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Morphotectonic study of a watershed controlled by active fault in Southern Garut, West Java, Indonesia

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Abstract

This research aimed to analyze geomorphological shapes of the Cilaki watershed in Southern West Java in relation to geological structures using a geomorphological approach . The Cilaki watershed is characterized by wide valley shapes in the mid to upstream areas and narrow valley shapes in the downstream area, which shape is like a wine glass. The Cilaki watershed is dominated by Quaternary volcanic deposits, while in the downstream area Tertiary sedimentary rocks are exposed. The Cilaki watershed appears to be controlled by active fault, but it isn't known how its stage of activities. The morphotectonic analysis focuses on the influences of geological structures on the shape of the watershed using remote sensing method. The tectonic frame is determined by tectonical analysis base on Southern West Java tectonic setting. We divide the morphotectonic study of the Cilaki watershed into three parts: 1) the quantitative characteristics of the geomorphology; 2) morphometrical analysis; and 3) characteristics of the geological structures. The shape and boundaries of the Cilaki watershed are determined by their structural influences. The lithology of the Cilaki watershed is controlled by resent tectonic activities with class 1, because both the Quaternary volcanics and the Tertiary sedimentary rocks are systematically cut off by faults. The morphotectonic analysis offers a method that may support other studies concerned with neotectonics.

Keywords: Active fault, Cilaki watershed, Morphotectonic, Remote sensing.

1. Introduction

This study aims to define the influences of active fault structures on the shape and boundaries of the Cilaki watershed in the Cisewu areas, southern West Java. The subduction of the Indian-Australian tectonic plate underneath the Eurasia plate (Fig. 1a) has shaped the geological setting of Java (Darman and Sidi, 2000; Verstappen, 2010; Simandjuntak, 2015). The development of regional north-south oriented stress fields has resulted in compressional faulting in West Java during the Plio-Pleistocene, with dominating fault orientations directed North-South, West-East, Northwest-Southeast, and Northeast-Southwest (Hilmi and Haryanto, 2008). The reasearch area is affected by strongly regional tectonic activity with evidence for deformation processes and associated with active faults. As an active fault is define refer to Keller et al., (1996) that faults have moved in the past 10,000 years. A potentially active fault is a fault that had moved in the past 2 million years. And the inactive fault is a fault that has not been moved in the past 2 million years. Whereas the active fault is define a fault that moves in the Quaternary period and has the potential to move back in the future (Sukiyah et al., 2016).

The present study used data from field observations and remote sensing method. Morphotectonic approaches and various applications are mentioned in older text books and publications on geomorphology and geology (e.g., Doornkamp, 1986; Keller et al., 1996; Burbank and Anderson, 2009; Sukiyah et al., 2016) concerned tectonic study for many applications. The scope of our research is to study the role that remote sensing can play in morphotectonic analysis and their relation to the shape of watershed. Several researchers have used the morphotectonic analysis (Doornkamp, 1986; Dehbozorgi et al., 2010;

Permana et al., 2015; Sukiyah et al., 2016) to identify geological structures and morphotectonic characteristic with varying implementation in West Java areas. Here we report a new perspective of the genetic of the watershed base on remote sensing in morphotectonic study.

2. Geological setting

The research area is a part of the Garut and Pameungpeuk geological map regional sheet (Alzwar et al., 1992) and Sindang Barang and Bandar Waru geological map regional sheet (Koesmono et al., 1996). The Cilaki watershed area is in Cisewu regency, Southern Garut, West Java, Indonesia (Fig. 1b). The Cilaki watershed and surrounding area is an area that is densely populated and is a popular tourist destination. However, the area suffers from frequent landslides and earthquakes.

West-Java is part of an island arc characterized by tectonics and volcanism (Simandjuntak, 2015). The research area is part of the Southern Mountain Zone of West-Java (Van Bemmelen, 1949). It is a mountainous area with moderate to high slopes and plains occupying the coastal area. Stratigraphically, the research area is composed of the Cretaceous basement rock, Tertiary sedimentary rocks, Quaternary volcanic deposits and Holocene Alluvium, (Alzwar et al., 1992). Several active faults are found in West Java (Fig. 1c), such as the Baribis fault, the Cimandiri fault and the Lembang fault (Van Bemmelen, 1949; Hilmi and Haryanto, 2008). The study of the correlation of a shape of watershed and geological structures in the research area has thus far never been carried out in detail. Previous studies concerning landscape, lithology and geological structure have shown that the research area has been affected by tectonic activity from the Cretaceous up to recent (Hilmi and Haryanto, 2008).

