

INTERPRETING FAULT STRUCTURE EXISTENCE BASED ON GEOMORPHOLOGY QUANTITATIVE ANALYSIS IN BALEENDAH-CIPARAY AREA, BANDUNG, WEST JAVA

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Abstract

The research area is located in Cisangkuy sub watershed and Citarum upstream sub watershed (Baleendah-Ciparay, Bandung, West Java). This research was conducted to identify the existence of fault structures as an initial effort to overcome the landmovement in the research area. This research is done through quantitative geomorphology analysis and field observation. DEM-SRTM analysis was conducted to find indication of fault structure while spatial analysis was done to obtain morphometric data of sub watershed in research area. Field observations were conducted to determine the manifestation of fault structures and their impact on landmovement in the study area. The area of research is dominated by volcanic rocks from the late Miocene to Plistocene and the slopes are dominantly steep. Based on DEM-SRTM analysis, the strongly indicated main straightness pattern is a fault structure developing in relatively west-east trending research areas. Based on spatial analysis, watershed and watershed ratio (Rb) values is <3 and > 5 which is indicate strong indications of fault structures developing in the study area. The value of watershed density (Dd) between 1.86 - 7.83. That shows the river flow through hard rock and transporting a slight sediment material. The existence of a fault structure is characterized by the presence of a slicken side, joint, and springs. The existence of fault structures also caused the landmovement in the research area. Based on hypsometric analysis, the relative age of the landscape is young. Therefore, the initial effort to overcome the landmovement by tracing the vulnerable location of the land movement should involve a quantitative geomorphology approach. The result of this research based on quantitative geomorphology analysis can be used as the foundation in the early effort of prevention of land movement in research area and the other area.

Keywords: landmovement, watershed, quantitative geomorphology

Introduction

Citarum watershed is the largest watershed in West Java Province and surrounded by several mountains such as Mount Tangkuban Perahu, Mount Mandalawangi, and Mount Patuha Malabar. The Citarum watershed has an area of 6,614 km² which runs through Bandung, Purwakarta, Subang, and Bekasi districts. Geologically, the Citarum watershed and several sub watersheds have complex geological conditions, both from rock and structural aspects.

Geographically, the study area is located between 7°0'9,9" LS - 7°4'12,7" LS and 107°35'35,5" BT - 107°42'6,9" BT. Administratively, the research areas are included Baleendah and Ciparay Subdistricts, Bandung Regency, West Java and located in the Cisangkuy and Citarum Hulu watershed.

