MORPHOTECTONIC CHARACTERISTICS OF THE CILANGLA AND CIPATUJAH WATERSHED AT THE TASIKMALAYA REGENCY, WEST JAVA

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ABSTRACT : Watershed of Cilangla and Cipatujah area in Tasikmalaya Regency, West Java Province is a part of the Southern Mountain of West Java. West Java is an area of active tectonic and volcanic because it is located close to the collision zone between the Eurasian plate and the Indo-Australia. Tectonic activities at the subduction zone can trigger fault activities on the mainland. The research is aimed to determine the characteristics of morphotectonic and its implications on the structural conditions and the potential natural disasters that may occur in the study area. There are three analysis methods used in the research which are studio, field and laboratory methods. Studio analysis includes morphometric analysis based on mountain-front sinuosity (Smf), ratio of valley floor width to valley height (Vf), and bifurcation ratio (Rb). Morphometric aspects such as dimension and shape of watershed were analyzed by using data extraction from DEM and topographic map. The results of morphometry analysis of the research area show the tectonic influence is difference between Cilangla watershed and Cipatujah watershed. The measurement results of geomorphic index indicate tectonic classified as high and medium grade with Smf values range from 1 to 1.9, while the value of Vf range between 0.2 to 6. The area is covered by old volcanic rocks of Tertiary and Quaternary and Tertiary sedimentary rocks. Watershed of Cilangla and Cipatujah were controlled by the combination between lithology, weathering and active tectonic which allow the ground movement and earthquake that will happened in the future.

1. INTRODUCTION

1.1. General Background

Geologically, Indonesian archipelago is located at the convergence of the four plates; the Indo-Australian Plate, Eurasian Plate, Pacific Plate and the Philippine Sea (Hall, 2002). At the convergence of these plates, there are rows of volcanoes formed which turn into the belt of the earthquakes. The tectonic activity on this subduction zone tends to activate the faults located on the mainland (Hidayat, 2010). Soehaimi (2011) explains that West Java region is an area that is tectonically and volcanically active due to its proximity to the collision zone between the Eurasian continental plate and Indo-Australian plate.

Cipatujah Watershed is one of the watersheds in West Java with an area of 149.1 square km. Cilangla Watershed is located in the central part of the coastal region with an extensive area of 410.5 square km. According to Supriatna, et al (1992), based on the study of the Geological Map of Karangnunggal Quadrangle of the northern, middle, the southern parts, there are normal fault, reverse fault, and thrust fault in the form of the anticline and syncline. The structure development of quaternary rocks indicates the existence of active tectonic affecting the area.

By studying morphotectonic, other information, primarily related to changes in the landscape due to tectonic phenomena, will be obtained. The regions with active tectonics will also cause ground movement and several potential geological disasters. Therefore, this study is useful for obtaining information of the level of tectonic activity in the Cilangla – Cipatujah Watersheds, and their implications on the structure condition by using morphotectonic approach.

1.2. Regional Geology

Discussion on regional stratigraphy aims to obtain an overview of the rock formations found in the study area (Figure 1). The rock formations will be elaborated and sorted from the old formation to the younger formation, so that the composition of rocks, stratigraphic relation, and the age of rocks in the research area, can be indicated. The research area is included in the Geological Map of Garut and Pameungpeuk Quadrangle (Alzwar M. et al., 1992) and the Geological Map of Karangnunggal Quadrangle (Supriatna et al., 1992). Based on the previous research, the study area is composed of Quaternary and Tertiary rocks. The rocks are then classified into several formations based on their genetic similarity.

The stratigraphic sequence of the research area, starting form the oldest to the youngest, consists of Jampang Formation, Genteng Member Jampang Formation, Kalipucang Formation, Limestone Member Pamutuan Formation, Bentang Formation, Tuff Breccia, Granodiorite, Undifferentiated Quaternary Volcanic Rock Unit (Figure 1).

1.3. Tectonic Setting of West Java

The development of tectonic and geological structure of the western part of Java Island is affected by the subduction zone of Indo-Australian plate downward the Eurasian plate. The activity of these plates becomes a significant factor in the formation of the geological and stratigraphic structure of an area. As a result of the tectonic development, then, there is a difference in the formation of the geological structure in Java Island. Pulunggono and Martodjojo (1994) divide the geological structure patterns in Java into three main types (Figure 2).