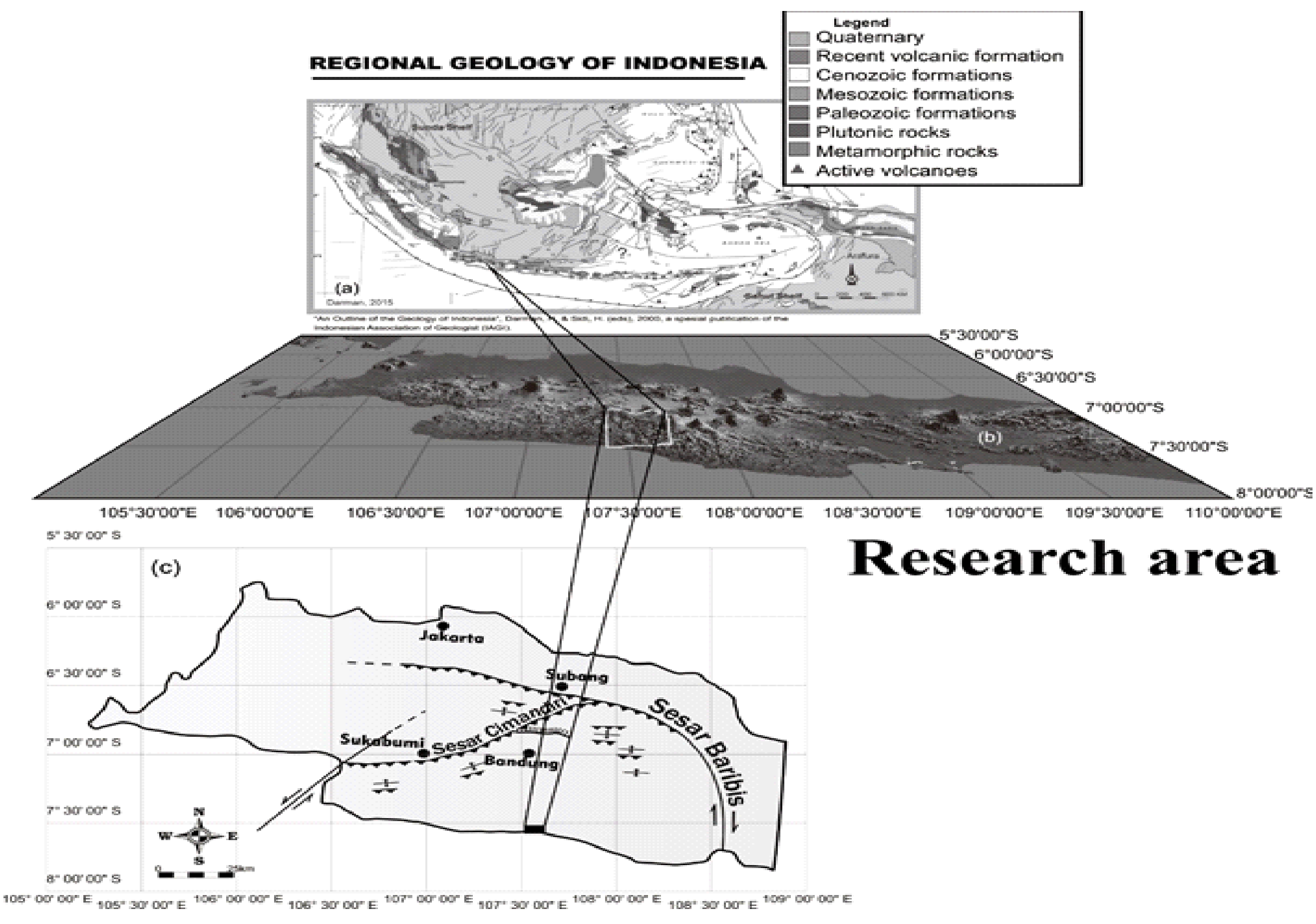

Fig. 1. (a) The regional geological setting of Indonesia; (b) the location of the research area in Cisewu regency, Southern Garut West Java Province; and (c) the major faults of West Java are the Baribis Fault, the Cimandiri Fault and Lembang Fault.

3. Materials and method

The measurements of several morphometry parameters were performed using a Geographic Information System (GIS); topographic maps (scale 1:25.000), geological maps scale 1:50.000 (Remote sensing method), regional geology map scale 1:100.000, digital imagery data from 2016 Aster DEM imagery and 2017 Google Earth imagery. We were used remote sensing method and combined with field observation, which is processed at Geological Agency laboratory Indonesia.

