digital Elevation Model data using Arcmap software. Based on the results obtained, there are 4 sub-watersheds in the research area that have different calculation values. Sub-Watershed 1 has an Af value is (66,025), Smf value is (1.43 – 4.56), and Bs value is (1,002). Sub-Watershed 2 has an Af value is (51,398), Smf value is (1.38 – 3), and Bs value is (0.907). Sub-Watershed 3 has an Af value is (49,536), Smf value is (1.17 – 2.91), and Bs value is (0.933). Sub-Watershed 4 has an Af value is (60,407), Smf value is (1.8 – 3), and Bs value is (1,486). Based on all the calculation results, the relative tectonic activity index (IATR) value is 3 which belongs to class 4 which indicates low tectonic activity in the research area. This is also supported by the calculation of the bifurcation ratio where only a small part of the river segment is affected tectonics, meaning most of the others are not active tectonically.

Keywords: Watersheds, Morphometry of Watershed, Digital Elevation Model (DEM), Cihea Village, Cianjur Regency

INTRODUCTION

Geomorphology is the study of landforms and the processes that influence its formation and investigate the relationship between forms and processes in its spatial arrangement (Van Zuidam R. A. dan Cancelado, 1979). As it develops, geomorphology does not only cover a static field that only studies the forms of the earth's surface, but also includes dynamic science so that it can predict natural events as interpolation. The description of the earth's surface can be expressed by mathematical quantities known as quantitative geomorphology.

Quantitative geomorphology can be used to analyse a characteristic of the research area. Aspects of geomorphological analysis include morphography, morphometry and morphogenetics. Morphography is a descriptive geomorphological characteristic of an area, such as plains, highlands, hills, mountain, etc. Morphometry can be defined as the quantitative aspect of a landform (Van

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Zuidam, 1983). While morphogenetic includes processes that occur in an area (endogenous and exogenous), the lithology of an area, and tectonics.

Through morphometric analysis, quantitative geomorphological analysis can be done using the morphometric aspects of watersheds. Watershed is a term in geography about rivers and its tributaries and the areas they affect. Watershed morphometry can be defined as a quantitative aspect of a watershed or a watershed characteristic parameter that can be measured and calculated (Van Zuidam, 1983). Aspects of watershed morphometry are grouped into four categories according to Morisawa (1959), including aspects of length or size, aspects of area or shape, aspects of relief, and non-dimensional aspects. Aspects of watershed morphometry are commonly used as a method in an approach to analyze tectonic activity in an area.

