The morphotectonic 3-D modeling of Cisadane watershed based on interpretation of satellite imagery and field survey in the region of South Tangerang, West Java, Indonesia

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Key words: Morphotectonic, 3-D model, Sag Pond, Active Fault, Cisadane River

SUMMARY

Cisadane watershed stretched from Bogor, Tangerang and Jakarta. The vital infrastructures are in this region. In physiographic, the area is included in coastal plain Jakarta and Bogor Zones. There are 18 rock formations that make up this region, Tertiary to Quaternary. There are anticline, syncline, and faults that developed in the study area. The most significant structures is Cisadane ancient fault, trending nearly north-south. Traces the geological structure is occupied by the main flow of the river Cisadane which can be interpreted from remote sensing data. Given the existence of the geological structure in this region potentially active, it is important to create a 3-D model of morphotectonic. The models are expected to provide further information related to the period of tectonic control of the region.

Data obtained from the interpretation of satellite imagery and field survey. Includes identification units associated with tectonic geomorphology, morphometric measurements on topographic maps, and field surveys. The data were then processed using Micromine software for easy construct 3-D models. In addition, do also quantitative data analysis using a probabilistic approach.

The results showed that the indications of the existence of the geological structure as the product of Quaternary tectonic include sag pond, folded river terraces, lithology offset, springs, and fracture. The old sag pond sediment outcrops under Serpong Formation, located in the east Cisadane River current. Some of the fields expected to be younger sag pond. The old sag pond lies in Cisadane be indicative of the presence of faults that control Cisadane trending northwest - southeast. The mechanism of trans-tensional faults due to horizontal motion resulted in the formation of sag pond. This goes on repeatedly so that the river terraces seem formed repeatedly. Sag pond relatively young, in the form of channel elongated parallel to the river which was formed on the river banks. This phenomenon is also a response to the presence of active faults horizontal. Zone shift in Cisadane river.

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1. INTRODUCTION

Landforms can be formed due to tectonic processes that occur in the earth. At the local and regional scale, tectonic phenomena can be identified from several landforms like escarpment, straightness of the valley, straightness of the ridge, river lineament, drainage patterns, etc. (Doornkamp, 1986; Verstappen, 1983). Indications of deformation can be observed through remote sensing data.

The old age rocks deformed are difficult to observe with remote sensing data. In general, they have been covered by younger sediments, even if exposed usually eroded. However, traces of tectonic product sometimes still recorded as reflected in morphometric characteristics of the watershed and drainage patterns (Howard, 1967). The study results of morphotectonic can be one of the references to determine periods of tectonic control of an area (Sukiyah et al, 2015).

Fault is a geological phenomenon which is common in the earth's crust. Fault is defined as the field of fracture is accompanied by a relative displacement of a block to block other rocks. The distance of the shift may be only a few millimeters to tens of kilometers, while the fault plane can cover a few centimeters to tens of kilometers (Billing, 1972).

Figure 1. Location of research area

Active faults in West Java is the source of earthquakes that can be grouped into three major active fault zones, i.e. Cimandiri fault, Baribis fault and Lembang fault (Soehaimi et al, 2004). Activation of the faults is marked by record earthquake damage in West Java. In the period between 1629 and 2007, have occurred at least 36 times the incidences of devastating earthquake in West Java (Supartoyo, 2008). Active faults can be seen from the morphotectonic aspect, namely the watershed dimensions, bifurcation ratio (Rb), drainage density (Dd), the index of sinuosity of mountain front (Smf), the ratio of valley-floor (Vf-ratio), and the straightness of the valley-ridge.

The research was conducted in Cisadane watershed (Figure 1). Cisadane watershed stretched from Bogor, Tangerang and Jakarta. In physiographic, the area is included in coastal plain Jakarta and Bogor Zones (van Bemmelen, 1949). The geological setting of that area has been mapped by Turkandi et al (1992) and Efendi et al (1998). There are 18 rock formations that make up this region, Tertiary to Quaternary.

There are anticline, syncline, and faults that developed in the study area. The most significant structures is Cisadane ancient fault, trending nearly north-south. Given the existence of the geological structures in this region potentially are active. It is important to create a 3-D model of morphotectonic. The models are expected to provide further information related to the period of tectonic control of the region.