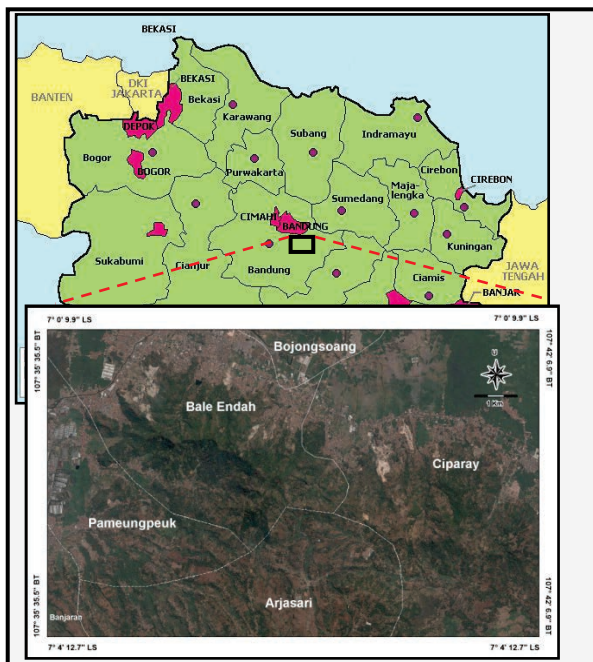


Figure 1. Research Area

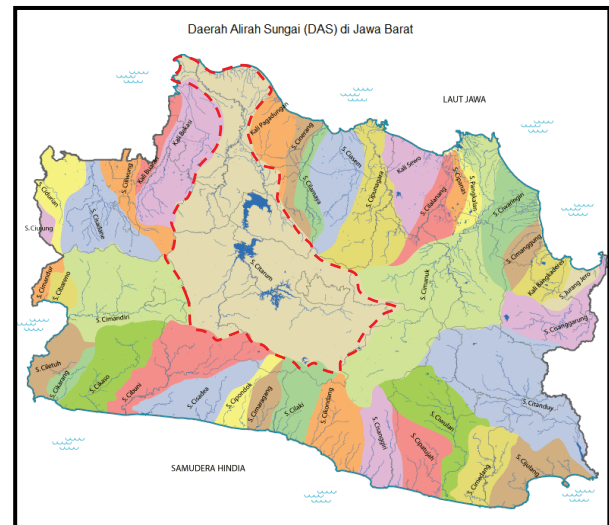


Figure 2. Citarum Watershed between the other watershed in West Java

Watershed is a water system consisting of surface and subsurface water streams (Hugget, 2007) that are limited by the ridges (Asdak, 1995). In West Java there are 40 watersheds (Anonymous, 2004). The Citarum watershed with sub watersheds such as Cisangkuy and Citarum Hulu watershed have been widely studied from various geological aspects, one of which is the geological structure. The growing geological structure will affect the tectonic and vulnerability conditions of the region. Research aims to identify fault structures as an initial effort to mitigate land movement in Baleendah-Ciparay, West Java through quantitative geomorphology and field observation.

The study area is included in the Quaternary Volcanic Zone. Quarter Volcanic Zone is a young volcanic sediment area between Bogor Zone and Bandung Zone (Martodjojo, 2003). Van Bemmelen (1949; in Martodjojo, 2003) states that the Bandung Zone is an intermountain depression. Bandung Zone is the peak of West Java geantiklin lifted then collapsed to form a low area. This low area is filled with young volcanic deposits or Quaternary volcanic deposits.

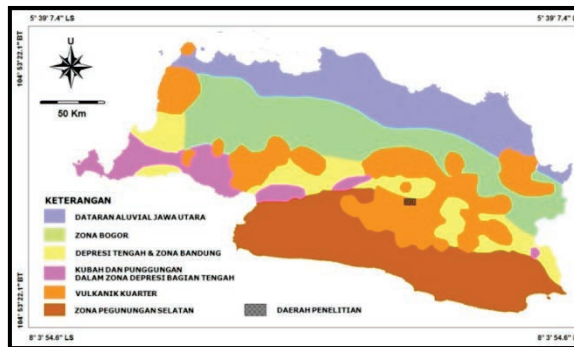


Figure 3. The Physiography of West Java (Van Bemmelen, 1949)

Java Island formed a folding and fault system due to the Eurasian Plate collision process moving south and the Indian Plate moving north. As a result, the folding axis tends to west-east direction. Suwiyanto (1978, in Martodjojo, 2003) identifies the four major directions of Landsat image alignment in West Java, U45°T, U10°T, U30°B, and U55°B. From the results of research, most of the straightness is recognized as a fault. The results of this study also reinforce that the regional pattern of geological structure of West Java is relatively west-east direction.

Sukiyah (1993) states that the analysis of straightness pattern with aerial photographs can be done to determine the condition of deformation of a region. Multiple and intersecting patterns, both ridge and river, indicate areas susceptible to deformation and indicated active tectonic control. Main et al. (2012) suggests that the watershed analysis can help determine the morphology of a region as well as the existence of the fracture. The fracture can be identified through the straightness of the contours at significant elevation. Contour differences are looked from the effect from the shadow of the fault.

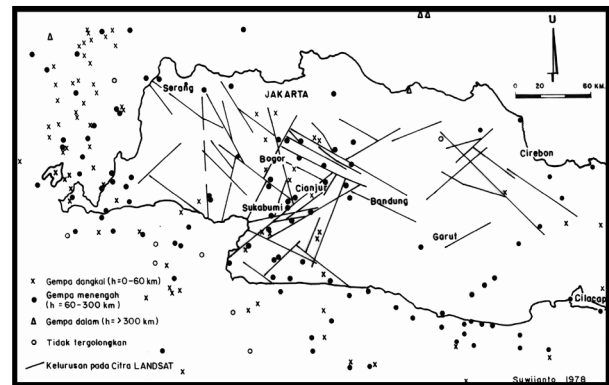


Figure 4. The main direction of Landsat image alignment in West Java according to Suwiyanto (1978; in Martodjojo, 2003)