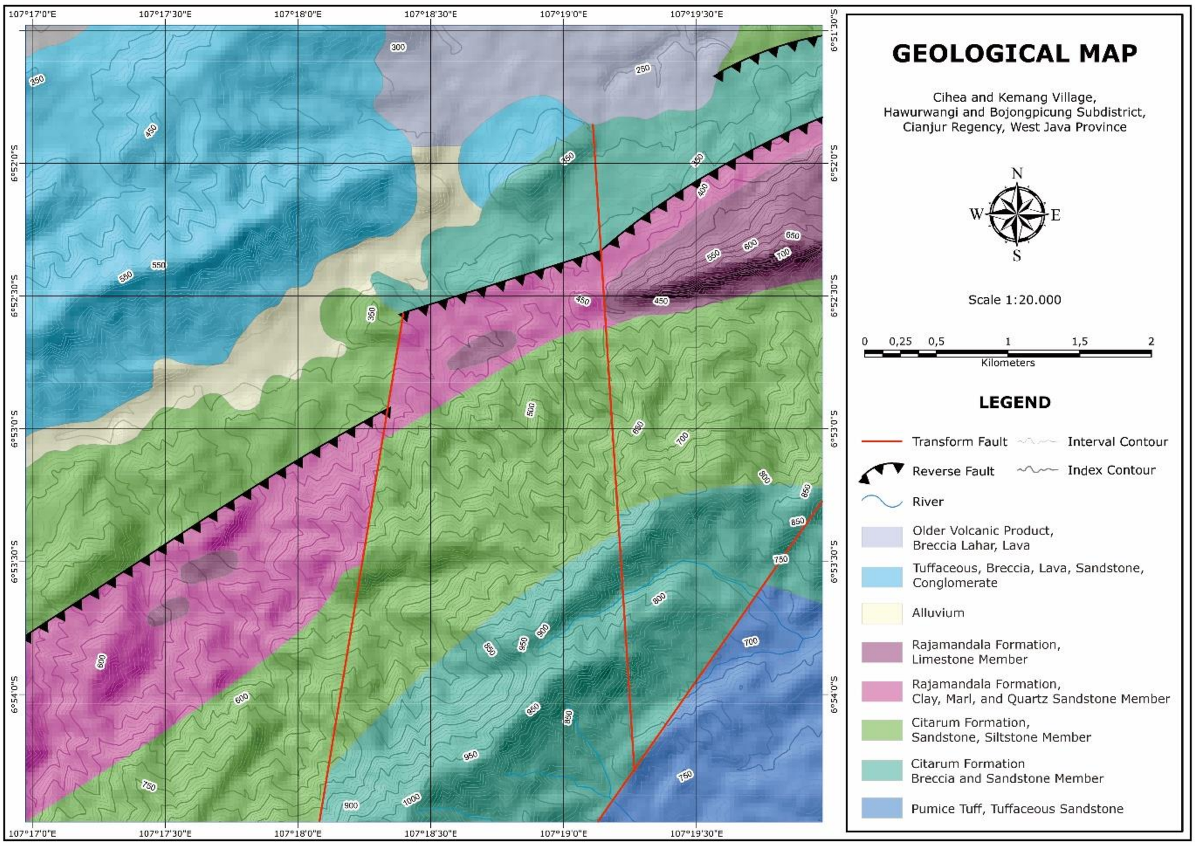

Figure 1. Geological Map of Research Area.

Administratively, the research area is located in Cihea Village, Kemang Village and its surroundings, Cianjur Regency, West Java. Geographically, the research area is 107°17'00" - 107°20'00" east longitude and 6°51'30" - 6°54'30" south latitude. Physiographically, the research area belongs to the Bandung Zone. Van Bemmelen (1949) in Martodojo (1984) states that the Bandung Zone is a depression among the mountains. Bandung zone is the peak of West Java geantiklin, then collapsed after the appointment on Late Tertiary. This low area is then filled with young volcanic deposits. In the Bandung Zone, there are several height consisting of old sediment deposits that pop up between volcanic deposits. In the research area there are several geological

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structures in the form of ascending faults in the northern regions and some horizontal faults in the southern part (Figure 1).

According to Boumman et al., (1973), western Java was influenced by 4 tectonic phases namely: Oligocene – Early Miocene Phase, Middle Miocene Phase, Pliocene Phase – Pleistocene and Quarter Phase. Regionally, geological structures in the research area are interpreted to be formed in the tertiary tectonic phase. It is the cause of the occurrence of some wrench faults directed northeast – southwest and cut the existing structures

This study is intended to determine tectonic activity in the research area through an approach from aspect of watershed morphometry, in the form of calculating the river order and bifurcation ratio (Rb), drainage density (Dd), asymmetry factor (Af), mountain front sinuosity (Smf) and watershed shape index (Bs).

METHODOLOGY

The research method in this research is uses studio analysis methods with the ArcMap software to process watershed morphometric data that are obtained from the results of Digital Elevation Model (DEM) data processing. The calculation result of watershed morphometry aspect be used to indicate the presence of tectonic control in the study area.

Bifurcation Ratio (Rb)

Determination of the bifurcation ratio will refer to the theory according to Soewarno (1991) and Strahler (1964) in Verstapppen (1983). The calculation of the bifurcation ratio (Rb) can be done in the following calculations:

$$R_b = \frac{N_u}{N_{u+1}}$$

Where:

Rb = Bifurcation Ratio

Nu = Number of Stream for Order-u

Nu+1 = Number of Stream for Order-u+1

From the results of calculations using the above formula, later the results of the calculation of bifurcation ratio will be aligned into the table below:

Table 1. Bifurcation Ratio Analysis According to Soewarno (1991) and Strahler (1964) in Verstappen (1983).

No.	Rb	**Description** (Soewarno, 1991)	**Description** (Strahler, 1964) **in** (Verstappen, 1983)
1.	< 3	The rise in flood water levels is rapid, while the decline is rapid.	If Rb<3 or Rb>5 then the watershed is not normal, possibly controlled by an active fault.
2.	3 – 5	The increase in flood water level is not too fast, while the decrease is not too fast (moderate).	
3.	> 5	The rise in flood water levels is rapid, while the decline is slow.	

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Drainage Density (Dd)

According to Horton (1945), drainage density (Dd) is the distance between a river in a watershed or sub-watershed and formulated as a comparison between the total of lengths of river segments with the area of watersheds or sub-watersheds. Drainage density indicates cutting the watershed into hillside branches by the river flow. Drainage density is also an index number that shows the number of tributaries in a watershed. The dainage density value of the river can be obtained in the following calculations:

$$Dd = \frac{\sum L}{A}$$

Where:

D_d = Drainage Density Index

A = Watershed Area

L = River Length Segment

According to Soewarrno (1991), the classification of drainage density is divided into 4 categories in the table below:

Table 2. Drainage Density Index Classification According to Soewarrno (1991).