2. METHODOLOGY

Data obtained from the interpretation of satellite imagery and field survey. The image used is the SRTM imagery 2015 with 30 m resolution (Anonymous, 2015). Includes identification units associated with tectonic geomorphology, morphometric measurements on topographic maps, and field surveys. Morphotectonic variables used to analyze tectonic activity are valley ratio (Vf-ratio), bifurcation ratio (Rb), drainage density (Dd), lineament of the valley and ridge, and sinuosity of mount front (Smf).

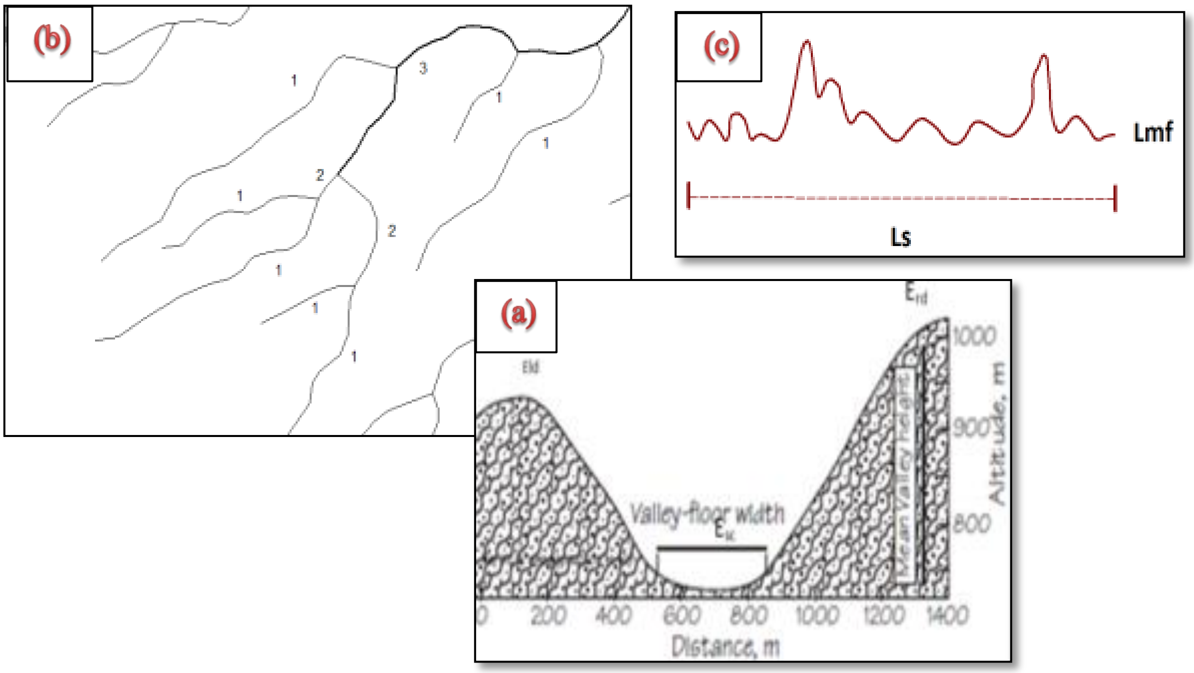

Figure 2. Illustrations of Vf-ratio (a), Stream order (b), and Smf (c)

Calculation of Vf-ratio use formula (1) and how data acquisition is shown in Figure 2a. The stream order system uses the modified Strahler method (Figure 2b). Based on the use of the system then calculated Bifurcation ratio using formula (2). Drainage density is obtained from calculation using formula (3). Rb and Dd calculation refer to van Zuidam (1985). The calculation of mount-front sinuosity use formula (4).

$$Vf = 2Vfw/[(Eld - Esc) + (Erd - Esc)] \quad \text{(1)}$$

$$Rb = \sum n / (n+1) \quad \text{(2)}$$

$$Dd = \sum n / A \quad \text{(3)}$$

$$Smf = Lmf / Ls \quad \text{(4)}$$

The data were then processed using Micromine software for easy construct 3-D models (Anonymous, 2016a). Arc map and Arc scene software are also used to provide a more detailed 3-D view (Anonymous, 2016b). Rosette diagram are used to display the results of the analysis. In addition, do also quantitative data analysis using a mathematic approach.