Meratus pattern is the oldest lineament pattern evolving in Java Island formed in Cretaceous – Paleocene period (80-52 million years ago) trending the northeast – southwest (NE – SW). Sunda pattern trends northwards – southwards (N – S) formed in the Early Eocene – Late Oligocene (53-32 million years ago). Java Pattern trends westwards – eastwards (W - E) formed in the Late Oligocene – Early Miocene (32 million years ago).

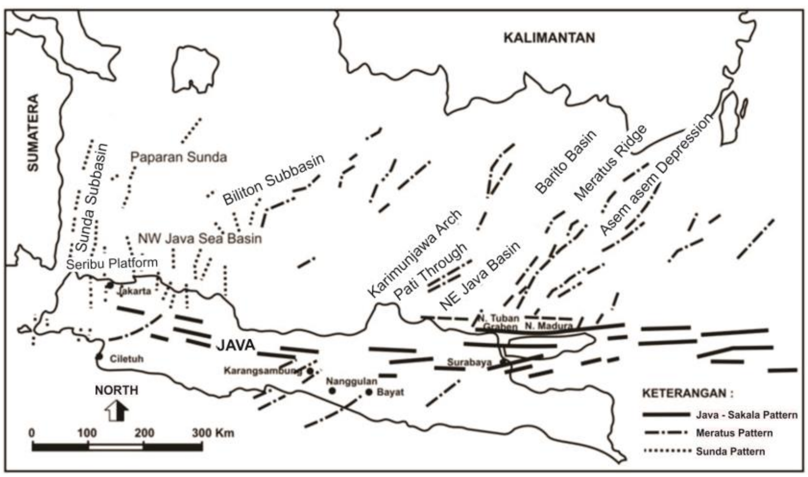

Figure 2. General Structure Patterns in West Java (Pulonggono and Martodjojo, 1994)

2. METHODOLOGY

One of the quantitative methods is the analysis of geomorphic indices. Geomorphic indices are the measurement for the parameters of landforms (eg. elevation, area, length of the river and etc.) which have a definite numeric value. Geomorphic indices can be a sensitive indicator on the changes in lithology, tectonic influences and erosion processes that develop in certain areas. The value of geomorphic indices obtained from the geological process will show certain characteristics.

This study applies the analysis of geomorphic indices such as the mountain front sinousity (Smf) and the ratio of the width of valley floor to valley height (Vf). While the morphometric analysis is conducted by calculating the bifurcation ratio. This research method utilizes the materials in the form of digital files of topographic basemap of the Southern Alps with 12.5 m of interval contour that is then obtained by the Geographic Information System (GIS), as well as geological data and regional geological structure.

Bull and McFadden (1977; in Doornkamp, 1986) define the mountain front sinousity (Smf) as the ratio of the length of the mountain front (Lmf) and the length of the mountain front projection onto a flat surface (Ls). When Smf approaches 1, then the straightness grows nearly ideal, indicating an active uplift. The increasing sinousity represents the process while the flow of water (stream) intersecting the mountain-plains boundary. Analysis of the variables Smf also supports a correlation between landscape and tectonic (Sukiyah, 2010). Figure 3 illustrates the calculation method of Smf. It can be calculated by using the equation (formula 1),

Smf = Lmf / Ls…………………….(1)

The ratio of the width of valley floor to valley height given the symbol Vf, is the value ratio between the width and height of the valley in an area. Vf value is calculated by the equation (2). Vfw is the width of the valley floor, Eld and Erd are the elevation of the left and right sides of the valley, Esc is the elevation of the valley floor. Figure 4 shows the method to calculate Vf. The high Vf value is associated with the low-speed uplift, so that the river will cross extensively on the valley floor and the shape of the valley will be widened. While the low Vf value will indicate a deep valley and the intensification of the river activity, that is associated with high-speed uplift.