3.1. Morphometry method

The main aspects of geomorphological analysis are morphography, morphogenetic and morphometry (Van Zuidam, 1985). Morphotectonic is defined as a description of the relationship between the tectonic processes and the surficial processes resulting in the formation of geomorphic features (Doornkamp, 1986; Keller and Pinter, 1996; Bull, 2007; Burbank and Anderson, 2009). It's usually related to Quaternary period which recent tectonic activities and active fault. Morphometric measurements are used as a part of a geomorphological analysis that uses quantitative measurements to determine of shape and dimension of landforms, environments, living organisms or other objects (Van Zuidam, 1985). The geomorphic index is a criteria to evaluate the occurrence of recent tectonic activity also known as neotectonic activity (Doornkamp, 1986).

Author has used 6 geomorphic indices to determine the tectonic activity , such as bifurcation ratio (Rb), Basin shape index (Bs), Mountain-front sinuosity (Smf), Valley height-width ratio (Vf ratio), Drainage density (Dd) and Circularity ratio (Rc). Table 3 is showing the results of Cilaki watershed morphometry calculation. Using this approach, the spatial variation in tectonic activity period can be identified.

3.2. Geological structure analysis

A path of isostatic frame and geological structures adjustment analysis in research area utilize geological structural approaches (Prucha, 1964). The geological structures, rosset diagram of joints and structural lineaments analysis is used to determine geological structure characteristic. There is a different method to interpret and identify the result analysis of the geological structures and the morphometric measurements, but most can be eliminated by basic geomorphological analysis (Doornkamp, 1986). The morphotectonic approach was used to determine tectonic activities of the Cilaki watershed.

4. Result and discussion

The tectonic geomorphology has been developed as basic reconnaissance tool to identify a geological structure area effectively (Bull, 2007). The geology map of the research area was reproduced by investigation from remote sensing analysis and field observation, as shown in Figure 2. The investigation of the geological structure is used to reveal the active fault influences on the Cilaki watershed conditions in the research area.

4.1. Morphotectonic characteristic

In recent study, other application of morphotectonic used to understanding of the genetic of the watershed. The Cilaki watershed covers an area of 385.1 km^2. The morphotectonic units of the Cilaki watershed can be subdivided into two periods of tectonic activity. One part is on structural activity resulting from movement tectonic in the Tertiary period, that is represented by faults structure cut off the Tertiary sedimentary rock unit. The other represents a response to post Quaternary period isostatic affected and represented by faults structure cut off the Quaternary volcanic rock unit.

4.1.1. Quantitative geomorphology

The Cilaki watershed was characterized by quantitative geomorphology analysis. The morphography unit of Cilaki watershed were classified into 6 units based on valley shape, elevation and surface areas in km2. The results of the morphometry measurement are shown in Table 1. The various of landscape is a response of the uplift occurrence and deformation processes. The result of morphogenetic analysis is showing the lithology of research area dominated Quaternary volcanic deposit with large 80% research area.