Drainage Density Index	Assessment	Description
<0,25	Low	If the Dd value is low then the flow of river passes through the rocks with hard resistance so that the sediment transport that is carried by the river flow is smaller
0,25 – 10	Medium	
10 – 25	High	If the Dd value is very high then the river flow passes through watertight rocks. This state indicated that the rainwater that becomes the flow will be greater.
>25	Very High	

Asymmetry Factor (Af)

Asymmetry factor is a way to determine the tilting of tectonic in units of watersheds. According to Keller et al., (1996) the value of asymmetry factor (Af) can be calculated using the formula:

$$Af = \frac{A_r}{A_t} x100$$

Where:

Af = Asymmetry Factor

A_r = Right Side Area from Watershed

A_t = Watershed Area

According to Keller et al., (1996) if the value obtained by asymmetry factor is 50, then the area is relatively stable, meaning that the tectonic process that works is very small. If the value of asymmetry factor is greater than or less than 50, there is a tilting due to tectonic. According to Dehborzogi et al., (2010) the tectonic class based on the value Af is divided into three classes, the table below:

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Table 3. Asymmetry Factor Classification According to Dehborzogi et al., (2010).

Class	Asymmetry Factor (Af)	Description
Class 1	Af ≥ 65 or Af < 35	Active Tectonic Activity
Class 2	35 ≤ Af < 43 atau 57 ≤ Af < 65	Less Tectonic Activity
Class 3	43 ≤ Af < 57	Inactive Tectonic Activity

Mountain-Front Sinuosity (Smf)

The mountain front sinuosity is a comparison between the value of the length of the mountain-front and the value of the straightline length of the mountain-front segment. Dehborzogi et al., (2010), divide the classification of tectonic classes based on the value of mountain-front sinuosity, the table below:

Table 4. Mountaon-Front Sinuosity Classification According to Dehborzogi et al., (2010).

Class	Mountain-Front Sinuosity (Smf)	Description
Class 1	Smf < 1,1	Active Tectonic Activity
Class 2	1,1 ≤ Smf < 1,5	Less Tectonic Activity
Class 3	Smf ≥ 1,5	Inactive Tectonic Activity

In simple terms, landscapes that are still affected by active tectonics will have a lower index of mountain-front sinuosity and vice versa. Smf values can be calculated using the formula:

$$Smf = \frac{Lmf}{Ls}$$

where:

Smf = Mountain-Front Sinuosity

Lmf = Length of Mountain-Front

Ls = Straight Length of Mountain-Front Segment

Watershed Shape Index (Bs)

Watershed shape index is a comparison between the long axis of a watershed measured from the longest point and the wide axis of a watershed measured from the widest (Dehbozorgi, et al., 2010). The watershed shape index will be elongated if the area have more active tectonic and will be rounded after the tectonic process slows down or stops. The calculation of the watershed shape index value can be calculated by the formula:

$$Bs = \frac{B_l}{B_w}$$

where:

Bs = Watershed Shape Index

B_l = Watershed Length Axis

B_w = Watershed Width Axis

The mountain-front sinuosity is divided into three classes, the table below:

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Table 5. Watershed Shape Index Classification According to Dehborzogi et al., (2010).

Class	Watershed Shape Index (Bs)	Description
Class 1	Bs ≥ 4	Active Tectonic Activity
Class 2	3 ≤ Bs < 4	Less Tectonic Activity
Class 3	Bs < 3	Inactive Tectonic Activity

Relative Tectonic Activity Index (IATR)

Relative Tectonic Activity Index (IATR) is a classification that is done by dividing the total of classes of watershed morphometry parameters by the total of parameters used. The method used in this study is a modification of Dehbozorgi et al., (2010) which divides tectonic classes using six morphometric parameters, namely: Hi, Af, SL, Bs, Vf, and Smf. The division of tectonic classes in this research area uses the morphometry parameters Af, Smf, and Bs. Furthermore, each parameter of the morphometry of the watershed is summed up according to its class and then devided with the total of parameters used. Furthermore, the division of class of Relative Tectonic Activity Index (IATR) based on IATR values from the three parameters of watershed morphometry. According to El Hamdouni et al., (2007) in Dehbozorgi et al., (2010), tectonic activity classes based on IATR values are divided into four in the table below:

Table 6. Relative Tectonic Activity Index Values According to El Hamdouni et al., (2007) in Dehbozorgi et al., (2010).

Class	Relative Tectonic Activity Index Values (IATR)	Description
Class 1	1 ≤ IATR < 1,5	Very High Tectonic Activity
Class 2	1,5 ≤ IATR < 2.	High Tectonic Activity
Class 3	2 ≤ IATR < 2,5.	Medium Tectonic Activity
Class 4	IATR ≥ 2,5	Low Tectonic Activity

RESULT AND DISCUSSION

From the data processing of digital elevation model (DEM), in the research area divided into 4 sub-watersheds with the largest sub-watershed area is 19,447 km^2 and sub-watershed with the smallest area is 1,609 km^2.

