Active Faults and Their Implications for Regional Development at the Southern Part of West Java, Indonesia

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Key words: active fault, GIS, morphotectonic, regional development, West Java

SUMMARY

Territory of the southern part of West Java has limited accessibility. Landforms with a steep slope and limited access roads make this area remains largely isolated. Various constraints occur this area so that their role in national development has not been optimal. Based on physiographic, this area was included in the Southern Mountains Zone (Van Bemmelen, 1949). This area is known to be controlled by tectonic based on a review of the literature already available. Fault is one tectonic product, which phenomena are found in the southern part of West Java. Fault is defined as a fracture plane followed by the relative displacement of a block of rock against rock block other. Distance shift is a few millimeters to tens of kilometers, while the size of the fault plane from a few centimeters to tens of kilometers (Billing, 1959). Levels of the active fault need to be known as a guide to develop the region. The methods that can be used are morphotectonic and geospatial analysis. Various parameters are used to determine the level of the active fault, including the type of fault, age of fault, fault intensity, seismicity, rock, and morphotectonic. The data used came from the results of previous studies which are already available, satellite imagery and topographic maps. Geographic Information System (GIS) software used to facilitate the analysis process. The quantitative and qualitative approaches used in data analysis. Morphotectonic analysis results support the interpretation that the units morphographic associated with tectonic referable early to determine the existence of a fault in the southern part of West Java. Empirical data related to the presence of active faults are found along the track landslides, especially in the southern Garut. Meanwhile, in the southern Cianjur and Sukabumi, landslides potential associated with the presence of the fault is still being studied further. The results showed that the activity of the fault in the southern part of West Java can be classified as inactive fault, potentially active fault, and active fault. Spatial distribution is also uneven, but forming zones in certain locations. Geological maps that exist need to be corrected to inform the public that many potentially active to active faults that have not been mapped in detail in the southern part of West Java.

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1. INTRODUCTION

Environmental degradation as a comfortable residence has become a global issue. One of the triggers is lack of response of the public and governments to the threat of geological disasters. Along with the progress of science and technology, it is known that the crust of the earth is not at rest. The intensity of the movement is triggered by conditions that occur in the interior of the Earth. The high intensity of movement that can be a source of disaster and a threat to the safety of mankind. An example is the movement of land, which can be triggered by the presence of active faults. Morphotectonic is the character of the landscape associated with tectonic (Doornkamp, 1986). Landscape characteristics quantitatively enriched understanding of morphotectonic. They are escarpment, the shape of the valley, the hills straightness, the rivers straightness, and drainage patterns.