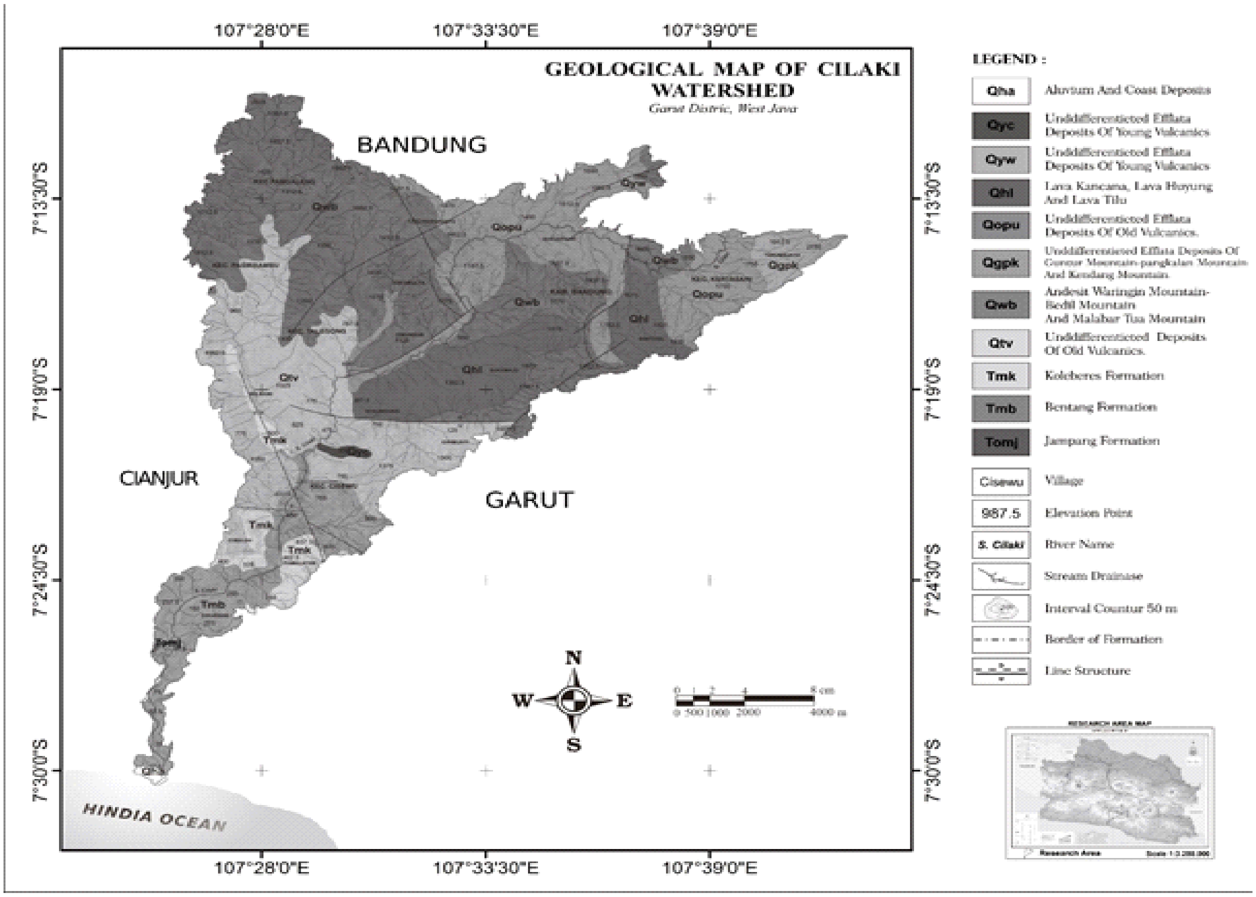

Fig. 2. The geological map of research area, comprising the Cilaki watershed and surrounding regions of Southern Garut, West Java Indonesia.

The uplift process can be caused by volcanic activity and tectonic movement (Permana et. al., 2015). The slope classification units, with slope values ranging from 0%-140% are shown in Table 2. The Cilaki watershed area is subject to strong deformation processes, as is visible in the field observation by the occurrences of strongly varying altitudes, scarps, shear joints, landslides, waterfalls and river terraces.

4.1.2. Tectonic activity

Interpretation of the bifurcation ratio (Rb) values has been done by the classification and calculation methods. The Cilaki watershed consists of stream orders 1 to 5. The average of Rb value of the research area (Quaternary volcanic deposit unit and Tertiary sedimentary rock unit) is Rb value 3.32 with range 2.0-7.0 (Table 3). The Rb value for a watershed with range between 3 and 5 usually identified as a moderate region with homogenous lithology (Sukiyah et al., 2016). In general, Rb values < 3 and > 5 are influenced by tectonic activities. The variation of Rb values in the research area are consistently from 0-2, 3-5 and 6-7, so that Rb values 3-5 suggest low tectonic activity. But in certain regions, the Rb value have values between range 0-2 and 6-7, it can be concluded that deformation is strongly influenced by neotectonic.

The Basin Shape Index (Bs) value is adopted as the whole maximum length (BI) and minimum length (Bw) measurement ratio on each sub watershed. The average Bs value of the entire Cilaki Watershed is 2.56 with a range of 0.79-8.33. The Basin Shape Index (Bs) describes the roundness or elongate of the watershed. A higher value of Bs than average are associated with elongated watershed and therefore with higher tectonic activity relatively. Low values indicated a circular shape watershed and low resent tectonic activity. The average Bs value of the Cilaki Watershed is greater than 2.56, which is suggested a medium to high tectonic activity influence.

The 33 points measurement of Mountain-front sinuosity (Smf) index of Cilaki watershed have been calculated to determine the tectonic activity class. The average Smf value of Cilaki Watershed is 1.219 with the range of 1.036-2.173 (Table 3). Using Smf index formulation provided the following classification: Class 1 active tectonics (Smf = 1.2-1.6), Class 2 moderate to slightly active tectonism (Smf = 1.8-3.4), Class 3 tectonically inactive (Smf = 2.0-7.0) and the Smf value approaches 1.0 with increasing straightness, that is used as an indication of recent uplift (Doornkamp, 1986). Generally, Smf values of Cilaki watershed classified into Class 1 as an active tectonism and associated landform include elongated watershed, steep slope and narrow valley floors. The Smf value can be classified into Class 2 – Class 3 in certainly region. This study concluded that the most active mountain fronts associated with active faults of the area.

