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Active Fault Analysis through Quantitative Assessment Method in Cikapundung Sub Watershed

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ABSTRACT

Cikapundung sub-watershed is one of the sub-watersheds at the upper of the Citarum River adjacent to an active regional fault, Lembang Fault. Active fault is a major factor in landform control in area that affected by tectonic activity. Therefore, an approach to identify tectonic activity in the research area through quantitative analysis (morphometry) is required. The morphometric analysis used to identify Index of active tectonics (IAT) uses four parameters, namely: Asymmetry factor (Af), Ratio of valley width and valley height (Vf), Basin shape index (Bs), and Mountain front sinuosity (Smf). Based on the parameters of Index of active tectonics (IAT), it can be concluded that 10 basins of the Cikapundung sub watershed has a class of low tectonic activity which may still be affected by the active Lembang fault. However, its existence should be noticed by the surrounding community and government, because the major earthquakes can occur anytime. In addition, the variation of Smf and Vf values caused by lithologic responses that are less resistant to weathering and erosion.
Keywords: Active fault, IAT, Cikapundung sub-watershed

I. INTRODUCTION

Tectonic geomorphology is defined as the study of landforms produced by tectonic processes, or the application of geomorphic principles to the solution of tectonic problems (Keller & Pinter 1996). According to Keller and Pinter (1996) Active fault is a fault that has moved in the past 10,000 years. Soehaimi (2011) states that the active fault in West Java which is the source of the earthquake is the Cimandiri, Baribis, and Lembang active fault. Therefore it is important to analyze the tectonic's active level in the Cikapundung Sub-Basin which is most likely still affected by the Lembang fault. The approach used to identify tectonic activity with quantitative analysis (morphometry).

The quantitative measurement of landform is based on the calculation of geomorphic indices using topographic maps, aerial photos, satellite images and field observation. Geomorphic indices are extremely useful for the study of drainage basins. The quantitative measurement of landform allows geomorphologists to calculate parameters, or geomorphic indices, which are useful in establishing the characteristics of an area (Baioni, 2007). The purpose of this study was to determine Index of active tectonics (IAT) with morfometric analysis in Cikapundung Sub-watershed.

Geological Setting

Geographically, the Cikapundung Sub- watershed located at 107° 35'40"-107° 44'40" East longitude and -6 °46'00 "- 6 ° 53'20" South latitude with a research area of 103.1 km^2. Administratively, the research area is a part of Lembang sub-district, West Bandung regency. Based on regional physiography, the research area is a part of the Bandung Zone.

According to Silitonga (1973), the oldest lithology in regional research area is an undifferentiated old volcanic products (Qvu) consists of volcanic breccia, lahar, and lava repeatedly interlayered This rock unit occurs in the Pleistocene Age. Furthermore, rock unit in the research are follwed by an undifferentiated young volcanic products (Qyu) consist of sandy tuff (Qyd), lapili, breccia, lava, and agglomerate, and pumiceous tuff (Qyt). This unit is Holocene. After that, lithology in research area is followed by the colluvium (Qc) in Holocene age, where the collovium deposition is relatively older than the alluvium deposition.

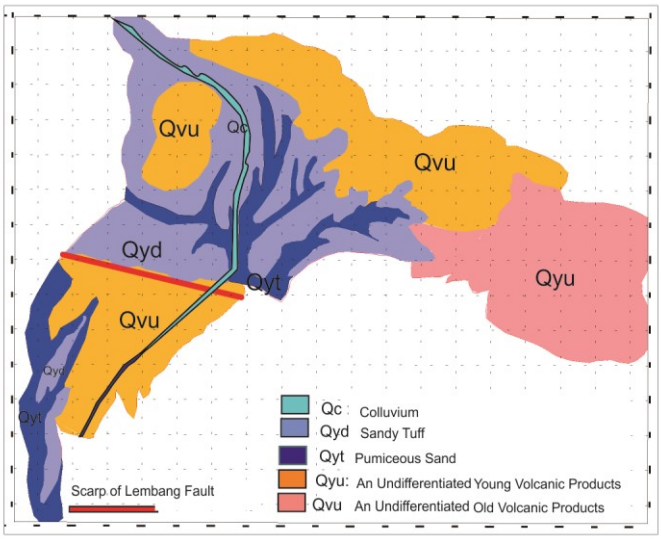

Figure 1. Geological Map Regional Research Scale 1: 200.000 (Based on Geological Map Scale 1: 100,000 Bandung By Silitonga, 1973)

