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Quantitative Geomorphology Approach in the Assessment of Relative Tectonic Activity in Cikandang Watershed, South West Java

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Abstract: Cikandang Watershed in Cisewu Block, South West Java, is an area with significant tectonic activity that is reflected in geomorphological characteristics. This study aims to evaluate the relative tectonic activity in the Cikandang watershed using a quantitative geomorphological approach. Research methods involved six morphotectonic parameters: Valley Height-Width Ratio (Vf), Mountain Face Sinusity (Smf), Basin Shape Index (Bs), Asymmetry Factor (Af), Integral Hypsometry (Hi), and River Length Gradient Index (SL). These parameters were analysed to determine the Index of Relative Tectonic Activity (IATR) in 45 3rd-order catchments. Results showed variations in the level of tectonic activity in the Cikandang watershed. Based on the Index of Relative Tectonic Activity (IATR) value, 6 catchments belong to the high tectonic class, 34 catchments are in the medium tectonic class, and 5 catchments are in the low tectonic class. Analysis results indicate the presence of intensive tectonic deformation. These distributions reflect the significant influence of 'moderate' tectonic activity which is also indicated by the role of erosional processes in shaping the geomorphology of the Cikandang watershed. Morphotectonic features such as V-shaped valleys and irregular drainage patterns support the indication of tectonic activity. This research provides an overview of the influence of tectonic activity on geomorphological development in the Cikandang watershed.

Keywords: cikandang watershed; index of active tectonic relative; morphotectonics; quantitative geomorphology

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Introduction

Indonesia is one of the countries with the highest tectonic activity in the world due to its location in the convergence zone of three major plates: Indo-Australian, Eurasian and Pacific (Verstappen, 2010). This tectonic activity not only shapes complex surface morphologies, but also increases the risk of geological disasters such as earthquakes and landslides (Wu and Hu, 2019). The South West Java area, particularly the Cikandang watershed in the Cisewu Block, has significant tectonic potential due to its proximity to the subduction zone of the Indo-Australian Plate beneath the Eurasian Plate.

Tectonic geomorphological study is one of the main approaches used to understand tectonic dynamics through landform analysis. Geomorphic indices can be used to identify the level of tectonic deformation in a region (Keller & Pinter, 2002). Through a quantitative approach, this research integrates these parameters to evaluate the relative tectonic activity in the Cikandang watershed.

Evaluation of tectonic activity using a quantitative approach offers the advantage of identifying areas vulnerable to deformation. Previous research has shown that a combination of geomorphic parameters can provide a more accurate picture of tectonic activity than a qualitative approach on its own (El Hamdouni et al., 2008).

This study is meant to evaluate the relative level of tectonic activity in the Cikandang watershed using six morphotectonic parameters, which are: Smf, Vf, Bs, Af, HI, and SL (Dehbozorgi et al., 2010; El Hamdouni et al., 2008). The results of this study are expected to not only provide an understanding of the tectonic dynamics in the Cikandang watershed, but also contribute to geological disaster mitigation and regional development planning based on quantitative geomorphological analysis. Thus, this research provides a scientific basis for sustainable regional management.

The geological setting of the Cikandang watershed (Table 1) is shown in the geological map (Figure 1) which illustrates some of the main geological units in the study area. Each unit represents different rock types and formations from the oldest (Late Miocene) to the youngest (Holocene):

Table 1. Geological setting of the Cikandang watershed and age of rocks in the study area

No.	Formation	Geological Age	Description
1	Tmpb - Bentang Formation	Late Miocene	Sedimentary rocks of tuffaceous sandstone, pumice tuff, mudstone, conglomerate and lignite
2	Tpv - Tuffaceous Breccia	Pliocene	Breccia, tuff and sandstone
3	QTv - Old Undecomposed Volcanic Rocks	Pleistocene	Tuff, tuff breccia and lava
4	Qgpk - Mount Guntur-Gunung Pangkalan and Mount Kendang Volcanic Rocks	Pleistocene	Loose rocks and lava composed of andesite-basalt, sourced from the old volcanic complex of Mount Guntur-Gunung Pangkalan and Mount Kendan
5	Qopu - Loose Spice Deposits from Old Undecomposed Volcanics	Pleistocene	Fine-coarse dacite crystal tuff, pumice-bearing tuff breccia and andesite-basalt old lava deposits
6	Qyp - Younger Volcanic Rocks	Holocene	Efflata and lava flows composed of andesite-basalt; the source of Mount Papandayan