Bifurcation Ratio (Rb)

In calculating the bifurcation ratio, the river order must be determined first. Map of the river order and the result of calculation bifurcation ratio can be seen in (Figure 2) and (Table 3).

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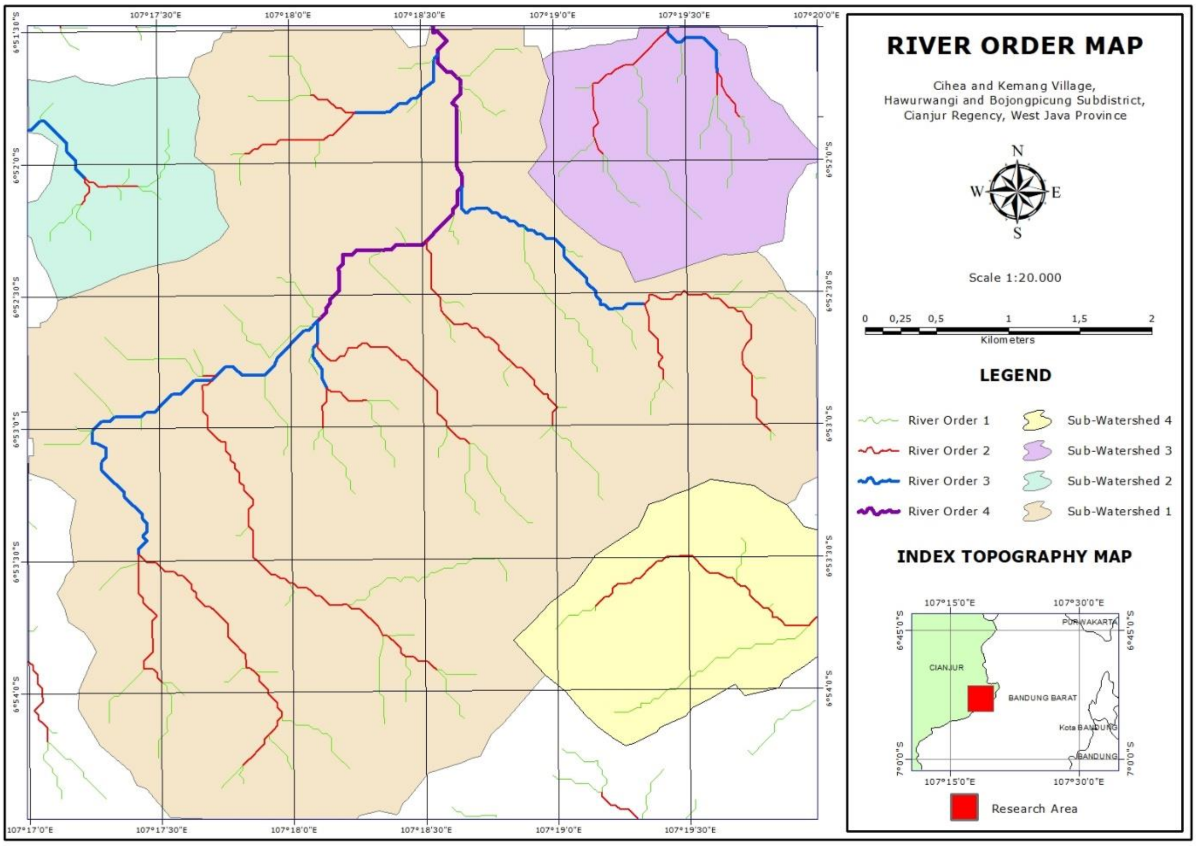

Figure 2. River Order Map of Research Area.

Table 7. Calculation of Bifurcation Ratio of Research Area.

Watersheds	Number of River Segment				Rb_{1-2}	Rb_{2-3}	Rb_{3-4}
	Order 1	Order 2	Order 3	Order 4			
Sub-Watershed 1	64	12	4	1	5,33	3	4
Sub-Watershed 2	7	2	1	-	3,5	2	-
Sub-Watershed 3	10	3	1	-	3,33	3	-
Sub-Watershed 4	5	1	-	-	5	-	-

Based on the results of the calculation of bifurcation ratio, the result show that Sub-Watershed 1 has 81 segments of rivers, Sub-Watershed 2 has 10 segments of rivers, Sub-Watershed 3 has 14 segments of rivers, Sub-Watershed 4 has 6 segments of rivers. Based on the bifurcation ratio calculation, it can be identified that most of the research area is not dominated by active tectonic. Active tectonic only affects a small segment of the entire research area because overall, the

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research area dominated by range of Rb value is 3 – 5.