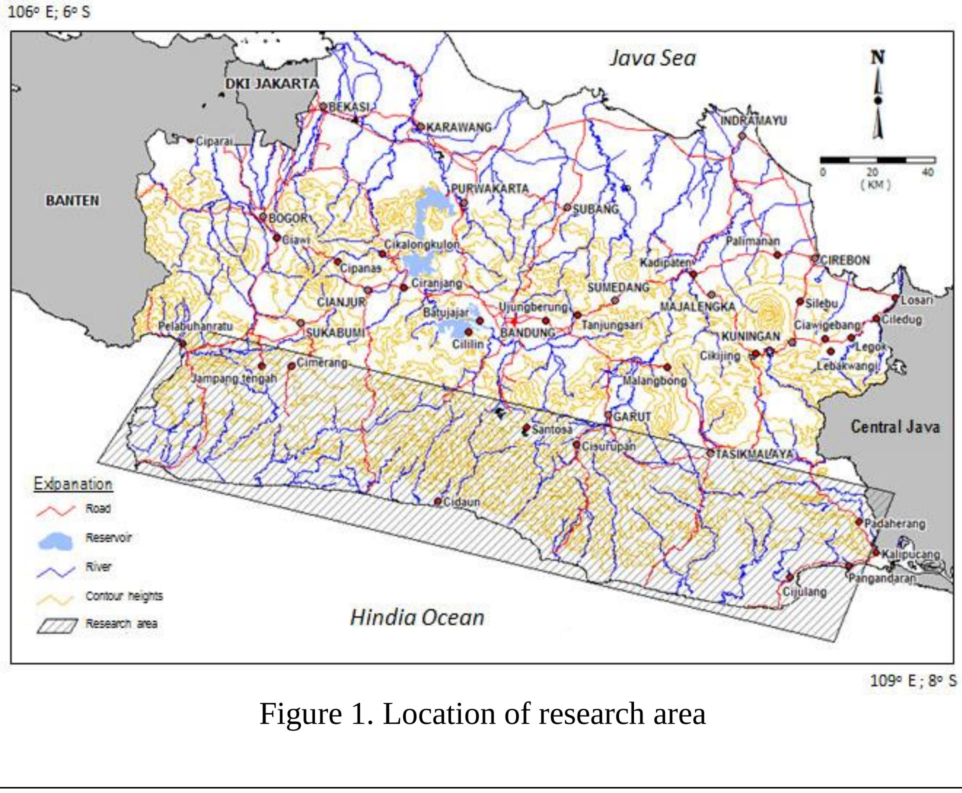

Figure 1. Location of research area

Fault is defined as an area of fractures followed by a relative displacement of a block of rock against rock block other. The distance can shift a few millimeters to tens of kilometers. Fault plane sizes ranging from a few centimeters to tens of kilometers (Billing, 1959). Active fault is a fault which is moving at a period of ten thousand years ago (Keller and Pinter, 1996). Potentially active faults are faults move at a period of two million years ago, while the fault is not active fault that has not moved in the past two million years ago. Another definition of active faults proposed by Huzita et al. (1992; after Munif, 2011), the fault moves since the quarter and has the potential to move back to the future. This fault intersects the surface morphology of Quaternary age, bypass rocks Quaternary age, which also occurs in volcanic regions engaged during the volcanic eruption, and normal faults that can be observed in mountain areas due to the force of gravity.
Region of the southern part of West Java has limited accessibility. Morphology with steep slope and limited road access makes the most of these areas are still isolated. Based on physiographic, this area was included in the Southern Mountains Zone (Van Bemmelen, 1949). Research activities related to the geomorphology and disaster has been done by some previous researchers, including by Sudradjat et al. (2009, 2010), Sukiyah et al. (2010), and Sulaksana et al. (2011, 2013). The results showed an association between morphometric watersheds, morphotectonic, and the presence of active faults. The condition was thought to be linked with the threat zone of geological disasters, such as earthquake, landslides, erosion, etc. This article discusses the identification of the existence of active faults in the southern part of West Java based on analysis of morphotectonic (Figure 1).

2. METHODOLOGY

The data used in this research are secondary and primary data. Secondary data were obtained from literature, while the primer can be obtained through image analysis SRTM-DEM and topographic maps were done in studio and field observations. The object of research is the landscape, tectonics elements, and the phenomenon of ground movement. The object of research can be identified through media such as satellite imagery, topographic maps, and other supporting data, as well as phenomena that can be described in the field (Figure 2).

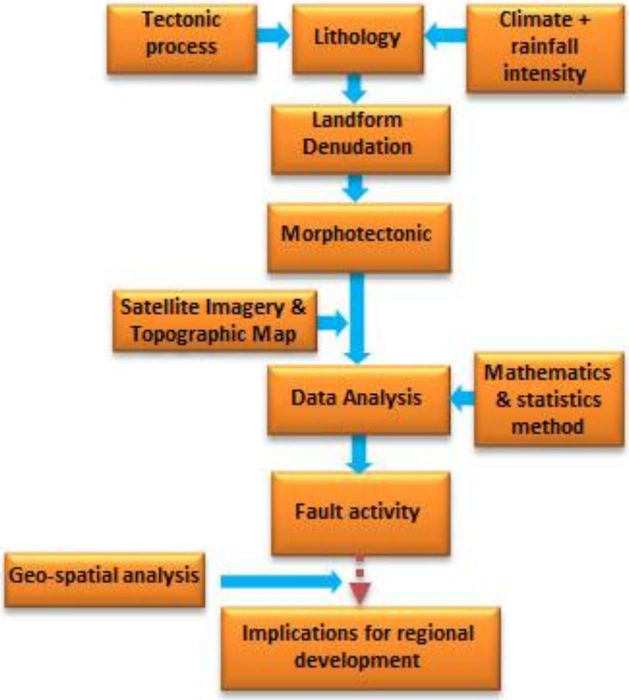

Figure 2. The mainframe of research methodology

Primary data extraction is done through satellite imagery and topographic maps, including:

- Identify and visual interpretation based on the key interpretations like appearance hue, pattern, shape, texture, and others.
- Integration of remote sensing data with other data types.
- Interpretation of topographic data quantitatively by measuring straightness morphology, river and mountain slope.