Vf = 2 Vfw / (Eld – Esc) + (Erd – Esc)……………(2)

The analysis of morphometric characteristic discussed in this study is the bifurcation ratio (Rb). The value of bifurcation ratio (Rb) is the ratio between the number of segments in any order and the number of segments of the next higher order (Horton's Law). The index number of the streams for an order can be determined, indicating the degree of the river branching, with the following formula (3),

Rb = Nu/(Nu+1)………………….(3)

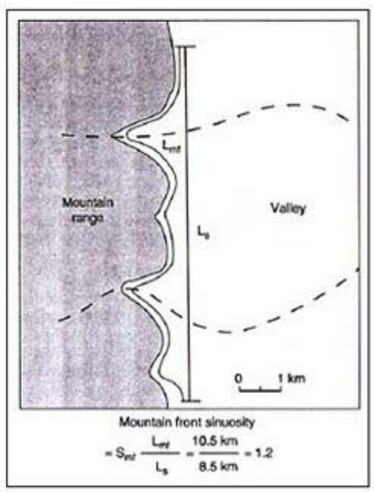

Figure 3. Method to Calculate Smf (Keller and Pinter, 1996)

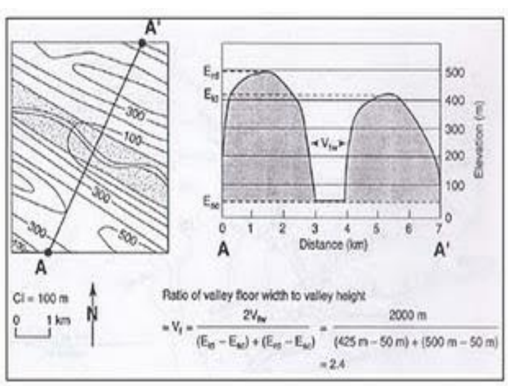

Figure 4. Method to Calculate the Ratio of Valley Floor Width to Valley Height (Keller and Pinter, 1996)

In addition to the analysis of geomorphic indices, another approach used is the product of the kinematic process. In this case, the tectonic deformation is in the form of joints which is believed that these things are related to tectonic forces in the research area.

3. RESULTS AND DISCUSSION

3.1. The Data Analysis of Joints

In this study, one data of joint was taken in Cipatujah Watershed, and three data of joints in Cilangla Watershed (Figure 5). Joint located on site 1 shows the relative direction of Northwest-Northeast while the alignment direction of the river segment relatively trends Northwest-Southeast. Joint on site 2 shows the relative direction of North-South and the river segment trends Northwards-Southwards. Joint on site 3 indicates the direction of Southwest-Northeast while the river segment trends Northwards-Southwards. Joint on site 4 shows the relative direction of North-South while the river segment trends relatively Northwest-Southeast. The population of joint azimuth on site 4 does not represent the river segment lineament of the area. The difference that exists between the joint and the river segment lineament indicates the presence of other factors that control the river segment, such as lithology and topography. Drainage pattern and catchments direction can be used as guidance for the existence of fault structures and joints structures, because the geological structures is weak zone/destroyed that easily weathered and eroded by flowing water (Haryanto, 2014).

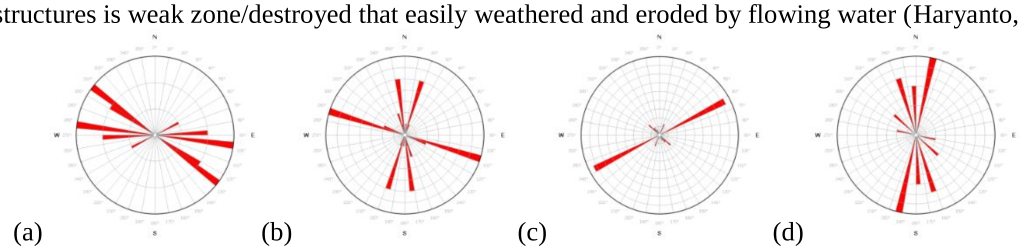

Figure 5. Rosette diagram based on field measurements, location 1 (a), 3 (c), 4 (d) in Cilangla watershed and location 2 (b) in Cipatujah watershed

3.2. Morphometric Analysis

The result of the bifurcation ratio (Rb) calculation as a whole indicates that Cipatujah and Cilangla Watersheds are controlled by active tectonic. Rb value which is averagely less than 3 (Table 1 and 2), proves that, quantitatively, the tectonic control is quite strong on both watersheds, especially in the stream ratio order 1 and 2.