Drainage Density (Dd)

Based on the results of the calculation of drainage density, the result of drainage density value ranged from 1,741 to 2,605. According to the Soewarno (1991) classification, the drainage density value of the entire sub-watershed is included in the medium density class that characterizes the flow of the river through the rocks with softer resistance, resulting in greater transported sediment.

Table 8. Calculating of Drainage Density of Research Area.

Parameters	Watersheds			
	Sub-Watershed 1	**Sub-Watershed 2**	**Sub-Watershed 3**	**Sub-Watershed 4**
Length of River Segment (km)	46,042	3,109	6,464	4,385
Watershed Area (km^2)	19,447	1,609	2,481	2,503
Drainage Density Value	**2,367**	**1,932**	**2,605**	**1,741**

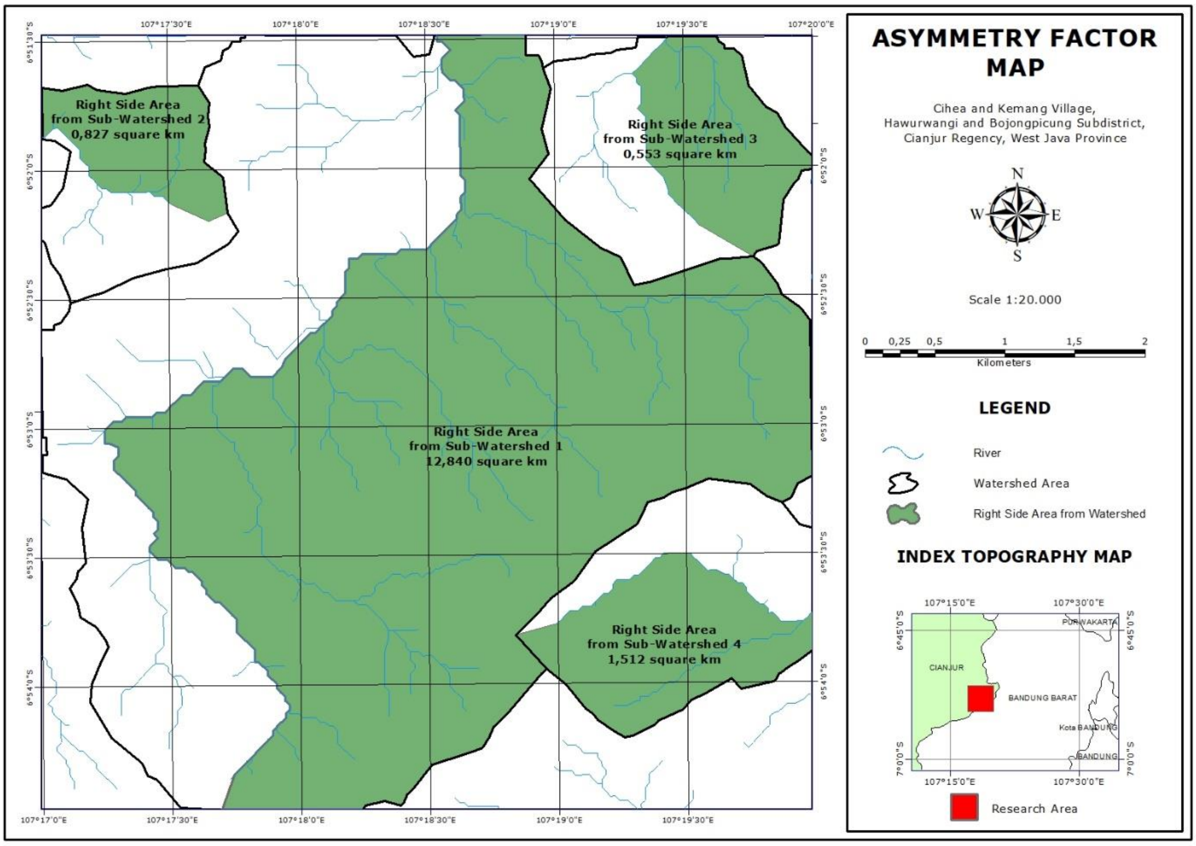

Figure 3. Asymmetry Factor Map of Research Area.

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Asymmetry Factor (Af)

Based on the results of calculations done on 4 sub-watersheds located in the research area, each sub-watershed has the following asymmetry factor values: sub-Watershed 1 (66,025), sub-watershed 2 (51,398), sub-watershed 3 (49,536) and sub-watershed 4 (60,407). Sub-Watershed 1 belongs to class 1 and Sub-Watershed 4 belongs to class 2. From the data that has been processed, sub-Watershed 1 and sub-Watershed 4 are indicated to be active tectonic controlled. It is known that the Af value generally obtained has a value of less than 50 and more than 50, then according to Keller et al., (1996) the research area has occurred tectonic tilting. However, to determine whether or not tectonic is active, classification is used according to Dehbozorgi et al., (2010) in general the research area is included in Class 3 with a value of Af (43 ≤ Af < 57), it can be identified that the research area is not dominated by active tectonic.