Table 1. The morphography classification units

NO	Morphography	Shape of Valleys	Area		Elevation (m)
			km²	%	
1.	Mountain	V	95.16	29.85	1500-3000
2.	High hill	V	184.6	57.91	500-1500
3.	Moderate hill	V	21.11	6.62	200-500
4.	Low hill	V	12.3	3.86	100-200
5.	Hinterland plains	U	3.15	0.99	50-100
6.	Plains	U	2.45	0.01	0-50

Table 2. The slope classification units

NO	Classification	Slope Percentage	Area	
			km²	%
1.	Very steep	70 – 140%	2.56	0.80
2.	Steep	30 – 70%	184.52	57.89
3.	Moderately steep	15 -30%	65.23	20.47
4.	Sloping	7 – 15%	37,24	11.68
5.	Gently slope	2 – 7%	25.5	8.01
6.	Flat	0 – 2%	3.65	1.14

Table 3. The morphometry measurement

No.	Parameters	Quaternary period		Tertiary period		Total Watershed	
		Range	Average	Range	Average	Range	Average
1	Bifurcation ratio (Rb)	2-7	3.30	2-6	3.38	2-7	3.32
2	Basin Shape Index (Bs)	0.93-8.33	2.68	0.79-4.73	2.22	0.79-8.33	2.56
3	Mountain-Front Sinuosity (Smf)	1.05-2.17	1.24	1.04-1.13	1.1	1.03–2.17	1.219
4	Valley height-width ratio (Vf ratio)	1.34-19.38	7.78	1.03-6.05	2.52	1.03–19.38	6.46
5	Drainage density (D_d)	0.85- 5.07	2.70	1.52-5.87	2.79	0.85-5.87	2.73
6	Circularity ratio (R_c)	0.16-0.85	0.512	0.39-0.85	0.616	0.16-0.85	0.538

Valley height-width ratio (Vf ratio) is another geomorphic index for identifying relatively young watershed in tectonically active areas. The Vf ratio value ranges between 0.05-0.5 that identified strongly tectonic activity, and the greater a Vf value is more not tectonically active (Bull, 2007). Using morphometry method, the total Vf ratio value of Cilaki watershed ranges 1.03-19.38 with average value of 6.46. The field survey data of Vf ratio value obtained that average value of the upstream area is 1.09, middle area is 0.23 and downstream is 0.12. Refer to this index geomorphic (Dehbozorgi et al., 2010) provided the following classification: Class 1 high active tectonics (Vf ratio < 0.5), Class 2 moderate to low active tectonics (Vf ratio = 0.5-1.0) and Class 3 tectonically inactive to slightly (Vf ratio > 1.0). The Vf ratio value of Cilaki watershed is Class 3 tectonically inactive relatively, but on particular region of the Vf ratio value include Class 1-Class 2 and associated with active faults.

Drainage density (Dd) is the stream length per unit area in region of watershed or sub-watershed (Sukiyah et al., 2016). We has calculated Dd value, the average Dd value of Cilaki watershed is 2.73 km/km² ranging from 0,85 to 5,87 km/km², indicating moderate drainage densities. The average value of Dd Cilaki watershed is classified as a moderate geomorphic index with a reference value between 0.25-10 (Sukiyah et al., 2016). The Dd values of Cilaki watershed greater 10 and lower 0, 25 is strongly influenced by tectonic activity.

The circularity ratio (Rc) value is obtained by calculating the proportion between Sub-Watershed area (A) with circle area (constant n = 3.14) which have same circumference (p) of its sub-watershed. Refer to the Rc value greater than 0.5 indicate that the Sub-watershed have rounded shape and 0,4-0,5 is indicated an oval shape. The average Rc value of Cilaki Watershed is 0.538 with range of 0.161-0,85. It can be concluded that an average Rc value is greater than 0.5 with a rounded shape. But the Rc value with range 0.4-0.5 can be identified toward various tectonic activity with an oval to rounded shape.

4.2. Active faults characteristic

Based on morphometry calculations in Table 3, the morphotectonics of Cilaki watershed can be classified into Class 1 to Class 3, related to the tectonic activity of Quaternary period. The morphometry method was also used to find geological structure characteristic data, it consisted of structural lineaments analysis, types of fault and another geological phenomenon.