3. RESULT AND DISCUSS

Indication of the geological structure in the watershed Cisadane possibility is related to tectonic activity that make up the region. The phenomenon of important geological structures namely Cisadane ancient fault, trending nearly north-south. Traces the geological structure is occupied by the main flow of the Cisadane river which can be interpreted from remote sensing data (Figure 3).

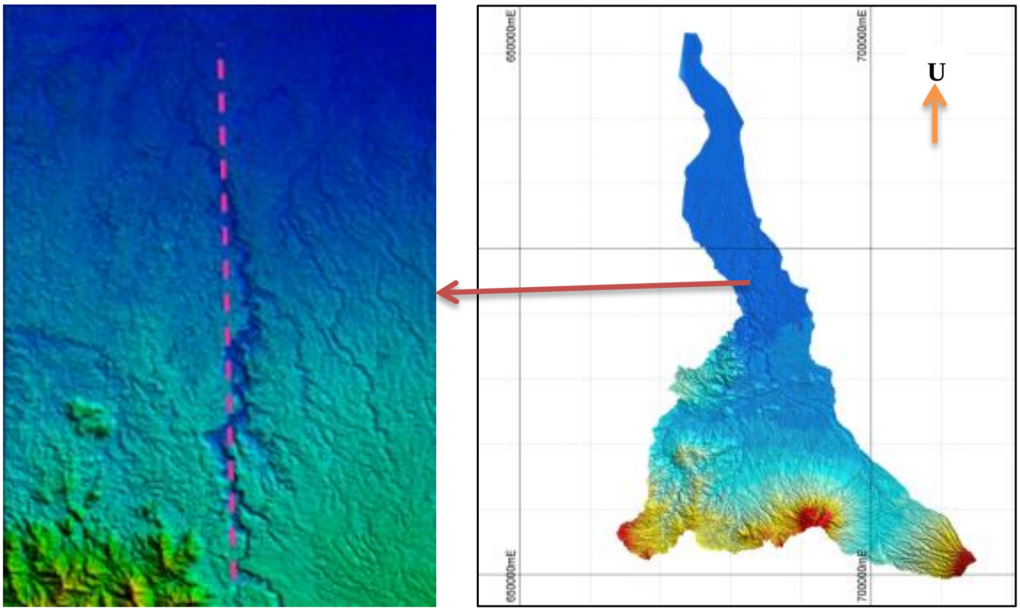

Figure 3. Main channel of Cisadane river as trace of old Cisadane fault

The morphotectonic variable used to analyze the tectonic activity is Vf-ratio, Rb, Dd, lineament of valleys and ridge, and Smf. In general, the results obtained show that there is still tectonic activity in the region. However, if compared with the existing literature turns tectonic activity that takes place in this region is low.

3.1 Vf-ratio

The ratio of valley bottom width and valley height (Vf-Ratio) can be used to determine tectonic activity. Bull (2007) states that the value of Vf-ratio in the face of highly active mountains experienced uplift ranges from 0.05 to 0.5. The greater the value of the ratio, the tectonic activity decreases.

The results of data processing Vf-ratio, both the results of the calculations in the studio and the results of measurements in the field, can be classified into 4 classes, namely I, II, III, and IV. In general, if compared with the Vf-ratio classification of Bull (2007) and Keller & Pinter (1996), tectonic activity in the Cisadane watershed can be classified as low. However, in some places showed an anomaly that is Vf-ratio <1 which is classified level of medium to high tectonic activity. Indications of high tectonic activity levels were found in 2 locations: Cilangkap and near Cihowe. Meanwhile, medium tectonic activity is found in several locations in the south and southeast.

Table 1. Classification of tectonic activity degree based on Vf-ratio

No	Vf-ratio	Data	Class	Annotation	Interpretation (Keller & Pinter, 1996)
1	0.15- 0.50	2	I	High uplift	High uplift and V-shape valley (Vf-ratio < 0.50)
2	0.50- 1.00	4	II	Medium uplift	Medium uplift (Vf-ratio = 0.5-1.0)

3	1.00-10.00	8	III	Low uplift	Low uplift and U-shape valley (Vf-ratio >1.0)
4	>10.00	7	IV	Very low uplift	

3.2 Bifurcation Ratio (Rb)

The rivers in the central Cisadane watershed have a range of order 1 to order 6, with a total river segment count of more than 2,000. Bifurcation ratio has a range of values from 0.44 to 38.00. Based on the calculation of bifurcation ratio in the central of the watershed, it can be concluded that the sub - watersheds in the area have an average Rb value of less than 3, i.e. in the range of 1.20 - 2.00. This indicates that the area has been deformed due to active tectonics.