Mountain-Front Sinuosity (Smf)

The value of mountain-front sinuosity calculation is performed on 53 mountain-front. Based on the calculation results, smf values are obtained as follows: Sub-Watershed 1 (1,43 – 4,56), Sub-Watershed 2 (1,38 – 3), Sub-Watershed 3 (1,17 – 2,91) and Sub-Watershed 4 (1,8 – 3). Overall, the dominance of smf value obtained more than 1.5. Based on the classification of Degbozorgi et al., (2010), tectonic activity has not affected the research area because the research area belongs to class 3 with a value of smf ≥ 1.5.

Table 9. Calculating of Mountain-Front Sinuosity of Research Area.

Sub-Watershed		Lmf	Ls	Smf
Sub-Watershed 1	Smf 1	0,47	0,25	1,88
	Smf 2	0,64	0,19	3,37
	Smf 3	0,31	0,16	1,94
	Smf 4	0,35	0,17	2,06
	Smf 5	0,55	0,14	3,93
	Smf 6	0,83	0,33	2,52
	Smf 7	0,3	0,13	2,31
	Smf 8	0,54	0,19	2,84
	Smf 9	0,88	0,24	3,67
	Smf 10	1	0,28	3,57
	Smf 11	0,48	0,21	2,29
	Smf 12	0,92	0,39	2,36
	Smf 13	0,91	0,33	2,76
	Smf 14	0,67	0,32	2,09
	Smf 15	0,77	0,22	3,50
	Smf 16	0,71	0,19	3,74
	Smf 17	0,53	0,25	2,12
	Smf 18	0,43	0,23	1,87
	Smf 19	0,58	0,22	2,64
	Smf 20	0,47	0,24	1,96
	Smf 21	0,53	0,17	3,12
	Smf 22	0,62	0,32	1,94
	Smf 23	0,37	0,23	1,61
	Smf 24	0,36	0,19	1,89
	Smf 25	0,46	0,19	2,42
	Smf 26	0,54	0,33	1,64
	Smf 27	0,33	0,13	2,54
	Smf 28	0,82	0,18	4,56
	Smf 29	0,45	0,27	1,67

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	Smf 30	0,43	0,24	1,79
	Smf 31	0,33	0,23	1,43
	Smf 32	0,54	0,37	1,46
	Smf 33	0,4	0,24	1,67
	Smf 34	0,63	0,29	2,17
	Smf 35	0,72	0,25	2,88
	Smf 36	0,47	0,29	1,62
Sub-Watershed 2	Smf 37	0,46	0,27	1,70
	Smf 38	0,36	0,19	1,89
	Smf 39	0,26	0,18	1,44
	Smf 40	0,42	0,14	3,00
	Smf 41	0,29	0,21	1,38
Sub-	Smf 42	0,45	0,29	1,55
Watershed 3	Smf 43	0,47	0,4	1,18
	Smf 44	0,35	0,12	2,92
	Smf 45	0,39	0,32	1,22
	Smf 46	0,32	0,26	1,23
Sub-Watershed 4	Smf 47	0,27	0,15	1,80
	Smf 48	0,37	0,2	1,85
	Smf 49	0,33	0,13	2,54
	Smf 50	0,48	0,25	1,92
	Smf 51	0,97	0,4	2,43
	Smf 52	0,54	0,18	3,00
	Smf 53	0,59	0,26	2,27