Activities of field observations, in addition to the documentation associated with tectonic geomorphology, also observed the potential for landslides. Some indication of the potential for landslides, which are the presence of cracks in the soil or rock, the emergence of water seepage in the walls of the slopes, land loose above impermeable rock, river water suddenly muddy after rain, cracks horseshoe on a slope or road, pole electricity or tree began leaning, the cliffs are fragile and gravel began to fall, etc.

Response variables of landform and tectonic are reflected by drainage density (Dd), bifurcation ratio (Rb), and mount-front sinuosity (Smf). The variables analyzed in this study. The value of drainage density (Dd) obtained from the division between the total length of the river segments ($\sum n$) and the watershed area (A) which is displayed in the formula (1). Number of river segments of order n is divided by the rivers of order n + 1 produce a bifurcation value ratio (formula 2). If $Rb<3$ or $Rb>5$, then the watershed is deformed (Verstappen, 1983). Bull and McFadden (1977; after Doornkamp, 1986) defines that sinuosity of the mountain-front (Smf) as the ratio between the length of the mountain-front (LMF) and the length of the mountain-front projection onto a flat surface (Ls) shown in the formulae (3). Classification of Smf calculation results may reflect the degree of tectonic activity (Table 1).

$$Dd = \frac{\Sigma L}{A} \qquad \text{.......} \quad (1)$$

$$Rb = \frac{\Sigma n}{N+1} \qquad \text{.......} \quad (2)$$

$$Smf = \frac{Lmf}{Ls} \qquad \text{.......} \quad (3)$$

Table 1. Classification of tectonic activity degree based on mount-front sinuosity (Doornkamp, 1986)

Class	Smf	Tectonic activity	Explanation
1	1.2 to 1.6	Active tectonic	Associated with alluvial fan landform, elongated shape watershed, narrow valley floor, a steep slope.
2	1.8 to 3.4	Tectonic activity is weak to moderate	Associated with alluvial fan landscape, watershed extends, steep slope, the valley floor is wider than the flood plain
3	2.0 to 7.0	inactive tectonic	Associated with the mount-front landform pediment and embayments, only a steep slope on rock layers resistant, valley widened and integrated.

3. RESULT AND DISCUSSION

3.1. Tectonic features on satellite imagery

The focus of research conducted in the area of Sukabumi, Cianjur, and Garut. The results of the analysis of satellite imagery in the area shown in Figures 3 and 4. Lineament interpretation of images SRTM-DEM (TTI Production, 2008) was conducted to determine the distribution of tectonic elements, including fault. Straightness morphology is a response of the control of the geological structure. Lineament related to tectonic generally a ridge, a zone of depression, in contrast elevation, etc. In addition lineament can also be a manifestation of changes in vegetation that allegedly occupy a weak zone as a result of geological structure controls.

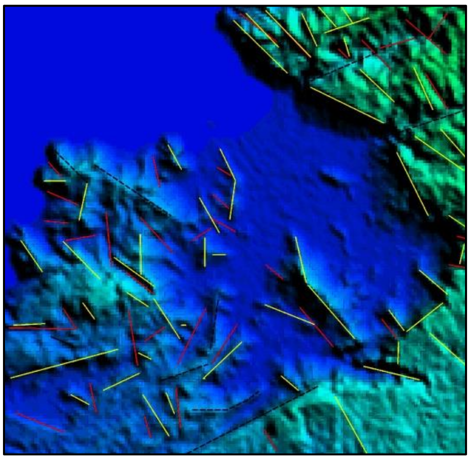

Figure 3. Distribution of lineament on SRTM-DEM image in Sukabumi, a dotted line (structural geology), bright-yellow line (the ridge lineament), rather dark-red line (valley lineament)

Land form controlled by geological structure in the area Ciletuh (Sukabumi) forming elongated hills with steep slopes. In addition, the valley Ciletuh also flanked by the escarpment that extends from southwest to northeast in the north and the escarpment that extends from southwest to northeast. Morphographic unit is seen in contrast, both the image of the SRTM-DEM and topographic maps. Fluvial valley in the region characterized by the shape of the land in the form of alluvial plain. Distribution of fluvial valleys form a rectangular pattern similar to the drainage in the region.

The trellis drainage pattern dominant in the southern Garut (Figure 4). This pattern suggests that there is a tectonic controls that influence it. Valleys are narrow and tend to elongate also an indication of a strong tectonic control. The geological structure in the area of research can also be seen from the lineament. Withdrawal lineament of the ridge and the river lineament on SRTM-DEM image is done by drawing strict lines that show the landscape extends caused by certain geological processes. From the observation, measurement, and analysis of the indications of the geological structure, and correlated with lineament interpretation of SRTM-DEM image, then allegedly developing fault structure and joint dominant in southern part of Cianjur-Garut. The fault structure and a joint structure of Quaternary age, due to developing on Tertiary and Quaternary roks.