The areas that susceptible to deformed and controlled tectonics can actively undergo mass movement. Mass movement is the movement of the soil or rocks in an upright, flat, or sloping direction from the original position. The displacement involves the release of rock material from the top of the slope to the foot of the slope due to slope instability and gravity (Sharma, 2010). Hutchinson (1968; in Hansen, 1984) states that the movement of the soil includes the creep and landslide. Varnes (1984) argues that landslides consist of fall, topple, slide, flows, and lateral spread. Mass movement on the ground, debris accumulation, and on the base rock can occur and stop at any time. This process is destructive if it destroys the infrastructure. Therefore, the movement of the land must be wary and immediately sought the solution.

Methodology

The object of this research are slope, river, fault structure, and mass movement. The object is examined through quantitative geomorphology and field observation. Quantitative geomorphological analysis involves DEM-SRTM analysis and spatial analysis. DEM-SRTM is used to know the indication of fault structure whereas spatial analysis is done with slope map, regional

geology map, and river flow pattern map to know morphometry data of sub watershed. Field observation to determine the manifestation of fault structures and their impact on mass movement in the study area.

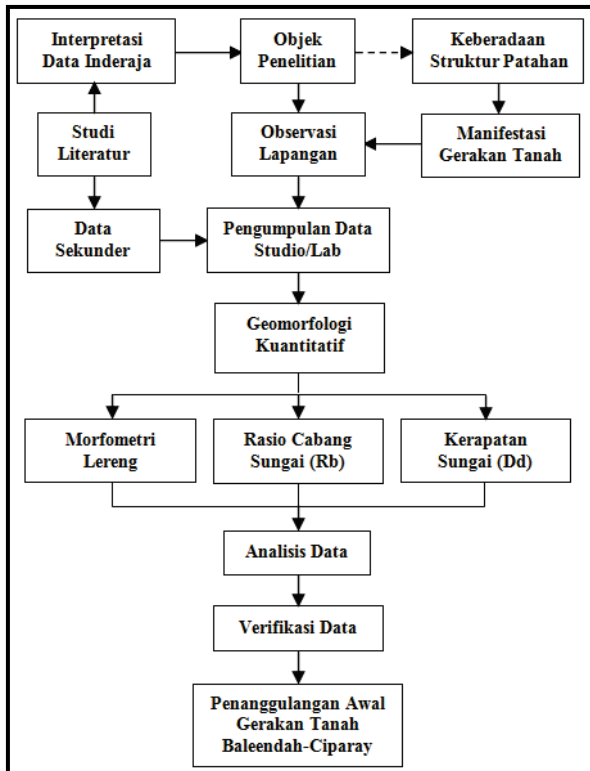


Figure 5. Research framework

Slope Morphometry

The slope shows the angle of the slope in percent / degree (Saribun, 2007). The slope of the slope can be determined with a 1: 50,000 scale topographic map and 1 x 1 cm grid-cells. Each grid-cell is drawn perpendicular to the contour (Zakaria, 2008). The drawing is used in slope calculation:

$$S = \frac{(n-1) \cdot Ic \cdot 100}{dx \cdot sp} \quad (1)$$

Notes:

S = slope slope (%); n = number of contours cut off flat lines; Ic = Index contour interval; dx = flat line distance perpendicular to the contour; sp = map scale

Kelas Lereng	Sifat-sifat proses dan kondisi alamiah	Warna
0 - 2° (0-2 %)	Datar hingga hampir datar; tidak ada proses denudasi yang berarti	Hijau
2 - 4° (2-7 %)	Agak miring; Gerakan tanah kecepatan rendah, erosi lembar dan erosi alur (sheet and rill erosion). rawan erosi	Hijau Muda
4 - 8° (7 - 15 %)	Miring; sama dengan di atas, tetapi dengan besaran yang lebih tinggi. Sangat rawan erosi tanah.	Kuning
8 - 16° (15 -30 %)	Agak curam; Banyak terjadi gerakan tanah, dan erosi, terutama longsoran yang bersifat nendatan.	Jingga
16 - 35° (30 - 70 %)	Curam; Proses denudasional intensif, erosi dan gerakan tanah sering terjadi.	Merah Muda
35 - 55° (70 - 140 %)	Sangat curam; Batuan umumnya mulai tersingkap, proses denudasional sangat intensif, sudah mulai menghasilkan endapan rombakan (koluvial)	Merah
>55° (>140 %)	Curam sekali, batuan tersingkap; proses denudasional sangat kuat, rawan jatuhnya batu, tanaman jarang tumbuh (terbatas).	Ungu