Table 1. The Rb value of Cipatujah watershed

Sub basin	Total stream length (km)	Stream order				Total	Bifurcation ratio		
		1	2	3	4		Rb 1-2	Rb 2-3	Rb 3-4
CL01	203.30	163	32	2	1	198	5.09	16.00	2.00
CL02	3.46	3	1	-	-	4	3.00	-	-
CL03	6.05	7	2	1	-	10	3.50	2.00	-
CL04	1.50	2	1	-	-	3	2.00	-	-
CL05	1.19	2	1	-	-	3	2.00	-	-
CL06	1.14	2	1	-	-	3	2.00	-	-
CL07	20.44	12	2	1	-	15	6.00	2.00	-
CL08	1.61	2	1	-	-	3	2.00	-	-
CL09	6.24	5	2	1	-	8	2.50	2.00	-

CL10	2.12	2	1	-	-	3	2.00	-	-
CL11	32.83	19	4	2	1	26	4.75	2.00	2.00
CL12	23.53	16	4	2	1	23	4.00	2.00	2.00
CL13	52.08	38	11	3	1	53	3.45	-	3.00
CL14	13.65	10	2	1	-	13	5.00	2.00	-
CL15	22.85	8	2	1	-	11	4.00	2.00	-
CL16	8.26	4	1	-	-	5	4.00	-	-
CL17	6.34	3	1	-	-	4	3.00	-	-
CL18	8.32	3	1	-	-	4	3.00	-	-
CL19	11.59	2	1	-	-	3	2.00	-	-
CL20	3.29	2	1	-	-	3	2.00	-	-
CL21	1.58	2	1	-	-	3	2.00	-	-
CL22	2.18	3	1	-	-	4	3.00	-	-
CL23	49.75	19	4	1	-	24	4.75	4.00	-
CL24	5.64	2	1	-	-	3	2.00	-	-
CL25	7.30	4	1	-	-	5	4.00	-	-

Tabel 2. The Rb value of Cipatujah watershed

Sub basin	Total stream length (km)	Stream order				Total	Bifurcation ratio		
		1	**2**	**3**	**4**		**Rb 1-2**	**Rb 2-3**	**Rb 3-4**
CP01	1.37	2	1	-	-	3	2.00	-	-
CP02	1.78	2	1	-	-	3	2.00	-	-
CP03	1.93	2	1	-	-	3	2.00	-	-
CP04	1.94	2	1	-	-	3	2.00	-	-
CP05	1.65	2	1	-	-	3	2.00	-	-
CP06	2.79	2	1	-	-	3	2.00	-	-
CP07	106.47	76	8	2	1	87	9.50	4.00	2.00
CP08	17.08	6	1	-	-	7	6.00	-	-
CP09	9.69	6	2	1	-	9	3.00	2.00	-
CP10	9.05	7	2	1	-	10	3.50	2.00	-
CP11	14.90	12	1	-	-	13	12.00	-	-
CP12	1.27	2	1	-	-	3	2.00	-	-
CP13	34.35	22	4	1	-	27	5.50	4.00	-
CP14	2.83	3	1	-	-	4	3.00	-	-
CP15	1.73	2	1	-	-	3	2.00	-	

3.3. Morphotectonic Analysis

Landscape characteristics quantitatively enriched understanding of morphotectonic. They are escarpment, the shape of the valley, the hills straightness, the rivers straightness, drainage patterns (Sukiyah, 2015). The existence of active faults in an area can be recognized from the characteristics of morphotectonic. Variety of parameters can be used to assess characteristics. Several morphotectonic variables used in this study, i.e. mount-front sinuosity (Smf) and ratio of valley floor width to valley height (Vf).

Mountain Front Sinousity

Active tectonic conditions in the study area is also determined from the mountain-front sinuosity parameter index (Smf). Analysis of the variables Smf also supports a correlation between landscape and tectonic (Sukiyah, 2015). The Smf value is calculated on 32 sites including 21 sites in Cilangla Watershed and 11 locations in Cipatujah Watershed. The result of Smf calculation generally indicates susceptible values ranged from 1.09 to 1.99. Based on the tectonic degree classification by Bull and Mac Fadden (1977), grade 1 with Smf value between 1.2 to 1.6 is contained at 22 locations, grade 2 with Smf value between 1.8 to 3.4 is at 7 locations, while the Smf value that is less than 1.2 is at 3 locations. Thus, from these calculations, it can be concluded that most of the areas of research show the influence of active tectonic processes. Based on the calculation, Smf values at Cipatujah Watershed are ranged from 1.21 to 1.98, while the Smf values at Cilangla Watershed are ranged from 1.09 – 1.99.The complete result of Smf calculation is presented on Table 3 and 4.