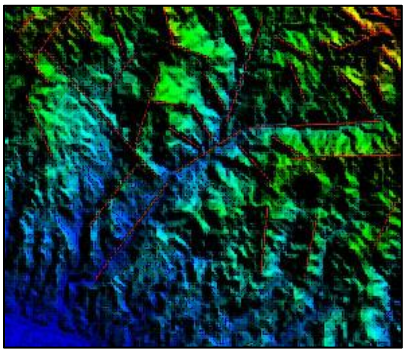

Figure 4. The lineament of river and ridge in SRTM-DEM image of Cikandang watershed, Garut are, West Java

3.2. Morphotectonic as active fault indication

Other morphotectonic phenomenon that can be found in the region Ciletuh is a ridge, waterfalls, valleys shaped "V", and triangular facets. Waterfall known as Curug Awang cut Ciletuh River, is a trending fault scarp N100^{o}E (Figure 5). Morphotectonic which are common is the triangular facet, which ranks truncated and eroded hills which form a triangle impression (Figure 6). Morphotectonic unit is contained along the hills stretching from northwest to southeast, then turn south tend to be trending southwest, circling the valley Ciletuh.

Figure 5. Curug Awang at fault scarp cut Ciletuh River, Sukabumi area, West Java

Figure 6. Triangular facet at Ciletuh valley, Sukabumi area, West Java

The results of field observations showed that so long escarpment associated with the presence of geological structures turned out to found the existence of the phenomenon of landslides. Curug Cimarinjung apparently not safe because it tends prone to rock falls. This is a loose rocks from the cliff which is a fault scarp. In some segments of the road leading to and around the area Ciletuh, found their symptoms are continuous landslides, especially adjacent to fault zones.

Form of Cisadea watershed at Cianjur region looks widened toward downstream, tends to form parallel. Such watershed form indicates there are two major rivers that flow. Drainage patterns grouped into three, namely anastomotic, subdendritic, and subtrellis. Anastomotic pattern occupies an area dominated by rocks and sediment are tuff, sand, and alluvium. Direction of the river in line with the direction of flow. The pattern developing on the rocks with a relatively homogeneous hardness that are mainly sandstones. Subtrellis drainage pattern is controlled by the structure of the indications found in the river Cigugur. This segment of the river meandering as if compressed, generally formed due to compression. This drainage pattern formed by rivers and streams Cisarua Cigugur composed by volcanic breccia, sandstone and tuff. The results of the calculation of the 13 sub-waatersheds obtained Rb-values ranging from 1.5 until 4.7. Rb value of less than 3.0 or more than 5.0, indicated deformed (Verstappen, 1983). This research area has largely Rb value ranging from 1.23 until 2.8, which it has been deformed by the tectonic activity. Dd value calculation result is further classified for the assessment of the texture of the landscape (Sukiyah, 2009), which is divided into six classes.

At the border area Cianjur and Garut there Cipandak watershed. Its shape resembling bird feathers, extending from the north to south (Figure 7). This watershed coincides with a horizontal fault Cipandak. Although the characteristic shape of the watershed and drainage patterns already reflect tectonic control, but its existence has been no related publications. This phenomenon was also supported by quantitative analysis of morphometric parameters of the watershed. Cipandak river and its tributaries form trellis drainage pattern. The overall order of the river ranges from 1 to 5. It appears that $Rb_{4\text{-}5}$ very small and far away from the normal condition of a watershed, where R_b is 3 until 5, meaning that the main rivers experiencing significant tectonic control. Fault shear of Cipandak contained in the central part of the watershed that coincides with the main stream, with direction of southwest - northeast. Three parameters used to determine the extent of Watershed Cipandak tectonic control, namely the density of drainage (D_d), bifurcation ratio (R_b), and azimuth of river segmen lineament. Analysis of the population of data D_d, R_b, and the lineament of the river segment, indicating that there was an effect on the movement of the two blocks of the fault.