Figure 6. Slope Classification (Van Zuidam, 1985; in Noor, 2010)

River Flow Patterns

Howard (1967) has divided the flow patterns into several groups (Figure 7). Characteristic of river flow pattern is geomorphology study to know tectonic condition in a region. The result of tectonic movement which can be related to the geological structure can be seen in the system of river flow pattern.

Watershed Morphometry

Morphometry is defined as the quantitative aspect of a landform (van Zuidam, 1985). The watershed morphometry is a way of providing a quantitative assessment of a watershed. Watershed morphometry deals with geological aspects such as topography, rock types, and climatic conditions in an area. Watershed morphometry includes wide watershed, river basin ratio, and river flow density.

Wide watersheds can be calculated with topographic map (Sosrodarsono and Takeda, 2003; in Hidayah, 2008). If the watershed limit has been determined, then the

area of the watershed can also be known. (Priyono and Savitri, 1997; in Hidayah, 2008).

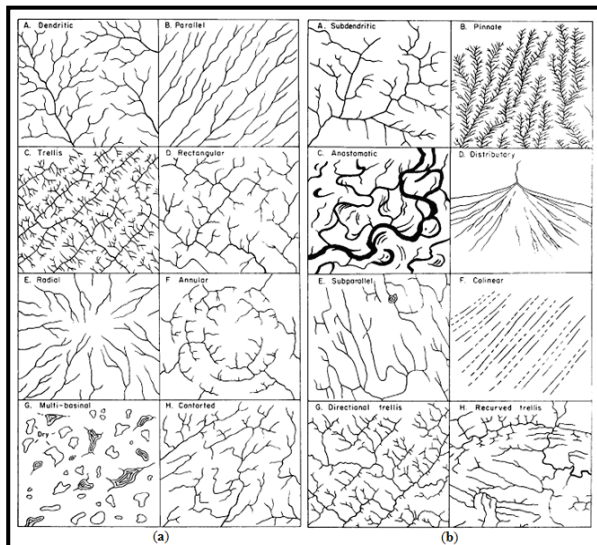


Figure 7. Basic Flow Pattern (a) and modification (b)

Bifurcation ratio is the branching position of the river channel in the order of the river parent in a watershed (Soewarno, 1991; Ramdan, 2006). The ratio of river branch (R_b) is expressed as the ratio between the number of river segments u (N_u) and the number of river segments u + 1 (N_{u + 1}) (Strahler, 1964, Hidayah, 2008):

$$R_b = N_u / N_{u+1} \quad (2)$$

Strahler (1964; in Verstappen, 1983) states that if a watershed has bifurcation ratio of less than 3 or more than 5 then it is indicated that the watershed has been deformed due to active tectonics.

Drainage density is an index showing the number of tributaries in a watershed. Drainage density shows the rock hardness and geological condition of a region. The value of river flow density, the total river length (L) contained in a watershed divided by the watershed (A) (Strahler, 1957, Hidayah, 2008):

$$D_d = \Sigma L / A \quad (3)$$

Table 1. Classification of Drainage density (Hidayah, 2008)

Drainage Density (D _d)	Class (D _a)	Characteristics of River Flow Density
< 0,25	Low	A low-to-moderate value indicates the river channel passes through hard resistance rocks so that the transport of sediments transported by the stream is smaller.
0,25 – 10	Medium	
10 – 25	High	High - very high value indicate the flow of the river through the waterproof rocks, rainwater that becomes runoff will be greater.
> 25	Very High	

Result and Discussion

Geology of Research Area

The geology of the study area consists of 4 rock formations (Alzwar et al., 1992). The formation is dominated by volcanic rocks from the Late Miocene to the Holocene. The physical properties of the rocks ranging from loose to very hard. Under geologic conditions, the fracture structure can be estimated through the Geological Map (Figure 8).