Likewise wider area, it can be concluded that the sub-watersheds in the area have Rb value of majority less than 3, i.e. in the range 0.44 - 2.50. This condition gives an indication that the area has also been deformed due to active tectonics.

3.3 Drainage Density (Dd)

The value of Dd in a number of sub watersheds in areas closer to the main river has a range of 1.19 - 1.95. This indicates that the area is covered by lithology with physical properties classified as medium hardness. The condition is reflected in the river channel that passes rocks with medium resistance, so that the sediment is transported by the stream a little. Likewise for sub watersheds located in areas further away from major rivers, has a Dd value ranging from 0.95 to 3.52. Lithology as the base of the region tends to have medium resistance.

3.4 Lineament

The lineament associated with the geological structure can provide information about tectonic activity in an area. In the field the phenomenon is expressed in the form of ridges, depression zones, and escarpment. Based on the lineament analysis shown in the rosette diagram, the center of the watershed has a dominant North-East direction. The existence of geological structures in this area is supported by fractures data analysis which shows the direction of force equal to the lineament data obtained through studio analysis. Then it can be concluded that the pattern of geological structures formed in this region is reflected by the pattern of lineament. The analysis results are shown in Figure 4.

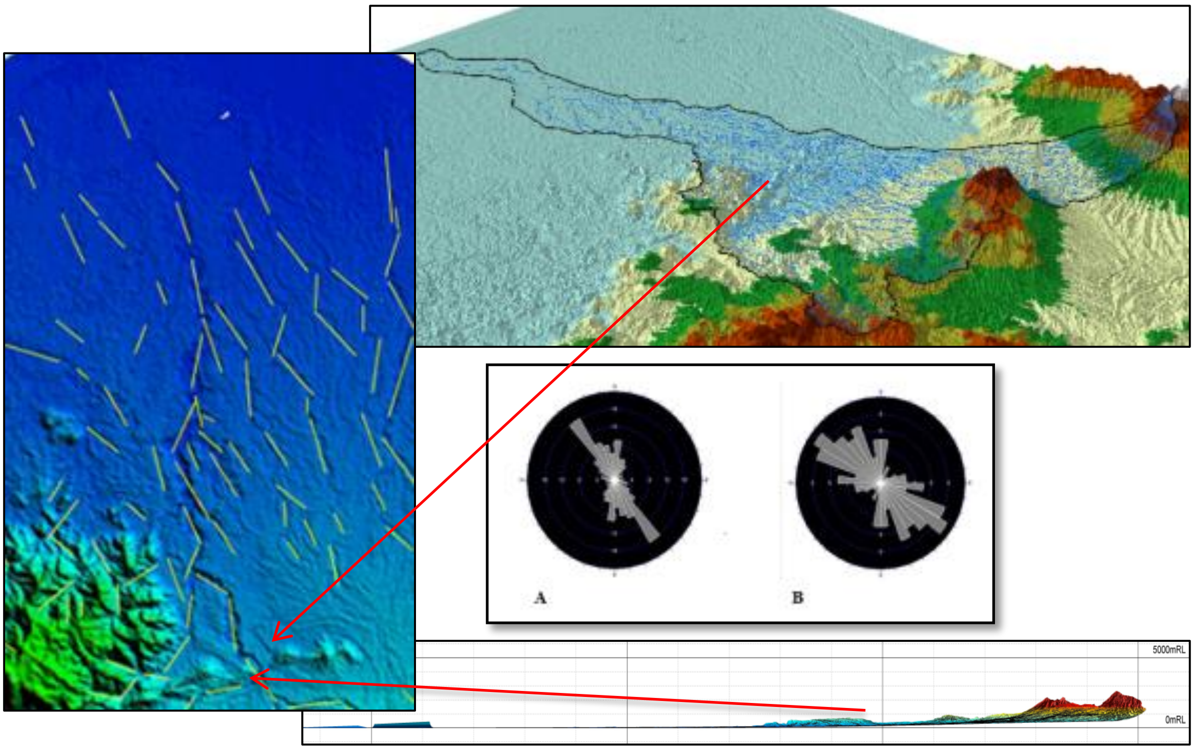

Figure 4. Distribution of lineaments and Rosette diagram; scarp lineament (A) and hill lineaments (B).