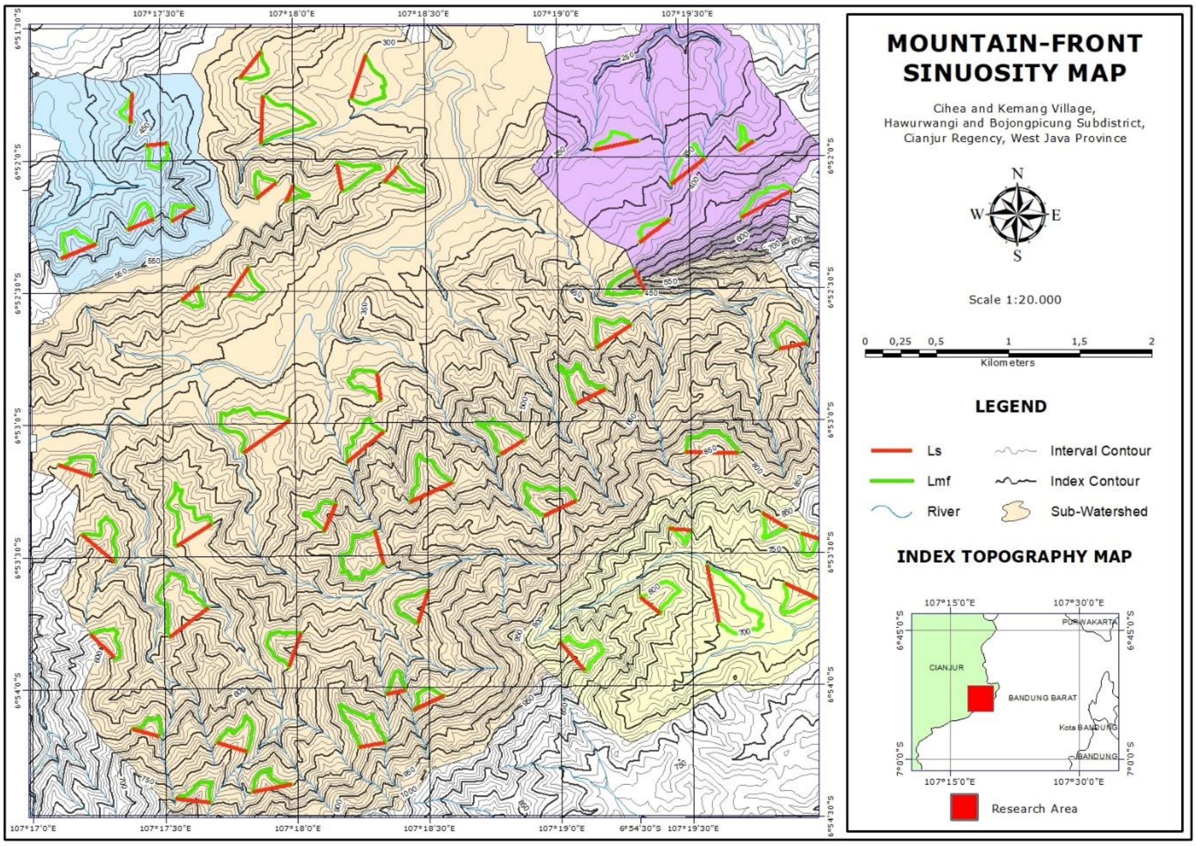

Figure 4. Mountain-Front Sinuosity Map of Research Area.

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Watershed Shape Index (Bs)

Based on the calculation results, the watershed shape index value of the research area form is as follows: Sub-Watershed 1 (1,002), Sub-Watershed 2 (0,907), Sub-Watershed 3 (0,933) and Sub-Watershed 4 (1,486). According to the classification of Dehbozorgi et al., (2010) all sub-watersheds included to class 3 which has the value is < 3 which indicates tectonic processes slowing down or stopping so that the sub-watershed form is increasingly rounded.