Table 2. Rock formations in the research area

Formation	Lithology Information	Age
(Qd) Lake Sediment	Clay, silt, fine to coarse sand, gravel, tuffed	Holocene
(Qmt) Volcanic Rock Malabar-Tilu	Tuf, lava breccias contain a little bit of pumice and lava	Pleistocene
(Qwb) Andecite Waringin-Bedil, Malabar Tua	Lava, breccias and tuffs, arranged by andesite pyroxene and hornblende	Pleistocene
(Tmt) Beser Formation	Breccia tufan and lava, arranged andesite to basalt	Late Miocene

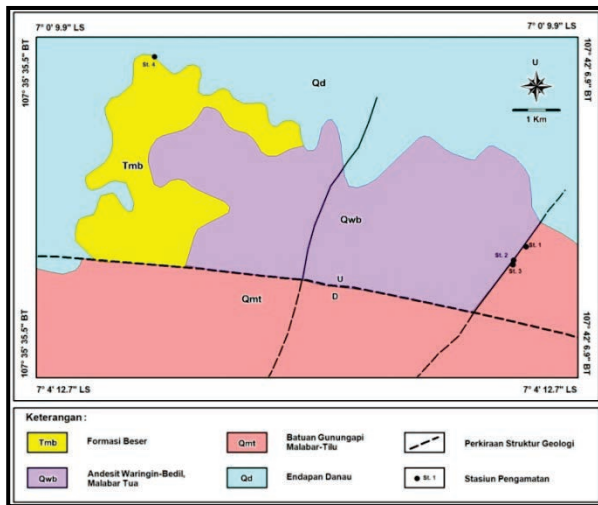


Figure 8. Geological Research Area (Alzwar dkk., 1992)

Morphology of Research Areas

The morphology of the study area consists of four slope classes, ie flat, slightly sloping, somewhat steep, and steep. The geological condition of the research area can be identified through the slope slope map (Figure 9). Endogenous processes (volcanism and structural) develop in the middle to the south. This can be seen from rock products dominated by volcanic rocks as well as an indication of a growing structure in the middle of the study area.

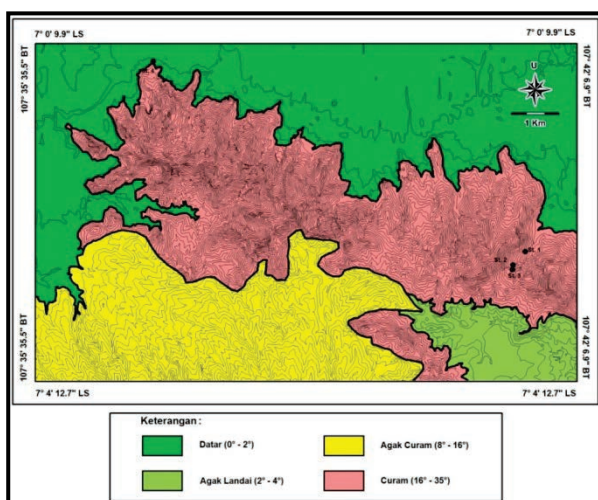


Figure 9. Slope map of the research area

Interpretation of the existence of fault structures

The landscape and various visions on the surface of the earth can be formed by tectonics. On a local and regional scale, tectonic phenomena are recognized from several distinctive landscapes such as gawir, valleys, hilly and streamlines, river flow patterns, and so forth (Doornkamp, 1986). The existence of fault structures should be identified by DEM-SRTM and field observations. The existence of fracture structure in the field can be reviewed from several aspects, namely:

1. Lineament of DEM-SRTM
2. River flow pattern
3. Morphometry of sub watershed
4. Fault scarp
5. Joint
6. Water springs

1. DEM-SRTM

The morphology and indication of fracture structure of the study area can be identified through DEM-SRTM. The area of research is dominated by longitudinal hills in the middle to the south while the plain in the west and north. The existence of fault structures can be identified by early indication of lineament. The main straightness pattern of the west-east trending research area. This pattern of structure shows a close relationship with the pattern of geological structure of West Java which is relatively west-east direction.