3.5 Sinuosity of Mountain-Front (Smf)

Smf calculation is performed on 27 locations distributed in the central of Cisadane watershed. The measurement sites are concentrated in the southeastern, southern, and northwest regions that have more dense contours than the middle to the north. The results of the calculation of Smf are shown in Table 2.

In the area close to the main river, the Smf value obtained from the calculation is in the range 1.02 - 1.08 or close to the value 1. Therefore, based on the classification of Doornkamp (1986) it can be concluded that tectonic activity tends to be active. Meanwhile, in areas further away from the main river, Smf was found in the range 1.03 - 1.74, approaching the group of values of 1.2 – 1.6. Based on the classification of Doornkamp (1986) it can be concluded that tectonic activity on more remote areas also includes active tectonics.

Table 2. The data of Smf value calculation in the central of Cisadane watershed

No	Lmf (km)	Ls (km)	Smf
1	1.30	1.27	1.03
2	2.92	2.71	1.08
3	5.25	4.86	1.08
4	2.57	1.98	1.30

5	4.74	3.54	1.34
6	3.56	2.88	1.24
7	2.08	1.57	1.32
8	2.80	1.99	1.41
9	1.26	1.02	1.24
10	3.07	2.03	1.51
11	3.29	1.96	1.68
12	1.32	1.12	1.18
13	3.42	2.39	1.43
14	3.19	2.64	1.21
15	3.27	2.16	1.51
16	1.19	0.95	1.26
17	1.30	1.07	1.22
18	1.71	1.26	1.36
19	1.62	1.29	1.25
20	1.35	1.11	1.22
21	1.74	1.40	1.25
22	1.22	0.99	1.24
23	3.24	2.59	1.25
24	4.13	2.97	1.39
25	2.34	2.01	1.16
26	0.15	0.13	1.13
27	5.59	3.21	1.74

3.6 The indicate of geological structure

Field data indicating the presence of geological structures as products of Quarter's old tectonics include sag pond, folded river terraces, offset of rock layers, springs, and fractures.

In the center of the Cisadane watershed was found an old sag pond sagging outcrop containing charcoal, exposed on the Cisadane River below the Serpong Formation. The location is on the eastern part of the Cisadane River. Also found some rice fields are estimated sag pond younger than previous sag pond. The old Sag pond that lies on the Cisadane River becomes an indication of the existence of a fault that controls the Cisadane river in northwest-northwest direction. The old sag pond is exposed at 68 m, while the river edge elevation is 52 m. This indicates that the exposed sag pond has been uplifted.

The trans-tension mechanism of horizontal motion leads to the formation of sag ponds, and then the sag pond is uplifted. This goes on over and over so that the river terrace appears to form a ladder structure. In the area close to the main river was also found a relatively young sag pond, a channel elongated parallel rivers that are formed on the banks of the Cisadane river. This phenomenon is also a response to the existence of an active shear fault with the shifting zone of the Cisadane river.

Table 3. Tectonic activity and type of geological structure

Lithology	Explanation
Tuff of Serpong formation	Northwest - southeast trending, compression, shear fault
Limestone of Bojongmanik formation	Northwest - southeast trending, tension, normal fault
Andesite	Northwest - southeast trending, compression, shear fault
Basal of Dago Mount	Northwest - southeast trending, tension, normal fault
Sandstone	North – south trending, compression, shear fault
Tuff- Breccias (Late Miocene)	North – south trending , tension, normal fault
Lava of old volcanic (Late Miocene)	West - east trending, compression, shear fault
Sandstone of Bojongmanik formation	Southwest – northeast trending, compression, shear fault
Basal of Dago Mount (Tertiary)	Southwest - northeast trending, compression, shear fault or thrust fault
Sandstone of Bojongmanik formation	Northwest – southeast trending , compression, thrust fault
Sandstone of Bojongmanik formation	Northwest – southeast trending , compression, shear fault