Low Smf value (around 1) will form mountain front with a straight linear shape, and little or even without any curve. High Smf large (greater than 1.5) will form a lot of curves along the mountain front as a result of the dominant erosion process after the process of fault formation. The low Smf value is related to active tectonic reflected by the shape of the straight mountain front with little or even without any curve. The high Smf value depicts the dominant erosion process after the cessation of tectonic process reflected on the mountain front with a lot of curves or bends.

Tabel 3. The Smf value of Cipatujah watershed and classification of tectonic grade are based on Bull and Mac Fadden (1977)

site	Smf	Tectonic grade
22	1.53	active
23	1.98	moderately
24	1.29	active
25	1.44	active
26	1.82	moderately
27	1.21	active

site	Smf	Tectonic grade
28	1.58	active
29	1.30	active
30	1.32	active
31	1.41	active
32	1.27	active

Tabel 4. The Smf value of Cilangla watershed and classification of tectonic grade are based on Bull and Mac Fadden (1977)

site	Smf	Tectonic grade
1	1.28	active
2	1.53	active
3	1.33	active
4	1.99	moderately
5	1.47	active
6	1.38	active
7	1.74	moderately
8	1.99	moderately
9	1.40	active
10	1.30	active
11	1.28	active

site	Smf	Tectonic grade
12	1,98	moderately
13	1,92	moderately
14	1,13	active
15	1,49	active
16	1,09	active
17	1,42	active
18	1,71	active
19	1,13	active
20	1,91	moderately
21	1,45	active

The Ratio of Valley Floor Width to Valley Height

The locations to calculate the ratio of valley floor width to valley height of Cipatujah and Cilangla Watersheds are on each order of the river from the headstream to the estuary spreading from west to the east. The total calculation of Vf value is on 34 sites including 21 sites at Cilangla Watershed and 13 sites at Cipatujah Watershed. The value of Vf will depict the ratio between the width and height of a valley regarding with the uplift because of tectonic force. Low tectonic speed will be characterized by the value of Vf that is relatively high, so that the river will erode the floor of the widespread valley. While the low Vf value will reflect a deep valley that is related to the speed of the uplift, regarding with the active tectonic process.

Vf values at the research area are ranged from 0.20 to 4.81. The Vf values of 18 sites have less than 1, and 15 locations have more than 1 including 2 sites that have 3.92 and 4.81 of Vf value. In Cilangla Watershed, there are 3 locations with high-speed uplift, 2 locations with low-speed uplift, and 16 locations with medium-speed uplift. In Cipatujah Watershed, there are 6 locations with high-speed uplift, and 7 locations with low-speed uplift. Therefore, it can be said that Cipatujah Watershed has a higher-speed uplift compared to Cilangla Watershed. The complete Vf calculation result is shown in Table 5 and 6.

Tabel 5. The Vf value of Cipatujah watershed and classification of tectonic grade are based on Bull and Mac Fadden (1977)

site	Vf	Uplift Rate
55	1.53	moderately
58	0.45	active
61	1.26	moderately
63	0.19	active
64	0.49	active
68	1.22	moderately

site	Vf	Uplift Rate
71	0.37	active
72	1.91	moderately
73	0.82	moderately
74	0.25	active
75	0.88	moderately
76	0.21	active
79	1.03	moderately

Tabel 6. The Vf value of Cilangla watershed and classification of tectonic grade are based on Bull and Mac Fadden (1977)

site	Vf	Uplift Rate
1	0.94	moderately
3	1.02	moderately
4	0.81	moderately
5	1.08	moderately
7	1.85	moderately
8	0.85	moderately
13	0.36	moderately
14	1.83	moderately
15	0.44	active
18	3.92	inactive

site	Vf	Uplift Rate
22	0.68	moderately
29	0.97	moderately
30	0.37	active
31	0.91	moderately
33	1.95	moderately
37	1.01	moderately
39	4.80	inactive
53	0.90	moderately
42	1.22	moderately
44	0.41	active
49	1.19	moderately