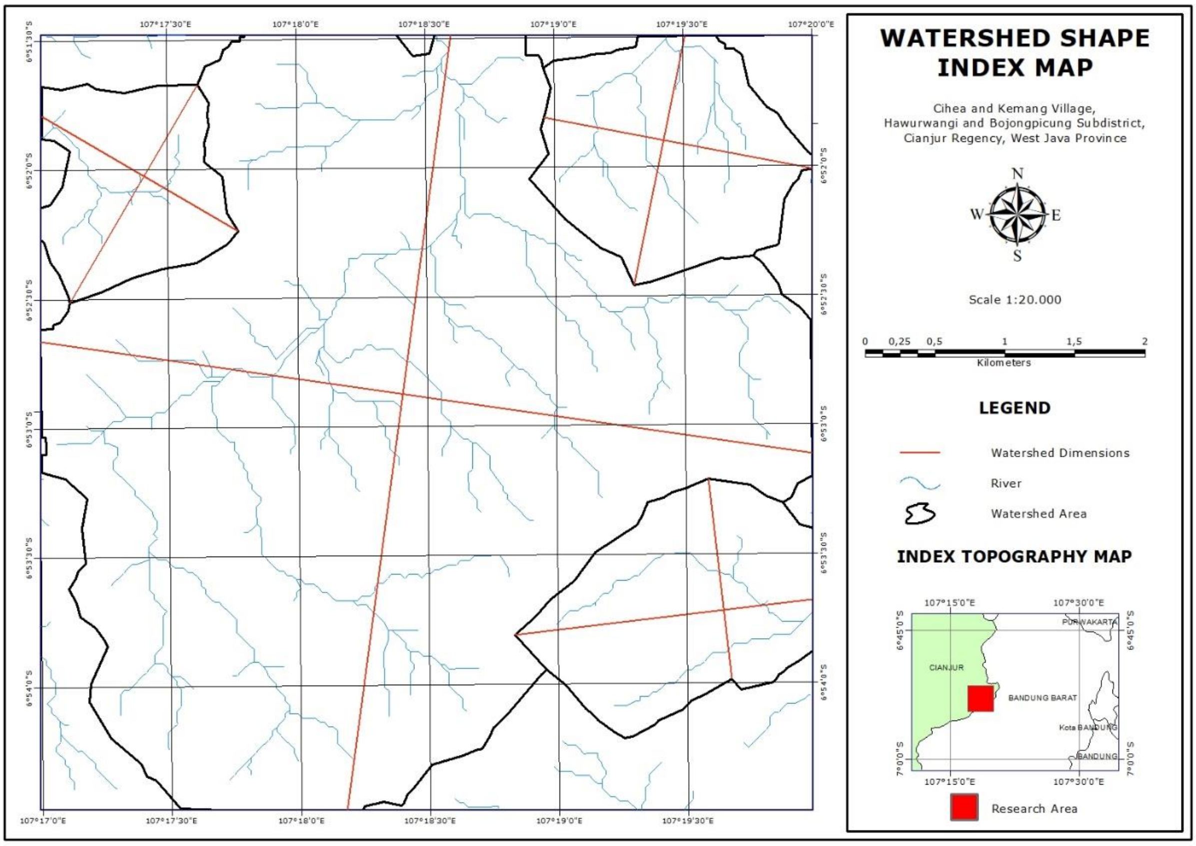

Figure 5. Watershed Shape Index Map of Research Area.

Table 10. Calculating of Watershed Shape Index of Research Area.

Parameters	Watersheds			
	Sub-Watershed 1	**Sub-Watershed 2**	**Sub-Watershed 3**	**Sub-Watershed 4**
Watershed Length Axis (km)	5,580	1,635	1,824	2,137
Watershed Width Axis (km)	5,565	1,801	1,953	1,438
Watershed Shape Index Value	**1,002**	**0,907**	**0,933**	**1,486**

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Relative Tectonic Activity Index (IATR)

The results of watershed morphometry analysis using five parameters, namely: bifurcation ratio (Rb), drainage density (Dd), asymmetry factors (Af), mountain-front sinuosity (Smf), and watershed shape index (Bs). Three of these parameters (Af, Smf and Bs) have been grouped into three tectonic classes, namely: Class 1, Class 2, and Class 3. Analysis of tectonic activity in the research area using accumulated morphometric parameters based on watershed analysis, namely Af, Smf, and Bs. The calculation below:

$$IATR = \frac{\sum Class\ of\ each\ parameter}{\sum Parameter\ is\ used}$$

$$IATR = \frac{Class\ 3(Af) + Class\ 3\ (Smf) + Class\ 3(Bs)}{3\ (Af, Smf\ and\ Bs)}$$

$$IATR = \frac{9}{3}$$

$$IATR\ Value = 3$$

Based on the results of classification according to El Hamdouni et al., (2007) in Dehbozorgi et al., (2010) in the research area included in class 4 with IATR value is 3. This indicates that in the research area included in the area with low tectonic activity or tectonic activity has stopped.

CONCLUSION

Based on the result, regionally the research area belongs to the Bandung Zone. In the research area there are several geological structures in the form of reverse fault and transform faults located in the northern and southern parts of the research area. Based on the results obtained, the research area is an area with inactive tectonic activity. Tectonics are not actively interpreted that the geological structure in the research area is formed from tertiary tectonic results, so that in the present, the structure in the research area has been covered by quaternary volcanic material, so that the process that plays a more role in the process of landform is the process of weathering and erosion.

This is evidenced by several quantitative analysis results including bifurcation ratio, drainage density, asymmetry factor, mountain-front sinuosity, and watershed shape index.

From the calculation of asymmetry factors in the research area, results were obtained in the form of Sub-Watershed 1 (66,025), Sub-Watershed 2 (51,398), Sub-Watershed 3 (49,536) and Sub-Watershed 4 (60,407). From the dominance of the value of asymmetry factors obtained, the research area is an area that is not active tectonically. The asymmetry factor value is still not far from the number 50 and may indicate that the sub-watershed in the area is still relatively symmetrical so as to indicate low tectonic activity.

Based on the calculation of mountain-front sinuosity obtained the value of Sub-Watershed 1 (1.43 – 4.56), Sub-Watershed 2 (1.38 – 3), Sub-Watershed 3 (1.17 – 2.91) and Sub-Watershed 4 (1.8 – 3). From the dominance of the value of mountain-front sinuosity obtained, most obtained a value of > 1.5 which may indicate that the tectonic activity of the research area tends to be inactive. While from the calculation of watershed shape index, it can be seen that the sub-watershed form in the research area

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tends to be rounded which also indicates low tectonic activity or has stopped.

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