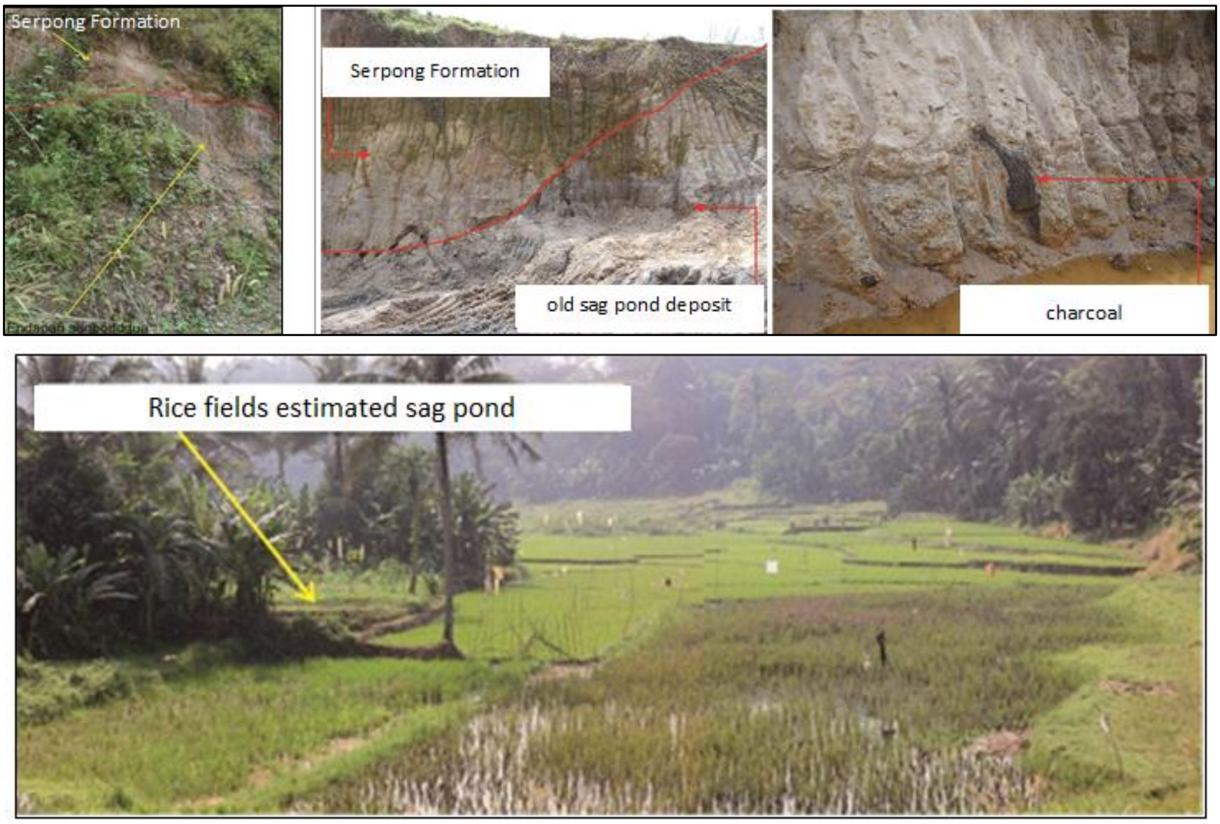

Figure 5. The existence of sag pond deposits that have uplifted on the banks of the Cisadane river

In the southern part there are young river terrace sediments, located on the eastern side of the Cisadane river showing a crease. This is an indication of the presence of control by the fault that works on the Cisadane river. There is an offset in clay stone lithology. At this location, the strike / dip of the lithological offset is found N355^{o}E/61^o and N340^{o}E/45^o with a shift of 1 meter. At this location, the strike / dip offset of the lithology found is N25^{o}E/79^o with a shift of 15 cm. At this location, the strike / dip offset of the lithology found is N185^{o}E/73^o and N279^{o}E/82^o with a shift of 17 cm.

The springs in the study area are at a scarp of 42.10 m long, and some form a pond like a pool of water reservoirs. Springs are commonly found on the eastern side of the Cisadane river, many of which are exposed to the south of the study area. The springs as indication there is channel connecting between groundwater and surface. It is allegedly formed by fault.