4.2.1. Tectonic movement

The local tectonic analysis of research area carried out using remote sensing method of lineament structure analysis. A lineament is a linear feature in a landform which is an expression of an underlying geological structure such as a fault, ridge, valley and stream river. The result of main force direction is set in from South to North. Figure 3(a) showing the result of lineaments interpretation of geomorphological surface. There is an aster DEM imagery map analysis and the right-side map is an extraction of lineaments map with the main force orientation of N-S azimuth. Figure 3(b) shows the result of structure lineaments analysis that is an extraction of lineaments map with the main force orientation of W-E azimuth relatively.

By the result of structural lineaments analysis, which was applied to determine of a tectonic frame. The development of geological structure of research area can be subdivided into two directions of the main force. First, a respond of tectonic activity resulting with main force from South to North in Quaternary period. The others is a tectonic activity with force direction from South West to North East in Tertiary period. The resulting of geological structure analysis is normal fault, reverse fault, wrench fault and fold.

4.2.2. Volcanic mountainous structural

The geological structure investigation is rather difficult to recognized in the Quaternary volcanic areas, which was covered by high weathering, erosion process and deformation processes. Morphotectonic approach were largely concerned with the association between landform and geological structure. Remote sensing method is useful to recognize of the suspect area and interpretation of the geological structures. These are validated by joints set analysis as structures evidence, another is fault scarps, waterfall, hot spring manifestation and changes in river pattern (Van Zuidam, 1985).