II. METHODS AND MATERIAL

All data Used for calculation of morphometric parameters, then the result of analysis is used to get Index of Active Tectonics (IAT). The Several indications of morphological appearance in the active tectonic area can be studied using four morphometric parameters, as follows:

- Asymmetry factor (Af)
- Ratio of valley width and valley height (Vf),
- Basin Shape index (Bs)
- Mountain front sinuosity (Smf)

The morphometric parameters Calculation include watershed area, river length, elevation or altitude, Mountain front sinuosity and long axis watershed. The calculation uses Mapinfo and Microsoft Excel software.

Asymmetry factor (Af)

Asymmetry factor index was developed to detect tectonic tilting at drainage basin scale or larger scale area (Hare & Gardner, 1985). This index is related to two tectonic and non-tectonic factors, Non-tectonic factors may be related to lithology and rock fabrics (Ghanavati, et al., 2016).

The asymmetric factor can be used to evaluate tectonic tilting at the scale of a drainage basin (Hare & Gardner, 1985; Keller & Pinter, 2002). The asymmetry factor is sensitive to the direction of the asymmetry and in drainage basins that display change of direction throughout the river; the opposite directions will compensate each other giving a lower value of Af. For this reason, the asymmetry factor is useful mostly in drainage basins where the asymmetry has the same direction (Baioni, 2007). The method maybe applied over a relatively large area (Hare & Gardner, 1985; Keller & Pinter, 2002).

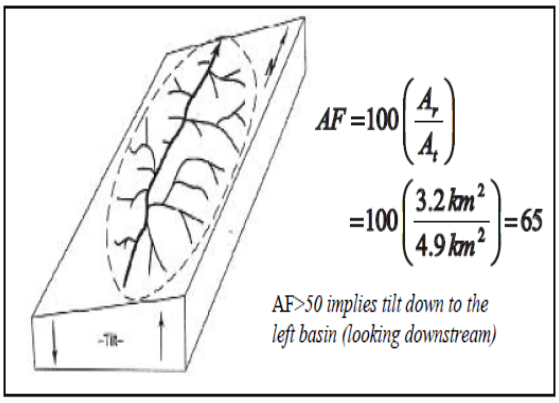

Figure 2. Illustration method of Asymmetric factor (AF) according to Keller and Pinter (1996)

The index is defined as follows:

$$Af = (Ar/At)\ 100$$

Where Ar is the right side area of the basin of the master stream (looking downstream) and At is total area of the basin that can be measured by ArcGIS software (Omidali et al., 2015).

Valley floor width-valley height ratio (Vf)

The Valley floor width to valley height ratio (Vf) is another index sensitive to tectonic uplift (Dehbozorgi et al., 2010). The index is a measure of incision and not uplift, but in an equilibrium state, incision and uplift are nearly matched. The calculation formula is in this manner (Cooley, 2015):

$$Vf = 2Vfw / [(Eld - Esc) + (Erd - Esc)]$$

Where Vfw is the width of the valley floor, and Eld, Erd and Esc are the elevations of the river-left and valley divides (looking downstream) and the stream channel, respectively (Bull, 2007).

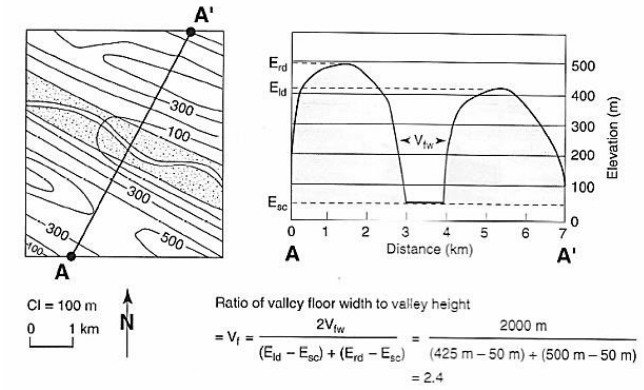

Figure 3. Illustration method of Valley floor width-valley height ratio (Vf) according to Keller and Pinter (1996)

Bull and McFadden (1977) found significant differences in Vf between tectonically active and inactive mountain fronts. Also, they found significant differences in Vf between tectonically active and inactive mountain fronts, because a valley floor is narrowed due to rapid stream downcutting. Valleys upstream from the mountain front tend to be narrow (Ramirez-Herrera, 1998), and Vf is usually computed at a given distance upstream from the mountain front (Silva et al., 2003).