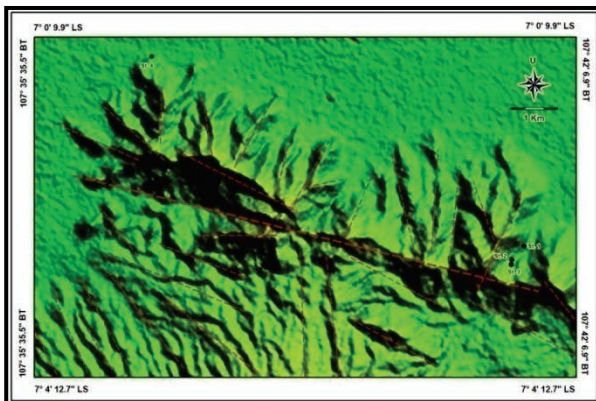


Figure 10. The straightness of DEM-SRTM shows the research area associated with the fracture structure

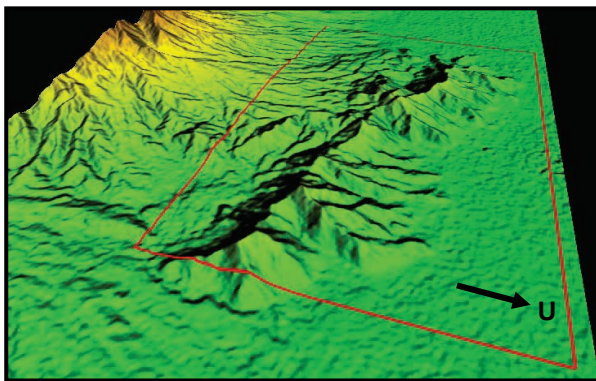


Figure 11. Indication of fracture structures in the study area

2. River Flow Pattern

The river flow pattern of the research area consists of five river flow patterns, namely anastomotic, parallel, subdendritic, subtrellis, and rectangular. Analysis of river flow patterns showing the fracture structure can be identified through subtrellis and rektangular patterns. Both patterns of river flow indicate the research area has a fault structure. Cooke and Mortimer (1971; in Doornkamp, 1986) suggest that the channel flow response or the formation of the flow pattern may be affected by tectonics.

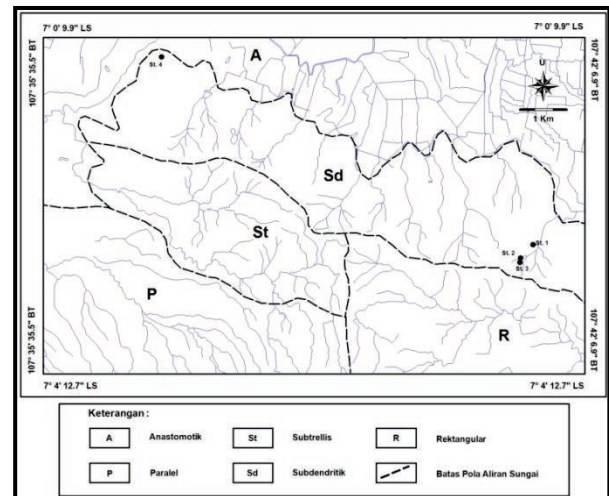


Figure 12. River flow pattern in the research area

3. Morfometri Sub DAS

The research area is located in several sub-watersheds of Citarum and Cisangkuy so that the research area is also influenced by the sub-watersheds condition around it. Based on quantitative geomorphology analysis, the research area and its surroundings consist of 2 Cisangkuy Sub-watersheds and 12 sub-watersheds of Upper Citarum. All the rivers on the sub-watershed are from Mount Malabar in the south and flow to the Citarum River in the northern part of the study area.