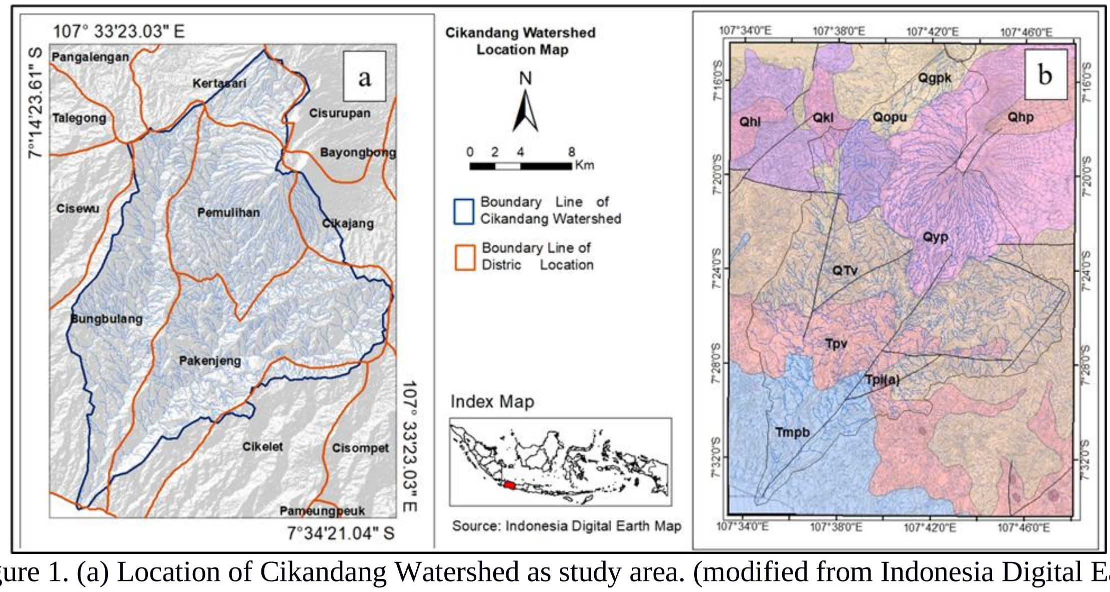

Figure 1. (a) Location of Cikandang Watershed as study area. (modified from Indonesia Digital Earth Map/Peta Rupa Bumi Indonesia (RBI) and (b). regional geological map of the research area (modified from Garut and surrounding area geological map by Alzwar & Akbar, 1992)

Data and Method

Among the techniques for examining tectonically active regions that can provide information on relatively high levels of active tectonic deformation are geomorphological indices (Bull and McFadden, 1977; Keller and Pinter, 2002; El Hamdouni et al., 2008). Six geomorphological parameters were used in this study, namely: Mountain Face Sinusity (Smf), Ratio between valley floor width and height (Vf), Basin Shape Index (Bs), Asymmetry Factor (Af), Hypsometric Integral (HI), and River Length Gradient Index (SL). By utilising digital images from DEMNAS, 1:25,000 scale topographic map from Rupa Bumi Indonesia (RBI) Digital map (Figure 2), and 1:100,000 scale regional geological map of Garut sheet (Alzwar & Akbar, 1992), measurements of various morphometric parameters were conducted using Geographic Information System (GIS) technology. Data processing was conducted at the Geomorphology and Remote Sensing Laboratory, Geological Engineering, Unpad Jatinangor Campus using Arc GIS 10.8 software.

Mountain Front Sinuosity (Smf)

Mountain front sinuosity is an index that reflects the balance between erosional forces that tend to cut and form depressions on the face of the ridge with tectonic forces that tend to create a straight mountain face shape. The Smf value is obtained from the ratio between the Lmf and Ls values, where Smf is the mountain front sinuosity index, Lmf is the length of the mountain face, and Ls is the perpendicular line of the mountain front. Mountain Front Sinuosity (Smf) can be calculated using the following equation (Doornkamp, 1986; Sukiyah et al., 2023):

$$Smf = Lmf / Ls \tag{1}$$

where:
Smf = Mountain front sinuosity
Lmf = Length of the curve of the mountain front segment (km)
Ls = Straight line length of mountain front segment (km)

Mountain front sinuosity (Smf) is one of quantitative analyses that reflects the balance between erosional forces that tend to cut through to form depressions in the ridge face (Keller and Pinter, 2002; Sukiyah et al., 2018). Low values of Smf are associated with active tectonics and direct uplift. As the velocity decreases, the erosion process will cut the mountain face irregularly and the Smf value will increase. Mountain front sinuosity values are associated with active fault zones. A small mountain-front sinuosity value indicates an association with active tectonics and direct uplift. In contrast, an increase in the mountain front sinuosity value indicates an erosional process that cuts the mountain front, resulting in an irregular mountain shape (Keller and Pinter, 2002; Sukiyah et al., 2015).

Ratio of valley floor width to valley height (Vf)

Ratio of valley floor width to valley height (Vf) indicates the degree of uplift of an area, which can be observed through the shape of river valleys, which tend to be either wide (U) or narrow (V). It measures the value of the ratio between valley width and height in an area (Keller & Pinter, 2002). The ratio of valley floor width to valley height (Vf) can be calculated using the following equation:

$$Vf = 2\ Vfw\ (Eld - Esc) + (Erd - Esc) \tag{2}$$

where:
Vfw = Valley floor width
Eld = Elevation of the left and
Erd = Elevation of the right side of the valley
Esc = Valley floor elevation

A high Vf value is associated with a low rate of uplift, causing the river to erode the valley floor laterally and form a wider valley, similar to the letter U. On the other hand, a low Vf value reflects a high rate of uplift, resulting in a narrow or V-shaped valley, with more vertical river erosion (El Hamdouni, 2008; Rendra et al., 2023).

Index of Drainage Basin Shape (Bs)

Index of drainage basin shape (Bs) is one of the quantitative analyses used to compare the length axis (Bl) measured from the longest to the wide axis (Bw) measured from the widest (El Hamdouni et al., 2008). The index of drainage basin shape (Bs) can be calculated using the following equation:

$$Bs = Bl / Bw \tag{3}$$

where:
Bs = Basin shape of the watershed
Bl = Length of the basin of a watershed
Bw = Width of the basin of a watershed

Bs values will be elongate and will tend to become circular after the tectonic process slows or tectonic processes slow down or stop in active tectonics (El Hamdouni et al., 2008; Ramírez-Herrera, 1998).

Asymmetric Factor (Af)

Asymmetric factor is a quantitative analysis method to determine the tectonic tilt of a watershed unit. The value of this asymmetric factor can explain in detail the area affected by tectonic-tilting, either at the scale of a small or large drainage basin (Keller & Pinter, 2002) and can be calculated by the formula:

$$Af = 100\ (Ar / At) \tag{4}$$

where:
Af = Asymmetric Factor
Ar = Area of the right part of the watershed (water flow towards the downstream) (km^2)
At = Total area of the watershed (km^2)

The analysis is obtained by making a cross section of the WCA slope direction according to the value of the asymmetric factor. (Keller & Pinter, 2002), states that, if the value obtained $Af = 50$ then the area is experiencing very small tectonic deformation so that it is relatively stable. Then if the value of $Af < 50$ or $Af > 50$, then there has been a tilt due to tectonics (El Hamdouni et al., 2008).