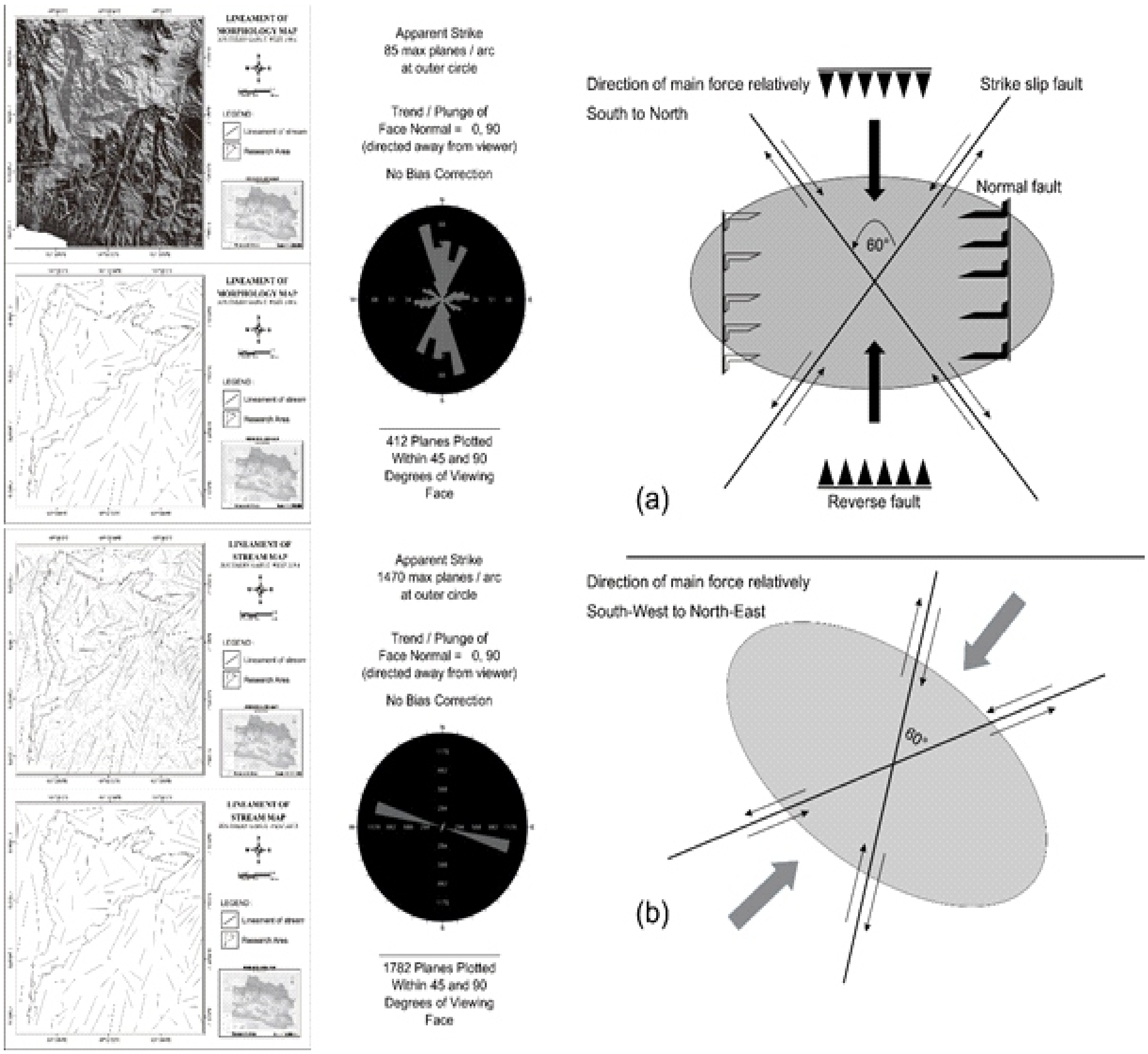

Fig. 3. The result of structural lineaments analysis showing a) a compression forces from South-North and b) a compression forces from SouthWest-NorthEast.

21 points measurement of joint set analysis in field have been done to determine various types of structures. This analysis is used to determine of the types of geological structures in the study area. The result of geological structure analysis is consisting several faults and a fold. The geological structure setting have role to configurate the shape of Cilaki watershed.

4.2.3. Fault and fold

We are divided DAS Cilaki areas into three faults region (Fig. 4) that is Pengalengan region (Upper part), Cisewu region (Middle part) and Rancabuaya region (Lower part). A fault or fold name is created and separated as a region which is passed through by a fault-fold or famous place. The discussion was begun from upper part to lower part areas, describe as follow:

Pengalengan is a village as Southern Bandung district, West Java, there is a Situ Cileunca lake as tourism place. The Pengalengan region is located at upper part of research area and consists of four faults that is Pasir Karasak fault, Wanasari fault, Rancamayar fault and Mount (Mt.) Sambung fault. The faults existence is identified by appearance of a fault scarp direction, landscape, geological regional map study and remote sensing interpretation by digital imagery. The hot spring appearance is manifestation of a geological structure and can help to draw a straight line of faults in their location.