4. CONCLUSION

Based on the value of Rb in Cipatujah and Cilangla Watersheds, it is dominated with Rb_{1-2} less than 3, which means that in those areas, the deformation occured due to the influence of active tectonics. The Vf analysis of Cilangla and Cipatujah Watersheds generates the value of 0.20 to 4.8. The calculation analysis indicates that the Smf value of Cipatujah Watershed is ranged from 1.21 to 1.98, while the Smf value of Cilangla Watershed is ranged from 1.09 to 1.99. Therefore, from the analysis results of the morphotectonic criteria above, it can be defined that the research area is included in the grade 1 up to grade 2, so that the morphology formed is a reflection of the level of tectonic activity in this area. Based on the value comparison of Vf and Smf between watershed of Cipatujah dan Cilangla, the tectonic activities at Cipatujah watershed is more active compare to Cilangla watershed which is precisely located at the southern part of the study area. The data supporting the existence of tectonic activity are also presented by the data analysis of faults indicating an active structure as well as by the data obtained from the emergence of the landform in the research area called triangular facet.

REFERENCES

Alzwar, M., dkk. 1992. *Peta Geologi Lembar Garut dan Pameungpeuk, Jawa*. Pusat Penelitian dan Pengembangan Geologi : Bandung

Bull, W.B. and McFadden, 1977. *Tectonic geomorphology north and south of the Garlock Fault, California. In Doehring, E. O., ed., Geomorphology in arid regions: Proc. Eighth Annual Geomphology Symposium, State Univerisity New York*, Binghamton, p.115-138.

Doornkamp, J. C. 1986. *Geomorphological Approaches to the Study of Neotectonics.* Journal of the Geological Society, London, Vol. 143, pp. 335-342.

Hall, R., 2002, *Cenozoic Geological and Plate Tectonic Evolution of SE Asia and the SW Pacific: Computer Based Reconstruction, Model and Animatio.* Journal of Asian Earth Science (20) 2002, 353 – 431.

Haryanto, E., Hardiyono., Mardiana, U. 2014. *Stucture Pattern of Volcanic Degradation Landform of Citarik Sub-CatchmentBased on Lineaments And Drainage Basin Morphometric*. Geoscience for Energy, Mineral Resources, and Environment applieds

Hidayat, Edi. 2010. *Penelitian Morfotektonik Kaitannya Dengan Potensi Gempa Bumi dan Gerakan Tanah di jalur Pegunungan Serayu Utara, Jawa Tengah.* LIPI, Kebumen.

Hidayat, Rahmadi. 2008. *Analisis Indeks Geomorfik Secara Kuantitatif*. Prosiding Geologi Nuklir dan Sumberdaya Tambang : Jakarta.

Keller, E. A. and Pinter N. 1996. *Active Tectonics (Earthquake, Uplift and Landscape)*. Upper Saddle River, New Jersey: Prentise Hall.

Martodjojo, S. 2003. *Evolusi Cekungan Bogor Jawa Barat.* Tesis Doktor Pasca Sarjana, ITB, Bandung, tidak diterbitkan.

Soehaimi A (2011). *Seismotektonik Jawa Barat dan Mikrozonasi Potensi Gempa Bumi DKI Jakarta*, Muslim D (Ed), Badan Geologi, Bandung.

Soewarno, 1991. *Hidrologi: Pengukuran dan Pengolahan Data Aliran Sungai (Hidrometri)*. Nova : Bandung

Sosrodarsono, S., dan K. Takeda, 2003. *Hidrologi untuk Pengairan*. Jakarta. Pradnya Paramita.

Strahler A. N.. 1952. *Hypsometric (Area-Altitude) Analysis of Erosional Topology.* Geological Society of America Bulletin 63.

Strahler A. N.. 1952. *Hypsometric (Area-Altitude) Analysis of Erosional Topology.* Geological Society of America Bulletin 63.

Sukiyah, E., Syafri, I., Sjafrudin, A., Nurfadli, E., Khaerani, P., Dian. 2015. *Morphotectonic and Satellite Imagery Analysis for Identifying Quaternary Fault at Southern Part of Cianjur-Garut Region, West Java, Indonesia*. Proceeding ACRS 2015 Paper ID. 508.

Sukiyah, E., Syafri, I., Winarto, J.B., Susilo, M., Saputra, A., Nurfadli, E. 2010. *Active Faults and Their Implications for Regional Development at The Southern Part of West Java, Indonesia.* FIG Congress.