Hypsometric Integral (Hi)

Hypsometric integral is an index that can describe the elevation distribution of a particular area of the landscape (Strahler, 1952). In general, the integral is applied to a specific drainage basin and is independent of the basin area. The hypsometric integral (Hi) can be calculated using the following equation (Keller and Pinter, 2002):

$$Hi = (\text{Mean Elevation} - \text{Minimum Elevation})/(\text{Maximum Elevation} - \text{Minimum Elevation}) \tag{5}$$

The hypsometric curve will be the representation of this equation. Based on the pattern of land in young, middle and old stages. The hypsometric curve can provide an overview of the land contours (Keller and Pinter, 2002). Digital elevation models (DEMs) provide the elevation values needed for the calculations. Integral hypsometry requires correlation with other geological settings and is not directly related to active tectonic relativity. This HI index, which is strongly influenced by rock resistance, is similar to the SL index. Tectonic activity and HI measurements are not directly correlated. Recent cuts in young geomorphic terrains formed by deposition can also produce high HI values (El Hamdouni et al., 2008).

River Length Gradient Index (SL)

The river length gradient (SL) index is very sensitive to changes in river slope and can be related to tectonic activity in an area (Keller and Pinter, 2002; Hidayat et al., 2021). This sensitivity is used to evaluate geological structure, slope, relationship with active tectonics, rock resistance, and topography. Areas with low SL index values indicate ongoing tectonic activity (neotectonics). The river length gradient (SL) index can be calculated using the following equation:

$$SL = (\Delta H / \Delta L) \times L \qquad (6)$$

where:
ΔH = Elevation difference from the point to be calculated
ΔL = River length up to the point to be calculated
L = Total length of the river from upstream to the point to be calculated

If a valley with a linear morphology is present, it indicates a horizontal fault movement that causes a small SL index value because the valley has been destroyed by the movement, so that the river flows through the valley with a low slope. Keller & Pinter (2002) state that the SL index can recognise low, medium and high levels of uplift. First-order rivers are most sensitive to neotectonic activity. The SL index can be used as an indicator to categorise the relative uplift level in an area.

Table 2. Classification of morphotectonic indexes (Dehbozorgi dkk., 2010; El Hamdouni dkk., 2008)

Morphotectonic Indexes	Class 1	Class 2	Class 3
Smf	Smf < 1,1	1,1 ≤ Smf ≤ 1,5	Smf > 1,5
Vf	Vf < 0,5	0,5 ≤ Vf ≤ 1,0	Vf > 1,0
Bs	Bs ≥ 4	3 ≤ Bs ≥ 4	Bs ≤ 3
AF	AF ≥ 65 atau AF < 35	35 Af ≤ 43 atau 57 ≤ AF < 65	43 ≤ AF < 57
Hi	Hi ≥ 0,5	0.4 ≤ Hi < 0.5	Hi < 0,4
SL	SL ≥ 500	300 ≤ SL ≥500	SL ≤ 300

Index of Active Tectonic Relative (IATR)

In morphotectonic calculations, most researchers use the six indices mentioned above, which are then categorised according to the level of tectonic activity. The total of all morphotectonic index classes is averaged to create the Index of Relative Tectonic Activity (IRTA). The average of several classes of geomorphic index parameters (S/n) is used to calculate the IATR.

$$IATR = S / n \qquad (7)$$

where:
IATR = index of relative tectonic activity
S = sum of class values of each geomorphic index
n = number of geomorphic indices

The Index of Relative Tectonic Activity (IRTA), which measures the level of tectonic activity, can be divided into four classes based on calculations: very high, high, medium and low. Class 1 is very high with S/n values between 1 and 1.5; class 2 is high tectonic activity with S/n values between 1.5 and 2; class 3 is moderately tectonically active with S/n values of 2 to 2.5; and class 4 is low tectonically active with S/n values > 2.5. These average (S/n) values are categorised into four classes of tectonic activity (IAT) (El Hamdouni et al., 2008).

Results and Discussion

Cikandang watershed has a fan-like shape. The smallest unit of analysis using the division of the Water Catchment Area (WCA) of the study area based on the division of the 3rd river order refers to the ratio of river order (Howard, 1967). The 3rd order measurement is one of the developments of Howard's method (1967) to find the same dimensions of a WCA and is more objective because it has the same order. This watershed consists of several drainage patterns, such as trellis, parallel, dendritic, and rectangular.

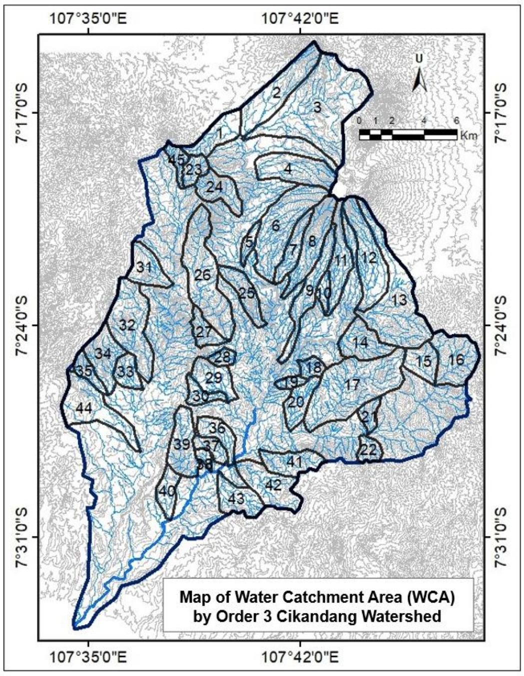

Figure 3. Map of the 3rd Order Catchment Area (WCA) in the Cikandang Watershed

Mountain Front Sinuosity (Smf)

The values of Smf will indicate the level of tectonic activity in the area. Increased sinuosity reflects the action of watercourses (rivers) cutting through the mountain-plains boundary. Smf values close to 1 (one) reflect near-ideal alignment, indicating active uplift. The influence of active tectonic forces is evident from the relatively straight mountain face with a low Smf value. The level of tectonic activity based on the Smf index value is divided into active, medium to weak, and inactive tectonic classes (Keller & Pinter, 2002) which can be seen in Table 3. The calculation of Smf in the study area is dominated by class 3 in the form of Low Tectonic Class. The calculation of the mountain face sinusitis (Smf) value in the Cibodas watershed was carried out on 45 mountain faces in each WCA. Based on the calculation results, the Smf value ranges from 1.56 (WCA 42) to 5.01 (WCA 24). Based on the Doornkamp Classification (1986), the overall Smf value is included in class 3, namely low tectonics because the Smf value is above 1.0.