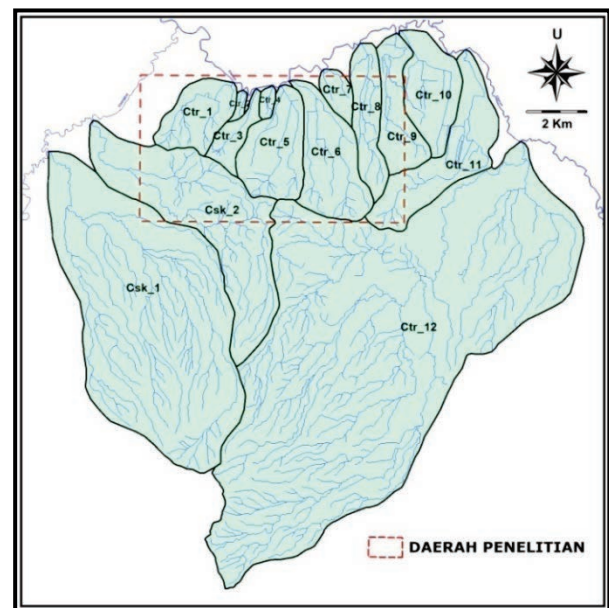


Figure 13. Research areas and sub-watersheds in surrounding

Table 3. Watershed of the study area

SubDAS	Large (km ²)	SubDAS	Large (km ²)
Csk_1	44.72	Ctr_6	7.79
Csk_2	19.41	Ctr_7	1.45
Ctr_1	4.73	Ctr_8	4.59
Ctr_2	0.34	Ctr_9	4.97
Ctr_3	2.03	Ctr_10	6.00
Ctr_4	0.50	Ctr_11	9.00
Ctr_5	6.56	Ctr_12	94.83

Bifurcation Ratio

The Cisangkuy sub-watershed and the Upper Citarum Basin sub-basin in the research area can be further analyzed by dividing the creeks into several river basins. The river order is used to calculate the aspect ratio of the river branch (Rb). Based on the analysis of the river basin ratio, all sub watersheds in the study area were dominated by the ratio of river branch (Rb) less than 3 and more than 5. Geologically, Rb value less than 3 and more than 5 indicates tectonic influence.

Table 4. Bifurcation Ratio (R_b) Sub DAS

SubDAS	R _{b1-2}	R _{b2-3}	R _{b3-4}	R _{b4-5}
Csk_1	1.94	1.78	2.25	2.00
Csk_2	1.81	2.33	1.29	7.00
Ctr_1	1.60	5.00	1.00	
Ctr_2	2.00			
Ctr_3	1.25			
Ctr_4	2.00			
Ctr_5	1.86	1.40		
Ctr_6	1.27	5.50		
Ctr_7	2.00			
Ctr_8	1.83	1.50		
Ctr_9	3.50	0.50		
Ctr_10	1.75	2.00		
Ctr_11	2.60	0.71		
Ctr_12	1.95	1.63	2.43	4.20

Drainage Density

Drainage density is influenced by the number of tributaries in sub-watersheds. These values indicate the characteristics and permeability of the soil. Based on the analysis of river flow density values, all sub watersheds in the study area have a drainage density (D_d) value between 1.86 - 7.83. Geologically, the D_d value between 0.25 - 10 is included in the medium category and shows the flow of the river through hard-hardened rocks so that the transported sediment material is not much. This is evidenced by geological maps (Figure 8) and field observations which indicate that the study area is dominated by volcanic products.

Table 5. Drainage Density (D_d) Sub DAS

SubDAS	D _d	SubDAS	D _d
Csk_1	2,86	Ctr_6	2.58
Csk_2	2,79	Ctr_7	1.86
Ctr_1	2,67	Ctr_8	3.11
Ctr_2	4,36	Ctr_9	2.44
Ctr_3	1,97	Ctr_10	2.16
Ctr_4	7,83	Ctr_11	2.22
Ctr_5	2,48	Ctr_12	2.92

4. Fault Scarp

Fracture structures have a very clear effect on the field of fractures in the field. The field is called a fault scarp. Fault scarp is an indication of the existence of a fault structure that can be found clearly in the research area and associated with the mass movement. Cotton (1948, in Doornkamp, 1986) states that fault scarp is one of the units or morphological formations that are closely related to tectonics. This causes fault areas tend to be susceptible to erosion and movement of the soil. Intensive erosion will lead to the appearance of a long straight valley.