Based on the analysis of fracture data visualized in the stereographic projection diagram using dips program, the direction of the forming fracture is relatively western-east to north-west. In this area is estimated to have a shear fault type due to dominance σ2 which is closer to the center point. Analyze solid data using the dips program that is the direction of the east-west decision results in north-south until north west- south east trending faults. Based on the direction of firmness combined with the age of the existing formation of fracture data, it is estimated that tectonic periods occur in Pliocene and Pleistocene. This tectonic period is associated with Java pattern with the west-east trending and Sumatran pattern with north west- south east trending. Quaternary tectonic activity in this region that includes folding, warping, faulting, decline, etc. starting from the Late Pliocene to the Holocene.

The development of various tool related to data processing is helpful, especially with regard to data visualization. The 3-D view seems more realistic to mimic the existence of a morphography unit that may reflect the dominant tectonic control. Figure 6 shows the results of topographic data processing in 3-D form. It is clear that the morphotectonic units in the image.

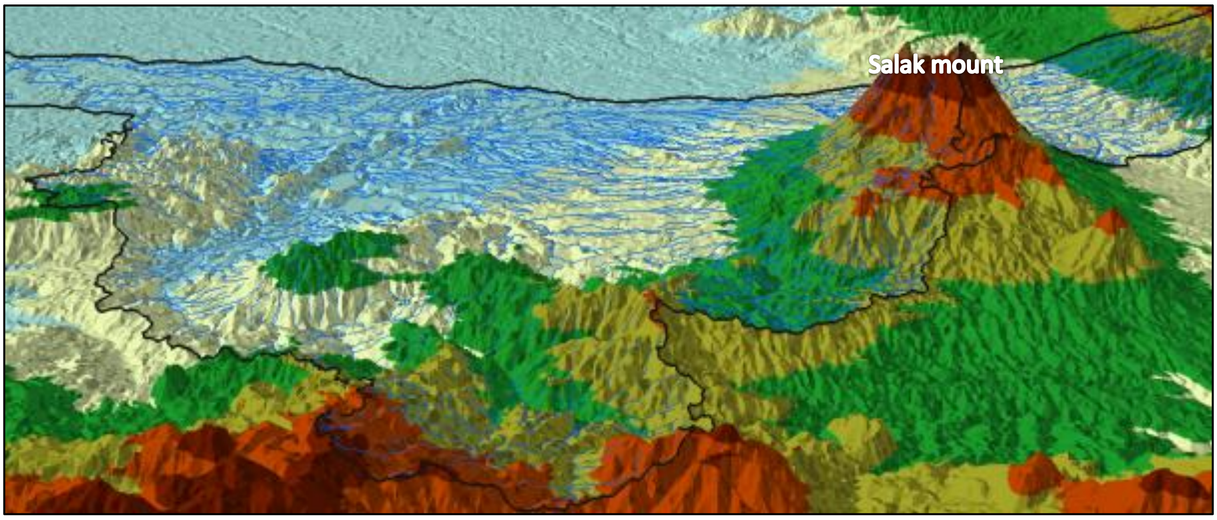

Figure 6. The appearance of 3-D Cisadane watershed from southwest direction

4. CONCLUSION

The results showed that the indications of the existence of the geological structure as the product of Quaternary tectonic include sag pond, folded river terraces, lithology offset, springs, and fracture. The old sag pond sediment outcrops under Serpong Formation, located in the east Cisadane river current. Some of the fields expected to be younger sag pond. The old sag pond lies in Cisadane be indicative of the presence of faults that control Cisadane trending northwest - southeast. The mechanism of trans-tensional faults due to horizontal motion resulted in the formation of sag pond. This goes on repeatedly so that the river terraces seem formed repeatedly. Sag pond relatively young, in the form of chanell elongated parallel to the river which was formed on the river banks. This phenomenon is also a response to the presence of active faults horizontal. Zone of shift in Cisadane river.

The appearance of 3-D Cisadane watershed is helpful in analyzing in more detail the existence of morphography units related tectonic. Extreme topography is very helpful to recognize the phenomenon in the field.

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BIOGRAPHICAL NOTES

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