Ratio of valley floor width to valley height (Vf)

Calculation of the ratio of valley width and height (Vf) was carried out as a total of 45 valleys distributed in the Cikandang watershed. Based on the data from the calculation of Vf, the ratio of valley width and height ranges from 0.07 (WCA 26) to 1.15 (WCA 14). By referring to the classification of Vf values according to Keler and Pinter (1996), there are 35 WCAs with Vf values < 0.5 which are included in class 1 (active tectonics) which are valleys with high levels of uplift and V-shaped, 6 WCAs with Vf values between 0.5 and 1.0 which are included in class 2 (moderate tectonics) which are valleys with moderate levels of uplift, and 4 Vf values > 1.0 which are included in class 3 (low tectonics) which are valleys with low levels of uplift and U-shaped.

Some of the larger Vf values may result from less resistant lithological response factors that result in very high erosion and change the shape of the river valley to become wider and U-shaped.

Index of drainage basin shape (Bs)

Based on the calculation, the Bs value in the study area ranges from 1.00 (WCA 16) to 6.94 (WCA 9). There are 31 WCAs included in class 3 (low tectonic), 8 WCAs included in class 2 (low tectonic), and 6 WCAs included in class 1 (active tectonic) (Table 4). Bs that fall into class 3 (low tectonics) are predicted to be related to tectonic processes that slow down or stop, so that the shape of the WCA is more rounded. In general, based on the Bs analysis, both WCAs with sedimentary and volcanic rock lithology, most of the Bs values are included in class 3 (low tectonic) as many as 31 WCAs. This shows that the tectonic process slows down and the erosion process tends to be more developed, causing the shape of the WCA to be more rounded, Bs which is included in class 2 (moderate tectonics) and class 1 (active tectonics) is estimated as a result of the presence of structures around the WCA.

Asymmetric factor (Af)

The calculation of the Af value in the Cikandang watershed in the study area was carried out at 45 WCAs (Table 5). Where based on the calculation results, Af values range from 15.65 (WCA 13) to 82.95 (WCA 44). Referring to the tectonic class classification of El Hamdouni (2008), it is found that 9 WCAs belong to class 3 (low tectonics), 16 WCAs belong to class 2 (moderate tectonics), and 25 WCAs belong to class 1 (active tectonics). Then, to show the level of asymmetry that develops in a watershed, the Af value is expressed as an absolute value then reduced by 50.

Based on the calculation of the |Af-50| value, the values range from 0.6 (WCA 23) to 34.3 (WCA 13). Referring to the classification of the asymmetry level of 45 WCAs. It was revealed that 20 WCAs were classified as strongly asymmetric basin, 0 WCAs were moderately asymmetric basin, 10 WCAs were gently asymmetric basin, and 9 WCAs were symmetric basin. The calculation method carried out is by calculating the total area of the WCA right from the upstream direction with the main river as the middle boundary of the river (Ar) which is then compared with the total calculated WCA area. For example, in WCA 1 the resulting Af value is 52.30 which is included in tectonic class 3 (low tectonics).

Hypsometric integral (Hi)

The calculation of Hi value is conducted using several tools in spatial data processing software. From the calculation of Hi according to El Hamdouni et al (2008), the division of tectonic classes is divided into 3 classes, namely class 1 ($Hi < 0.5$), class 2 ($0.4 < Hi < 0.5$), and class 3 ($Hi < 0.4$). Hi analysis was conducted on 45 Cikandang WCAs (Table 13). The results are that there are no WCAs classified into class 3 (low tectonics), 25 WCAs classified into class 2 (moderate tectonics), and 24 WCAs classified into class 1 (active tectonics).

Stream length-gradient index (SL)

The River Length Gradient Index (SL) value is very sensitive to changes in valley slope. This level of sensitivity of SL values can be used to evaluate the relation between active tectonics, rock resistance and topography. The SL value can be used to identify the current active tectonics and differentiate the uplift types in the active, medium and low tectonic classes. The calculation of the river length gradient index (SL) value in Cikandang catchment was carried out in 45 catchments. Based on the calculation results, the SL value ranges from 92.64 (WCA 1) to 684.758 (WCA 8), which refers to the classification of tectonic classes (El Hamdouni, 2008), it is found that 31 WCAs are classified as class 3 (low tectonics), 10 WCAs are classified as class 2 (moderate tectonics), and 4 WCAs are classified as class 1 (active tectonics). The calculation analysis of the SL index value was carried out using spatial data processing software. The method used is by determining 2 elevation points to get the DH value. Then, the DL value is the total length of the two elevation points, and the

L value is the total length from the midpoint upstream. In this case, the example is the SL value of WCA 1, which obtained a final SL value of 92.644, which is included in tectonic class 3 (Table 15).