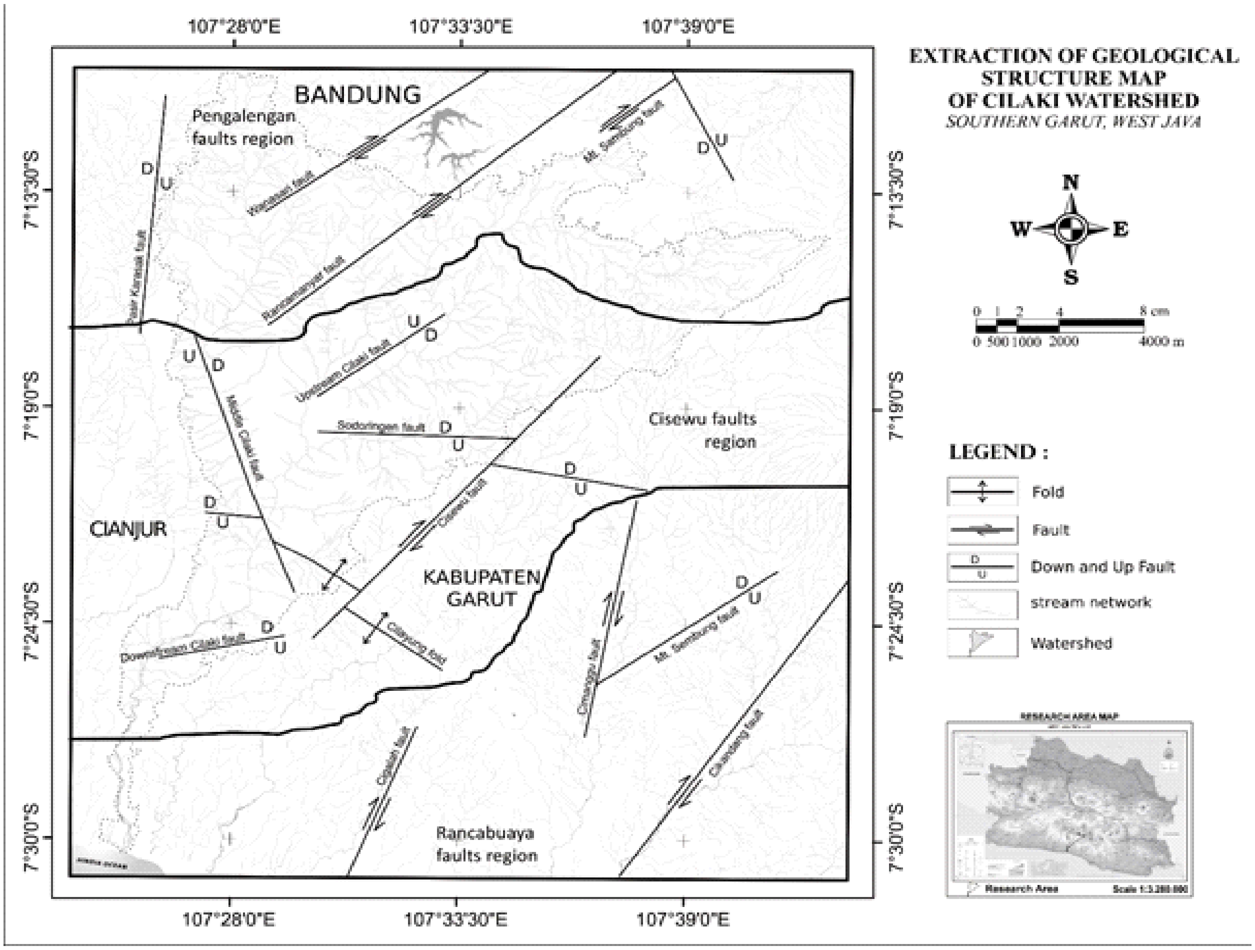

Fig. 4. The extraction of geological structure map. The research area is divided into three structure regions.

The Cisewu region is in Southern Garut district West Java that is characterized by volcanic mountainous area. The Cisewu structures region is consist of several faults and a fold that is formed by strongly tectonic activity, such as: Upstream Cilaki fault, middle part Cilaki fault, Cisewu fault, Cilayu fold and downstream Cilaki fault. Figure 4 is showing Cisewu region, there are located at the middle part in research area.

Rancabuaya is a beach tourism region in Southern Garut district West Java, which is located at lower part of research area. Rancabuaya faults region are consist 4 faults, such as Cimanggu fault, Mountain Sembung Fault, Cikandang Fault and Cigalah fault. These faults are not influence the shape of Cilaki watershed. Figure 4 showing Rancabuaya region existence, that faults extraction is an evident of neotectonic activity.

As the detailed field observations for these active faults have been recently carried out, common characteristics among these faults have clarified as follows:

1) The features of the fault morphology in research area are not so obvious.

2) The main force direction of tectonic frame is set in from South to North

3) There are 14 active faults with length of features between 4km to 20 km.

4) All active faults are strike-slip fault type and normal fault type, in which is dominated by faults with azimuth direction NE-SW and NW-SE.

5) The maturity of each fault is under the young stage on Quaternary period.

6) As an active fault has potential to produce large land slide in these areas, the careful furthermore detailed surveys are required.

4.3. The Shape and boundaries of the Cilaki watershed

Based on the morphotectonic study of the Cilaki watershed is classified into as an active tectonic setting. The research area is associated with active faults and is strongly influenced by the shape and boundaries of watershed. The various types of faults and folds are formed by the neotectonics activities. The active fault determined through morphological surface approach. The result of morphotectonic analysis show Cilaki watershed influenced by tectonic activities and vulcanism. The active fault continues to influence the shape and boundaries of Cilaki watershed. The shape and dimension of Cilaki watershed is a respond of tectonic activity resent. The morphotectonic study can used to predict a new perspective plan for land use and geological disaster mitigation.

5. Conclusions

Morphotectonic study of Cilaki Watershed concerned with a basic structure for recognizes the landscape which landform and drainage system have been affected by recent tectonic activity. This approach is useful to determine the origin of a shape and border of watershed by geomorphological analysis. The systematic morphotectonic offers promising perspectives for planning of land use and decision making. Further integration should take place between morphotectonic studies and other sciences related with tectonic activity whose study is needed to the presence of beneficial applicator.

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Author's Contribution

Johan Budi Winarto, proposed the main concept, frame research, analysis and created in write up. Emi Sukiyah, assisted in establishing quantitative geomorphology and tectonic activity by morphotectonic approach of the section, involved in assistance in preparation of illustration, figure and table. Agus Didit Haryanto, assisted in arrange, scope and fix up of methodology research and grammer, included determine of relevant remote sensing data and field data. Iyan Haryanto, did provision of relevant literature, tectonic model of research area and review and proof read of the manuscript, assisted in geological structure analysis and discussion.

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