Basin shape index (Bs)

Relatively young drainage basins in active tectonics areas tend to be elongated in shape normal to the topographic slope of a mountain. The elongated shape tends to evolve to a more circular shape (Bull & McFadden, 1977).

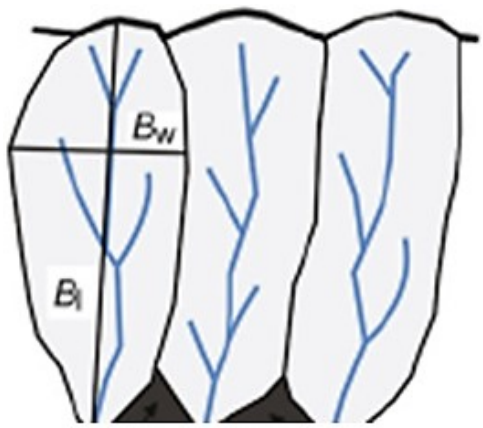

Figure 4. Illustration method of Basin shape index (Bs) according to Syed, A.M and Richard,G (2012)

The Horizontal projection of basin shape may be described by the basin shape index or the elongation ratio, Bs. The calculation formula is:

$$Bs = Bl/Bw$$

Where Bl is the length of the basin measured from the headwater to the mount, and Bw is basin width in widest point of the basin. Relatively young drainage basins in tectonically active areas tend to be elongated in shape, normal to the topographic slope of a mountain (Bull & McFadden, 1977). Therefore, Bs may reflect the rate of active tectonics (Dehbozorgi et al., 2010).

Mountain Front Sinuosity (Smf)

This index represents a balance between stream erosion processes tending to cut some parts of a mountain front and active vertical tectonics that tend to produce straight mountain fronts (Bull & McFadden, 1977).

Index of mountain front sinuosity (Bull, 2007) is defined as:

$$Smf = Lmf / Ls$$

Where Lmf is the sinuous length of the mountain measured along an undulating, weaving path at the mountain hill slope -alluvial fan slope break-, and Ls is the straight-line length of the main front segment.

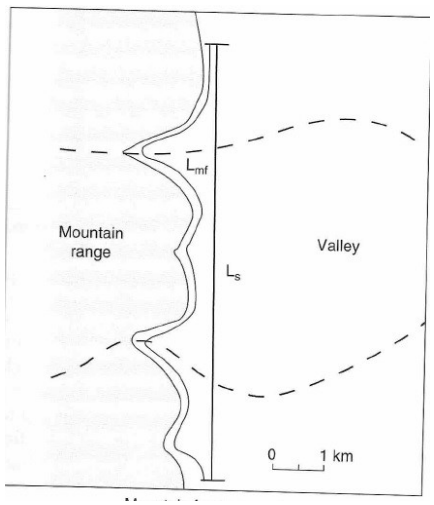

Figure 5. Illustration method of Mountain front sinuosity (Smf) according to Keller and Pinter (1996)

Index of active tectonics (IAT)

The average of the four measured geomorphic indices was calculated to evaluate the Index of active tectonics (IAT) in the study area which is the most important and widely used geomorphic index. This index represents a summary and average of the given geomorphic indices where used in the study as follows:

$$IAT=S/N$$

Where S represents the sum of previous indices and N represents the number of selected indices (Habibi & Gharibreza, 2015). The values of the index were divided into four classes to define the degree of active tectonics: 1—very high ($1.0 \leq IAT < 1.5$); 2—high ($1.5 \leq IAT < 2.0$); 3—moderate ($2.0 \leq IAT < 2.5$); and 4—low ($2.5 \leq IAT$) (Mosavi & Arian, 2015).