Index of Active Tectonic Relative (IATR)

Tectonic activity in the study area was analysed using six morphotectonic parameters including: (1) Mountain Front Sinuosity (Smf), (2) Ratio of valley floor width to valley height (Vf), (3) Index of drainage basin shape (Bs), (4) Asymmetric factor (Af), (5) Hypsometric integral (Hi), and (6) Stream length-gradient index (SL). The classification of tectonic levels applied in this study refers to the method developed by El Hamdouni et al. (2008), which divides the level of tectonic activity into three categories: class 1 (active tectonics), class 2 (moderate tectonics), and class 3 (low tectonics). Tectonic activity in the study area was analysed by using relevant geomorphic parameters. This approach follows the method used by El Hamdouni et al. (2008) in classifying tectonic activity in the Nevada region of Spain, as well as research by Dehbozorgi et al. (2010) in the Sarvestan region of Iran, which used six morphometric parameters: SL, Af, Hi, Vf, Bs, and Smf. These parameters were then categorised according to the tectonic class of each catchment and averaged to obtain the Index of Relative Tectonic Activity (IATR) value.

For example, WCA 1 has a Bs value that is classified as class 3, an Af value that is classified as class 3, a Vf value that is classified as class 2, a Smf value that is classified as class 3, a Hi value that is classified as class 2 and an SL value that is classified as class 3. The six indices that have been analysed, from WCA 1, are then summed (3 + 3 + 2 + 3 + 2 + 3) and averaged (13 / 6 = 2.17). The value of 2.17 is classified as class 3 IATR. Then, the tectonic activity class was divided based on the IATR values of the six morphotectonic parameters. The tectonic activity class based on the average value or IATR is divided into four classes, which are:

Table 3. Classification of IATR Values

No.	Class of tectonics activity	IATR values
1	1 (Very High)	1 < IATR < 1,5
2	2 (High)	1,5 < IATR < 2
3	3 (Moderate)	2 < IATR < 2,5
4	4 (Low)	IATR > 2,5

Based on the calculation results that have been obtained, the IATR values at 45 Cikandang WCAs are divided into three classes, namely class 2 (High Tectonic), class 3 (Medium Tectonic), and class 4 (Low Tectonic). The distribution of IATR values in 45 WCAs is class 1 are 6 WCAs, class 2 are 34 WCAs, class 3 are 5 WCAs, and there are no WCAs included in class 4. The results of this IATR analysis indicate that the research area has an influence from tectonics and is also influenced by the erosion process.

Table 4. Calculation result of Mountain Front Sinuosity (Smf)

WCA	Lmf	Ls	Smf	Class	WCA	Lmf	Ls	Smf	Class
1	2,284	1,08	2,11	3	24	4,536	0,91	5,01	3
2	2,555	1,14	2,23	3	25	1,534	0,61	2,52	3
3	7,483	2,60	2,88	3	26	8,163	2,81	2,91	3
4	4,682	1,75	2,67	3	27	3,533	1,04	3,40	3
5	2,020	0,59	3,40	3	28	1,289	0,77	1,67	3
6	3,755	1,69	2,23	3	29	3,196	1,51	2,11	3
7	2,155	0,95	2,27	3	30	2,241	1,43	1,57	3
8	2,967	1,19	2,49	3	31	3,295	1,85	1,78	3
9	2,185	0,69	3,17	3	32	5,352	2,19	2,44	3
10	2,555	0,83	3,07	3	33	2,661	1,32	2,01	3
11	2,349	1,10	2,13	3	34	1,613	0,77	2,10	3
12	2,831	1,15	2,46	3	35	0,818	0,45	1,80	3
13	3,256	1,87	1,75	3	36	1,967	1,18	1,66	3
14	4,167	1,30	3,19	3	37	1,462	0,81	1,80	3
15	3,812	1,61	2,37	3	38	1,120	0,66	1,69	3
16	6,532	2,31	2,83	3	39	2,180	1,10	1,98	3
17	6,398	2,44	2,62	3	40	1,619	0,97	1,67	3

18	2,875	1,23	2,34	3	41	3,040	1,55	1,96	3
19	1,826	0,80	2,27	3	42	2,609	1,67	1,56	3
20	2,046	1,23	1,67	3	43	2,890	1,34	2,15	3
21	2,056	0,96	2,13	3	44	3,100	1,88	1,65	3
22	2,091	1,08	1,94	3	45	2,373	1,38	1,72	3
23	3,223	1,29	2,50	3					

Table 5. Calculation result of Ratio of valley floor width to valley height (Vf)

WCA	Vfw	Eld	Erd	Esc	Vf	Class	WCA	Vfw	Eld	Erd	Esc	Vf	Class
1	78	1728	1843	1673	0,69	2	24	55	1609	1520	1408	0,35	1
2	40	1718	1693	1660	0,88	2	25	21	982	1009	861	0,16	1
3	68	1868	1960	1775	0,49	1	26	26	1250	1310	920	0,07	1
4	20	1863	1828	1740	0,19	1	27	40	1210	1045	861	0,15	1
5	22	1253	1263	1224	0,65	2	28	18	784	730	705	0,35	1
6	64	1290	1330	1218	0,70	2	29	21	773	705	638	0,21	1
7	58	1114	1129	1064	1,01	3	30	27	814	703	678	0,34	1
8	45	1316	1293	1190	0,39	1	31	41	1230	1065	965	0,22	1
9	35	960	906	836	0,36	1	32	37	810	900	670	0,20	1
10	32	1160	1075	1036	0,39	1	33	44	625	589	551	0,79	2
11	31	1230	1216	1161	0,50	2	34	36	949	982	793	0,21	1
12	25	1265	1285	1222	0,47	1	35	27	659	682	638	0,83	2
13	30	1279	1300	1175	0,26	1	36	34	384	356	293	0,44	1
14	34	1020	1171	872	0,15	1	37	31	424	358	305	0,36	1
15	34	1160	1350	1070	0,18	1	38	20	357	392	326	0,41	1
16	23	1149	1371	1239	1,10	3	39	30	591	680	452	0,16	1
17	73	1020	820	632	0,25	1	40	60	233	235	182	1,15	3
18	16	732	716	678	0,35	1	41	20	648	638	473	0,12	1
19	24	793	796	669	0,19	1	42	25	529	640	360	0,11	1
20	51	670	743	569	0,37	1	43	39	448	705	408	0,23	1
21	20	755	840	650	0,14	1	44	36	502	522	478	1,06	3
22	22	751	796	653	0,18	1	45	13	1742	1738	1682	0,22	1
23	32	1740	1715	1615	0,28	1							