Figure 14. The fault region is characterized by a fault escarpment

5. Joint

Joint is a fracture structure in rocks with little shift. Stacking age is also relatively difficult to determine because joint can be formed at any time geologic events. Joint in the study area had relatively small fractures, fairly regular patterns, and cut all the rocks. The analysis of solid data with rose diagrams shows structural patterns in relatively western-east trending research areas. The pattern of this structure shows a close relationship with the pattern of geological structure of West Java which is relatively west-east direction.



Figure 15. Andesite lava shows joint structure

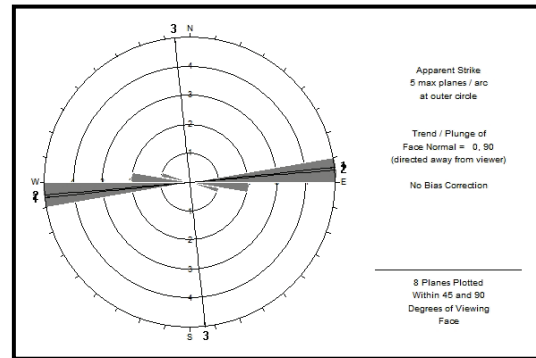


Figure 16. Rose diagram of the results of joint data processing

6. Water springs

The springs found in the study area are thought to originate from the Sedimentary Sedimentary System of Volcanic (Puradimadja, 1993). This aquifer system is formed from andesite lava and other volcanic rocks produced by Malabar Volcano product. The emergence of this spring is suspected because of the geological structure that developed in the research area in the form of fracture. Fractures as a medium can alter impermeable rocks such as lava or brecciated breccias into rocks that can drain groundwater.



Figure 17. The springs appear through fractures in the andesite lava (arrows)

Mass Movement and Countermeasures

The existence of fault structures is suspected to be associated with instability of

the slopes in the study area resulting in the occurrence of soil movement. The soil movement can be seen from the movement of the soil mass from the original position vertically (Figure 18). In addition, the movement of soil in the research area impacted on the damage to the bridge so as to interfere with the convenience of use of the bridge (Figure 19).

Regarding the existence of ground motion in the area of research, early countermeasures are certainly needed. Therefore, efforts are needed to map the degree of vulnerability and a comprehensive analysis of the risk of further ground movement. These efforts can be carried out in an integrated manner through initial tracking of vulnerable ground movement locations (quantitative geomorphological approach), study of the main factors causing ground motion, as well as the pursuit of an engineering technique to prevent further ground movement.

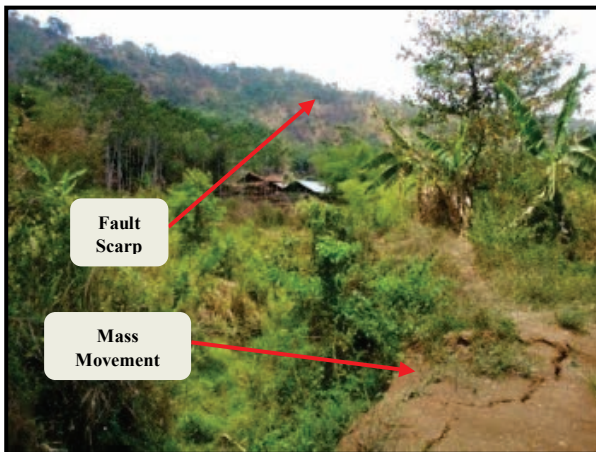


Figure 18. The movement of the soil is affected by the presence of a fault scarp



Figure 19. Cracks on the bridge as a manifestation of ground movement due to fault structures in the study area

Conclusion

The existence of a relatively east-west trending fault structure in the research area can be identified through quantitative geomorphology and field observation. The existence of a fault structure is suspected to be associated with ground motion in the study area. The movement of the land has a negative impact on the infrastructure of the bridge to the detriment of the community. Therefore, the prevention of ground movement through mapping the degree of vulnerability of soil movement and further analysis of the risk of ground movement should be undertaken. Initial efforts to overcome land movements by tracking vulnerable locations of land movements in an area should involve a quantitative geomorphology approach.

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