Tabel 1. Range of geomorphic indices (IAT) (El. Hamdouni et al., 2007)

No	Aspect	Relative tectonic activity		
		Class 1 (high tectonic activity)	**Class 2 (moderate tectonic activity)**	**Class 3 (low tectonic activity)**
1	AF	(AF > 65 or AF < 35)	(35 < AF < 43 or 57 < AF <65)	(43 ≤ AF < 57)
2	Vf	Vf <0,3	(1 < Vf <0,3)	Vf >1
3	Bs	Bs > 4	(3 < Bs < 4)	Bs < 3
4	Smf	Smf < 1,1	(1,1< Smf < 1,5)	Smf > 1,5

III. RESULTS AND DISCUSSION

In this study to analyze tectonic activity classes used several parameters of morphometry namely, Asymmetry factor (Af),Basin shape index (Bs) index, Mountain front sinuosity (Smf), and Valley floor width-valley height ratio (Vf). The values obtained from these morphometric parameters are used to analyze the index of tectonic activity (Keller and Pinter, 2002). The tectonic classes refers to El Hamdouni et al. (2007) as listed in Table 1.

Tabel 2. Value of Asymmetry factor (Af) in research area

Basin	Ar	At	Af
Ckp1	2,29	5,54	41,34
Ckp2	5,01	8,48	59,08
Ckp3	0,94	1,30	72,31
Ckp4	0,80	2,76	28,99
Ckp5	0,24	0,62	38,71
Ckp6	35,28	51,56	68,43
Ckp7	2,27	4,09	55,50
Ckp8	1,73	4,28	40,42
Ckp9	0,38	1,67	22,75
Ckp10	8,91	13,62	65,42
Average			49,29

The tectonic classes division based on the Af values can be divided into three classes; class 1 (Af> 65 or Af<35), class 2 (35 <Af <43 or 57 <AFf<65), and class 3 (43 <Af < 57) (El Hamdouni et al., 2007). The Af calculation results from 10 basin of Cikapundung Sub-watershed shows an average value of AF worth 49.49 which belongs to grade 3 (low tectonic activity).

Tabel 3. Value of basin shape index (Bs) index in research area

Basin	BI	BW	BS
Ckp 1	4380	1682	2,60
Ckp 2	3366	3191	1,05
Ckp 3	1994	809	2,46
Ckp 4	3353	1079	3,11
Ckp 5	1503	677	2,22
Ckp 6	6738	9756	0,69
Ckp 7	4321	1472	2,94
Ckp 8	3862	1477	2,61
Ckp 9	2034	978	2,08
Ckp 10	8255	2700	3,06
Average			2,28

The tectonic classes division based on the value of Bs can be divided into three classes; class 1 (Bs> 4), class 2 (3 <Bs <4), and class 3 (Bs <3) (El Hamdouni et al., 2007). The results of BS from 10 basins of Cikapundung Sub-waters show the average value of Bs worth 2.28 which belongs to grade 3 (low tectonic activity).

The tectonic classes division based on Smf values can be divided into three classes; class 1 (Smf <1,1), class 2 (1,1 1.5) and class 3 (Smf> 1.5) (El Hamdouni Et al., 2007). The Smf calculation results from 10 basins of Cikapundung Sub-waters show an average value of Smf worth 2.45 which belongs to grade 3 (low tectonic activity).

Smf value generally has almost the same variation value, except on Smf6-2, Smf6-6, Smf6_2, Smf6-6, and Smf9-1 which has a larger Smf value. This greater Smf value can occur due to lithologic response factor that is less resistant so that the erosion is very high and change the shape of river basin becomes wider and U-shaped. The big smf value if correlated with geological map of bandung (Silitonga, 1973) lies in sandy tuff (Qyd), pumiceous tuff (Qyt), and Colluvium (Qc) which have lower weathering and erosion resistance than an undifferentiated old volcanic products (Qvu) and an undifferentiated young volcanic products (Qvy), which is dominated by breccia and lava.