Table 6. Calculation result of Index of drainage basin shape (Bs)

WCA	Bl	Bw	Bs	Class	WCA	Bl	Bw	Bs	Class
1	4,16	1,44	2,88	3	24	3,20	2,16	1,48	3
2	7,15	1,32	5,42	1	25	4,53	1,09	4,17	1
3	8,28	6,74	1,23	3	26	7,74	1,95	3,98	2
4	5,06	1,71	2,96	3	27	2,36	1,50	1,58	3
5	2,82	0,80	3,52	2	28	1,68	1,07	1,58	3
6	6,47	2,14	3,02	2	29	3,39	1,84	1,85	3
7	4,88	0,93	5,23	1	30	2,30	1,24	1,86	3
8	6,71	1,31	5,13	1	31	3,39	1,96	1,73	3
9	9,04	1,30	6,94	1	32	6,34	2,74	2,31	3
10	2,49	0,78	3,18	2	33	2,21	1,90	1,17	3
11	6,81	1,45	4,71	1	34	4,18	2,41	1,73	3
12	6,58	1,81	3,64	2	35	2,64	0,91	2,92	3
13	9,70	2,77	3,51	2	36	3,07	1,75	1,76	3
14	3,52	2,59	1,36	3	37	2,30	0,90	2,56	3
15	2,35	2,16	1,09	3	38	1,48	0,75	1,98	3
16	3,23	3,22	1,00	3	39	4,27	1,37	3,10	2
17	7,54	2,99	2,52	3	40	3,34	1,24	2,70	3
18	1,72	1,28	1,34	3	41	3,88	1,80	2,15	3
19	2,00	0,64	3,15	2	42	4,34	2,41	1,80	3
20	3,38	1,33	2,53	3	43	3,44	2,35	1,47	3
21	2,32	1,11	2,09	3	44	5,79	2,71	2,14	3
22	1,58	1,47	1,08	3	45	2,44	1,18	2,07	3
23	2,24	1,43	1,56	3					

Table 7. Calculation result of Asymmetric factor (Af)

WCA	Ar	At	Af	Class	|Af-50|	Asymmetry level	WCA	Ar	At	Af	Class	|Af-50|	Asymmetry level

1	2,4	4,7	52,3	3	2,3	Symmetrical	24	1,99	4,41	45,14	3	4,86	Symmetrical
2	3,7	9,1	40,8	2	9,2	Slightly Symmetrical	25	1,13	3,90	28,92	1	21,08	Very Symmetrical
3	9,7	22,8	42,4	2	7,6	Slightly Symmetrical	26	5,38	12,76	42,17	2	7,83	Slightly Symmetrical
4	2,5	7,5	33,2	1	16,8	Very Symmetrical	27	1,66	2,67	62,19	2	12,19	Quite Symmetrical
5	0,5	1,4	33,6	1	16,4	Very Symmetrical	28	0,52	1,28	40,50	2	9,50	Slightly Symmetrical
6	2,7	11,5	23,0	1	27,0	Very Symmetrical	29	1,10	4,29	25,63	1	24,37	Very Symmetrical
7	1,0	3,5	28,1	1	21,9	Very Symmetrical	30	1,57	2,09	75,16	1	25,16	Very Symmetrical
8	2,8	6,8	41,4	2	8,6	Slightly Symmetrical	31	3,12	4,41	70,66	1	20,66	Very Symmetrical
9	4,1	5,9	68,5	1	18,5	Very Symmetrical	32	6,92	10,28	67,29	1	17,29	Very Symmetrical
10	1,1	1,4	75,0	1	25,0	Very Symmetrical	33	1,26	2,64	47,87	3	2,13	Symmetrical
11	3,9	5,4	71,3	1	21,3	Very Symmetrical	34	4,02	5,46	73,55	1	23,55	Very Symmetrical
12	5,5	8,9	61,8	2	11,8	Quite Symmetrical	35	0,61	2,04	29,93	1	20,07	Very Symmetrical
13	2,3	15,0	15,7	1	34,3	Very Symmetrical	36	1,39	3,20	43,39	2	6,61	Slightly Symmetrical
14	2,5	5,2	48,2	3	1,8	Symmetrical	37	0,83	1,96	42,54	2	7,46	Slightly Symmetrical
15	2,1	3,6	57,2	2	7,2	Slightly Symmetrical	38	0,50	0,87	57,30	2	7,30	Slightly Symmetrical
16	4,4	7,2	61,3	2	11,3	Quite Symmetrical	39	3,18	5,79	54,89	3	4,89	Symmetrical
17	8,5	16,5	51,9	3	1,9	Symmetrical	40	1,47	2,86	51,44	3	1,44	Symmetrical
18	0,6	1,6	38,0	2	12,0	Quite Symmetrical	41	1,31	4,59	28,59	1	21,41	Very Symmetrical
19	0,4	1,1	34,7	1	15,3	Very Symmetrical	42	4,68	6,81	68,65	1	18,65	Very Symmetrical
20	1,8	3,6	49,1	3	0,9	Symmetrical	43	1,91	4,64	41,22	2	8,78	Slightly Symmetrical
21	1,2	1,8	64,3	2	14,3	Quite Symmetrical	44	7,09	8,55	82,95	1	32,95	Very Symmetrical
22	0,7	1,9	39,0	2	11,0	Quite Symmetrical	45	0,52	1,76	29,50	1	20,50	Very Symmetrical
23	1,1	2,2	49,4	3	0,6	Symmetrical							

Table 8. Calculation result of Hypsometric integral (Hi)