Supriatna, S., dkk., 1992. *Peta Geologi Lembar Karangnunggal, Jawa.* Pusat Penelitian dan Pengembangan Geologi : Bandung

Van Zuidam, R.A. 1985. *Aerial Photo-Interpretation in Terrain Analysis and Geomorphologic Mapping, Smith Publisher*, The Hague, Amsterdam.

Verstappen, H. Th. 1983. *Applied Geomorphology: Geomorphological Surveys for Environmental Development.* New York: Elsevier Science Pub. Co. Inc. 437 p.

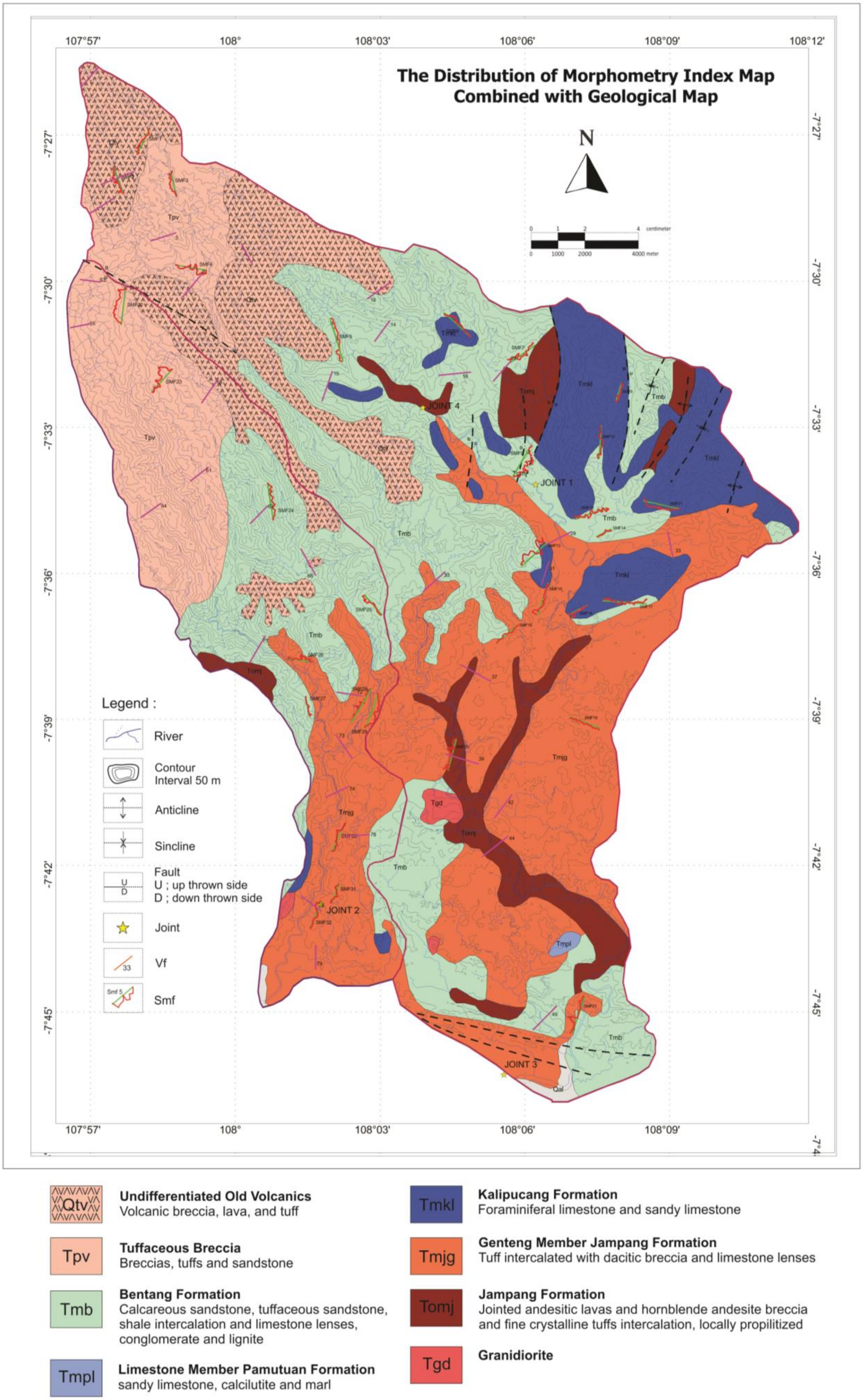

Figure 1. The distribution of morphometry index map combined with Geological Map