Tabel 4. Value of mountain front sinuosity (Smf) in research area

Basin	Kode	Lmf (Km)	Ls (Km)	Smf	Average
1	Smf1_1	3,29	1,25	2,63	2,97
	Smf1_2	2,47	0,74	3,34	
	Smf1_3	2,56	0,87	2,94	
2	Smf2_1	1,88	0,78	2,41	2,59
	Smf2_2	1,16	0,50	2,32	
	Smf2_3	1,22	0,40	3,05	
3	Smf3_1	2,20	0,91	2,42	2,50
	Smf3_2	1,88	0,90	2,08	
	Smf3_3	2,98	1,00	3,00	
4	Smf4_1	0,88	0,45	1,97	1,80
5	Smf5_1	1,67	0,64	2,60	2,47
	Smf5_2	1,30	0,48	2,72	
	Smf5_3	1,17	0,56	2,10	
6	Smf6_1	2,16	1,80	1,20	2,28
	Smf6_2	4,31	1,20	3,60	
	Smf6_3	2,20	1,50	1,47	
	Smf6_4	2,52	1,20	2,10	
	Smf6_5	3,52	1,80	1,96	
	Smf6_6	4,04	1,20	3,37	
7	Smf7_1	1,30	0,78	1,68	2,04
	Smf7_2	1,70	0,73	2,32	
	Smf7_3	1,60	0,75	2,12	
8	Smf8_1	1,86	1,14	1,63	2,12
	Smf8_2	2,63	1,14	2,31	
	Smf8_3	2,81	1,16	2,43	
9	Smf9_1	3,32	0,81	4,09	3,08
	Smf9_2	2,71	1,01	2,68	
	Smf9_3	4,36	1,77	2,46	
10	Smf10_1	1,83	0,73	2,50	2,67
	Smf10_2	3,13	1,10	2,85	
	Smf10_3	1,62	0,61	2,66	

The tectonic classes division based on Vf value can be divided into three classes, namely class 1 (Vf <0.3), class 2 (1 <Vf <0.3), and class 3 (Vf> 1) (El Hamdouni et al., 2007). The Smf calculation result from 10 basins in Cikapundung Sub-watershed shows the average value 1.19 which belongs to grade 3 (low tectonic activity).Vf1 up to Vf80 values generally have variations of values that are almost equal or not much of a difference except for Vf25, Vf26, Vf28, Vf35, Vf36, Vf39, Vf63, Vf71, and Vf75 values calculation with greater Vt values. The greater Vt value can occur due to lithologic response factor that is less resistant so that the erosion is very high and change the shape of the river basin becomes wider and U-shaped. The large Vt value if correlated with the geological map of bandung (Silitonga, 1973) Lies in sandy tuff (Qyd),pumiceous tuff (Qyt), and colluvium (Qc) which have lower weathering and erosion resistance than an undifferentiated old volcanic products (Qvu) and an undifferentiated young volcanic products (Qvy), which is dominated by breccia and lava.