WCA	avg.elv.	min.elv.	max.elv.	Hi	Class	WCA	avg.elv.	min.elv.	max.elv.	Hi	Class
1	1836,56	1829,97	1843,17	0,499	2	24	1598,52	1589,77	1607,23	0,501	1
2	2126,35	2110,90	2142,03	0,496	2	25	1002,18	991,47	1012,70	0,505	1
3	2077,78	2063,87	2092,30	0,489	2	26	1234,56	1215,03	1253,97	0,501	1
4	2058,48	2040,13	2076,87	0,500	2	27	944,01	934,13	953,87	0,501	1
5	1316,46	1311,37	1321,74	0,490	2	28	802,87	795,70	810,13	0,497	2
6	1787,08	1759,13	1814,90	0,501	1	29	829,23	817,47	840,70	0,506	1
7	1591,57	1569,70	1614,07	0,493	2	30	691,64	684,50	698,43	0,513	1
8	1370,97	1342,20	1399,77	0,500	1	31	1195,53	1184,20	1206,80	0,501	1
9	1370,97	1342,20	1399,77	0,500	2	32	965,93	950,10	981,80	0,499	2
10	1132,85	1125,50	1140,33	0,495	2	33	719,48	711,50	727,50	0,499	2
11	1771,41	1742,90	1800,03	0,499	2	34	949,07	934,40	963,57	0,503	1
12	1804,80	1778,67	1831,03	0,499	2	35	871,99	860,00	883,97	0,500	1
13	1775,12	1749,80	1800,50	0,499	2	36	477,59	468,80	486,20	0,505	1
14	1117,08	1106,67	1127,37	0,503	1	37	442,75	434,97	450,50	0,501	1
15	1303,85	1292,77	1315,27	0,493	2	38	368,03	362,13	373,90	0,501	1
16	1372,17	1358,30	1386,00	0,501	1	39	558,85	545,97	571,50	0,504	1
17	947,12	929,40	964,77	0,501	1	40	351,29	343,63	359,03	0,497	2
18	830,06	822,83	837,13	0,505	1	41	601,12	590,33	611,63	0,506	1
19	664,83	657,97	671,50	0,507	1	42	554,95	544,20	565,90	0,495	2
20	682,29	671,27	692,90	0,510	1	43	448,21	439,93	456,03	0,514	1
21	844,95	836,63	853,40	0,496	2	44	687,69	674,90	701,07	0,489	2
22	843,39	834,77	852,23	0,494	2	45	1800,52	1789,90	1811,03	0,503	1
23	1706,44	1699,07	1714,00	0,494	2						

Table 9. Calculation result of Stream length-gradient index (SL)

WCA	Nilai SL	Class	WCA	Nilai SL	Class
1	92,64422	3	24	153,8534	3
2	216,1736	3	25	487,9793	2
3	228,8281	3	26	492,4367	2
4	361,4006	2	27	276,4626	3
5	126,1953	3	28	153,6905	3
6	613,9634	1	29	190,3036	3
7	494,4112	2	30	181,7803	3
8	684,7577	1	31	274,247	3
9	587,3688	1	32	453,0128	2

10	194,5157	3	33	146,5314	3
11	331,2637	2	34	272,3814	3
12	534,3603	1	35	208,3002	3
13	278,9347	3	36	216,5864	3
14	235,4677	3	37	193,617	3
15	217,0468	3	38	151,8031	3
16	388,2766	2	39	298,7314	3
17	428,1959	2	40	159,5527	3
18	182,4023	3	41	332,8102	2
19	209,0458	3	42	322,2936	2
20	242,6018	3	43	251,3136	3
21	184,6642	3	44	176,9663	3
22	167,3285	3	45	236,0062	3
23	162,3894	3			

Table 10. Calculation results of Index of Active Tectonic Relative (IATR) in the research area Cikandang watershed

WCA	Bs	Af	Vf	Smf	Hi	SL	IATR	Class	WCA	Bs	Af	Vf	Smf	Hi	SL	IATR	Class
1	3	3	2	3	2	3	2,17	3	24	3	3	1	3	1	3	1,83	2
2	1	2	2	3	2	3	1,67	2	25	1	1	1	3	1	2	1,17	1
3	3	2	1	3	2	3	1,83	2	26	2	2	1	3	1	2	1,5	2
4	3	1	1	3	2	2	1,67	2	27	3	2	1	3	1	3	1,67	2
5	2	1	2	3	2	3	1,67	2	28	3	2	1	3	2	3	1,83	2
6	2	1	2	3	1	1	1,5	2	29	3	1	1	3	1	3	1,5	2
7	1	1	3	3	2	2	1,67	2	30	3	1	1	2	1	3	1,33	1
8	1	2	1	3	1	1	1,33	1	31	3	1	1	3	1	3	1,5	2
9	1	1	1	3	2	1	1,33	1	32	3	1	1	3	2	2	1,67	2
10	2	1	1	3	2	3	1,5	2	33	3	3	2	3	2	3	2,17	3
11	1	1	2	3	2	2	1,5	2	34	3	1	1	3	1	3	1,5	2
12	2	2	1	3	2	1	1,67	2	35	3	1	2	3	1	3	1,67	2
13	2	1	1	3	2	3	1,5	2	36	3	2	1	3	1	3	1,67	2
14	3	3	1	3	1	3	1,83	2	37	3	2	1	3	1	3	1,67	2
15	3	2	1	3	2	3	1,83	2	38	3	2	1	3	1	3	1,67	2
16	3	2	3	3	1	2	2	3	39	2	3	1	3	1	3	1,67	2
17	3	3	1	3	1	2	1,83	2	40	3	3	3	3	2	3	2,33	3
18	3	2	1	3	1	3	1,67	2	41	3	1	1	3	1	2	1,5	2
19	2	1	1	3	1	3	1,33	1	42	3	1	1	2	2	2	1,5	2
20	3	3	1	3	1	3	1,83	2	43	3	2	1	3	1	3	1,67	2
21	3	2	1	3	2	3	1,83	2	44	3	1	3	2	2	3	1,83	2
22	3	2	1	3	2	3	1,83	2	45	3	1	1	2	1	3	1,33	1
23	3	3	1	3	2	3	2	3									