Tabel 4. Value of Valley floor width-valley height ratio (Vf) in research area

Kode	Eld (m)	Erd (m)	Esc(m)	Vfw (m)	Vf
Vf1	1649	1700	1600	5	0,07
Vf2	1525	1487	1462	44	1,00
Vf3	1412	1424	1400	17	0,94
Vf4	1387	1387	1337	68	1,36
Vf5	1287	1224	1211	63	1,42
Vf6	1674	1724	1650	44	0,90
Vf7	1662	1649	1625	40	1,31
Vf8	1937	1937	1875	72	1,16
Vf9	1737	1699	1686	33	1,03
Vf10	1662	1612	1599	14	0,37
Vf11	1482	1400	1387	42	0,78
Vf12	1362	1375	1324	47	1,06
Vf13	1349	1362	1325	76	2,49
Vf14	1649	1662	1637	35	1,89
Vf15	1700	1687	1649	9	0,20
Vf16	1262	1262	1237	33	1,32
Vf17	1274	1248	1237	46	1,92
Vf18	1099	1100	1087	20	1,60
Vf19	1124	1137	111	181	0,18
Vf20	1287	1224	1211	63	1,42
Vf21	1224	1224	1187	29	0,78
Vf22	1337	1287	1274	64	1,68
Vf23	1224	1175	1112	36	0,41
Vf24	1162	1198	1137	44	1,02
Vf25	1162	1162	1137	96	3,84
Vf26	1174	1174	1132	132	3,14
Vf27	1199	1199	1162	92	2,49
Vf28	1225	1187	1174	72	2,25
Vf29	1212	1250	1199	64	2,00
Vf30	1325	1312	1287	28	0,89
Vf31	1412	1412	1374	62	1,63
Vf32	1387	1362	1337	21	0,56
Vf33	1287	1312	1262	10	0,27
Vf34	1424	1449	1387	13	0,26
Vf35	1687	1687	1675	54	4,50
Vf36	1599	1599	1587	43	3,58
Vf37	1487	1500	1467	5	0,19
Vf38	1287	1312	1262	10	0,27
Vf39	1237	1187	1162	188	3,76
Vf40	1462	1400	1346	90	1,06
Vf41	812	812	787	34	1,36
Vf42	912	924	874	21	0,48
Vf43	1024	1000	937	20	0,27
Vf44	1024	1024	987	15	0,41
Vf45	1075	1075	1049	40	1,54
Vf46	1124	1137	1062	10	0,15
Vf47	1149	1187	1124	37	0,84
Vf48	1100	1112	1087	17	0,89
Vf49	1237	1224	1199	56	1,78
Vf50	1074	1074	1049	18	0,72
Vf51	899	937	874	99	2,25
Vf52	999	999	974	68	2,72
Vf53	1024	1024	999	24	0,96
Vf54	1062	1062	1024	38	1,00
Vf55	1062	1074	1012	13	0,23
Vf56	1137	1124	1087	14	0,32
Vf57	1199	1237	1162	46	0,82
Vf58	1237	1249	1174	10	0,14
Vf59	1149	1187	1124	67	1,52
Vf60	1274	1300	1250	64	1,73
Vf61	862	862	849	7	0,54
Vf62	912	862	849	30	0,79
Vf63	837	824	799	89	2,83
Vf64	986	887	862	95	1,28
Vf65	962	987	912	44	0,70
Vf66	1062	1062	1024	52	1,37
Vf67	1100	1112	912	18	0,09
Vf68	1212	1187	1175	44	1,80
Vf69	987	999	937	25	0,45
Vf70	1250	1224	962	10	0,04
Vf71	812	812	787	34	1,36
Vf72	912	924	874	21	0,48
Vf73	1024	1000	937	20	0,27
Vf74	1024	1024	987	15	0,41
Vf75	1075	1075	1049	40	1,54
Vf76	1124	1137	1062	10	0,15
Vf77	1149	1187	1124	37	0,84
Vf78	1100	1112	1087	17	0,89
Vf79	1237	1224	1199	56	1,78
Vf80	1074	1074	1049	18	0,72
		Average			1,19

The tectonic classes division based on Vf value can be divided into three classes, namely class 1 (Vf <0.3), class 2 (1 <Vf <0.3), and class 3 (Vf> 1) (El Hamdouni et al., 2007). The Smf calculation result from 10 basins

in Cikapundung Sub-watershed shows the average value 1.19 which belongs to grade 3 (low tectonic activity).Vf1 up to Vf80 values generally have variations of values that are almost equal or not much of a difference except for Vf25, Vf26, Vf28, Vf35, Vf36, Vf39, Vf63, Vf71, and Vf75 values calculation with greater Vt values. The greater Vt value can occur due to lithologic response factor that is less resistant so that the erosion is very high and change the shape of the river basin becomes wider and U-shaped. The large Vt value if correlated with the geological map of bandung (Silitonga, 1973) Lies in sandy tuff (Qyd), pumiceous tuff (Qyt), and colluvium (Qc) which have lower weathering and erosion resistance than an undifferentiated old volcanic products (Qvu) and an undifferentiated young volcanic products (Qvy), which is dominated by breccia and lava.

IV. CONCLUSION

It seems that the calculated geomorphic indices by using GIS are suitable for assessment of the tectonic activity in the study area. The geomorphic indices such as Asymmetry factor (AF), Ratio of valley width and valley height (Vf), Basin shape index (Bs), and Mountain front sinuosity (Smf) are calculated 10 basins of the Cikapundung Sub watershed. Based on the morphometric analysis, Index of active tectonics (IAT) in research area includes a low tectonic class (class 3). Whereas the larger Smf and Vf calculations may indicate a lower rock resistance effect on the erosion and weathering process to form a U-shaped basin.

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