Conclusions

Relative tectonic activity in the study area is influenced by geological processes, including six morphotectonic parameters: Valley Height-Width Ratio (Vf), Mountain Face Sinusity (Smf), Basin Shape Index (Bs), Asymmetry Factor (Af), Integral Hypsometry (Hi), and River Length Gradient Index (SL). The calculation of the Index of Relative Tectonic Activity (IATR) in 45 catchments showed a distribution in three main classes: class 1 (active tectonics), class 2 (moderate tectonics), and class 3 (low tectonics). The majority of the area is classified as medium tectonic with 31 WCAs (84%), while the remaining 6 WCAs (9%) are active and 5 WCAs (8%) are low tectonic. The analysis also indicates that the study area is influenced by a combination of moderate to low tectonic activity and significant erosional processes. The results of this study provide a scientific basis for disaster risk mitigation planning, optimisation of natural resource management, and sustainable regional development.

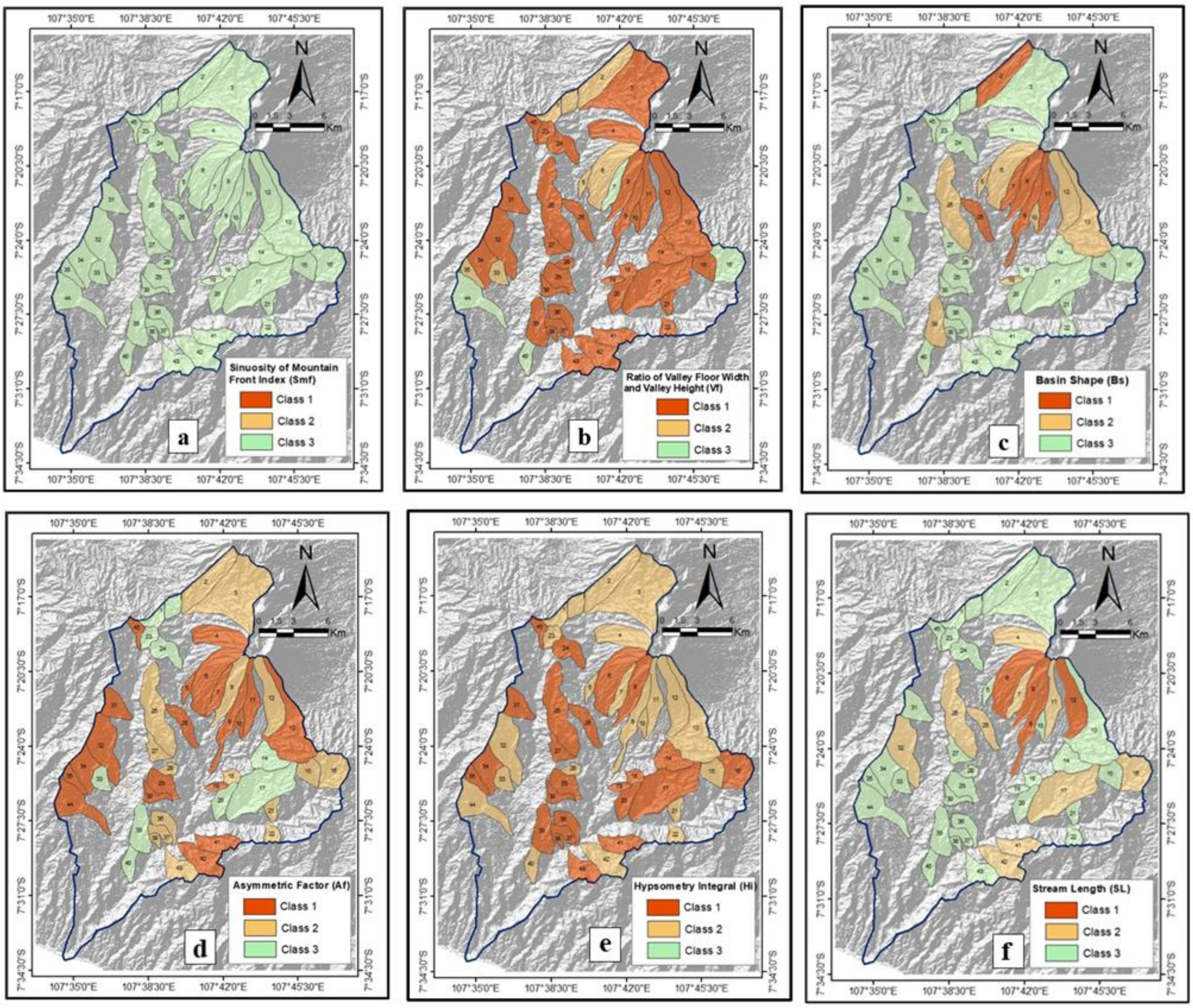

Figure 4. Map of spatial distribution from calculation result (a) Smf, (b) Vf, (c) Bs, (d) Af, (e) Hi, (f) SL at Cikandang watershed

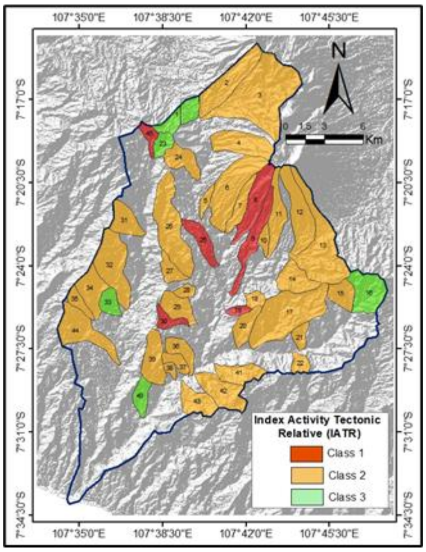

Figure 6. Map of the calculation results the Relative Tectonic Activity Index (IATR) at the Cikandang watershed

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