Cilayu, Cikandang and Cikaingan watersheds located in southern Garut region. Drainage patterns are trellis, parallel, and rectangular. The whole drainage pattern reflects the geological structure. Upstream Cilayu watershed at Mount Melati while downstream were in the Gunung Kawung Jantung area and has an area of approximately 62,610 sq m. Length of the main river that flows in the Cilayu watershed reached 28,170 meters with a maximum width of Cilayu watershed is approximately 7,010 m. Sub watershed located in Watershed Cilayu has an extensive range of 345,90 until 22090,00 sq.m. Determination of watershed shape is done by comparing the Cilayu watershed shape and available Watershed shape according Sosrodarsono and Takeda (1987) and Ramdan (2006). From the analysis it can be concluded that sub-watershed Cilayu dominated by shaped bird feathers. Sub-watershed shape similar bird feathers have characteristics that flood discharge is relatively small compared to the flood discharge in the another shape. The concentration of water longer in the sub watershed elongated compared with the sub Watershed that flared or circular (Asdak, 1999). Cilayu watershed has a total length of river reaches 200,249.64 meters, which are grouped into the order of 1 to 4 with 266 stream segments. Bifurcation ratio (R_b) have a value ranging from 1.20 to 5.80. Most sub-watershed has an average value of R_b is less than 3 and more than 5. That phenomenon shows that in some locations in the watershed Cilayu indicated deformed due to the influence of active tectonics. Based on the analysis show that the whole sub-watersheds have D_d values ranging from 2.4 to 4.8. Based on several publications, Dd values ranging from 0.25 to 10 in medium category (Anonymous, 2007; after Hidayah, 2008). The analysis of two parameters indicate that the upstream sub-watersheds Cilayu controlled by active tectonics. Morphotectonic characteristics in the Cilayu watershed can be an indication of the effect of active tectonics are as follows:

- Lineament of ridge and valley
- Lineament of drainage pattern
- Extreme curve of the river around Cibaregbeg and Rancadarandan
- Wide depression zones and occupied by alluvial deposits in the southern part of Cilayu watershed.

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. Smf index values obtained from the calculation ranged from 1.2 to 1.3. This phenomenon shows that the case of up lift as an indication of tectonic activity in the watershed Cilayu.

The shape of Cikandang watershed relatively similar fans (Figure 8). It shows that the watershed is composed of varied stream pattern. The drainage patterns are trellis, parallel, dendritic, and annular. Stream order in the Cikandang watershed range from 1 to 6. Cikandang watershed is controlled by dextral horizontal fault, which divides the central part of the watershed. The fault direction is southwest - northeast. Partly segments of stream Cikandang through these fault zones. Analysis carried out on drainage density and bifurcation ratio of the watershed straddling two fault blocks. Analysis of these data to determine the level of activity of these two fault blocks. The analysis showed that tectonic causes deformation in this watershed. Drainage patterns in this region are trellis, parallel, dendritic, and subparallel. On the trellis pattern, distribution rivers along the side facing the subsequent flow. Parallel patterns tend to be aligned, moderate-bit steep slopes, are influenced by the geological structure, located on an elongated hills. The pattern is formed by Cirompang River and its tributaries. Dendritic pattern forming a network similar to the bones of leaves, develops on rocks with relatively similar hardness. The pattern is formed by Ciarinem river, Ciawitali river and Cibalubur river and its tributaries. Subparallel drainage pattern formed by a tributary Cikandang.

Cikaingan watershed has very unique shape, like bird feathers with a clear boundary. Elongated shape from north to south, and seemed to lean in the middle and downstream. Drainage patterns varied, i.e. dendritic upstream and trellis in the middle. Drainage density in the upstream region (north) is relatively more tightly in the appeal downstream (south). Differences in the extreme character of drainage pattern between upstream and downstream watershed actually shows control of tectonic in this region. The rivers that make up Cikaingan watershed order 1 to 6. Bifurcation ratio (R_b) between the river of order 4 and 5 as well as between the rivers of the order of 5 and 6 is very extreme. Both are well below and above the range of normal R_b for watershed. That phenomenon shows very strong tectonic influence on the river of order 4, 5, and 6. Type normal fault, in which blocks of the northern part of the relative moving down (hanging wall) of the blocks in the southern part (foot wall) also contributed to the extreme influence morphometric characteristics between the upstream and downstream Cikaingan watershed. Drainage density (D_d) between the upstream and downstream also showed extreme differences. Cikaingan Watershed upstream (approximately Singajaya) controlled by normal faults Singajaya. The phenomenon is supported by the results of the analysis with probabilistic approach to population of drainage density (D_d) and the bifurcation ratio (R_b) rivers in the sub-sub-watershed located in block A relative drop (hanging wall) and block B are relatively fixed (foot wall)

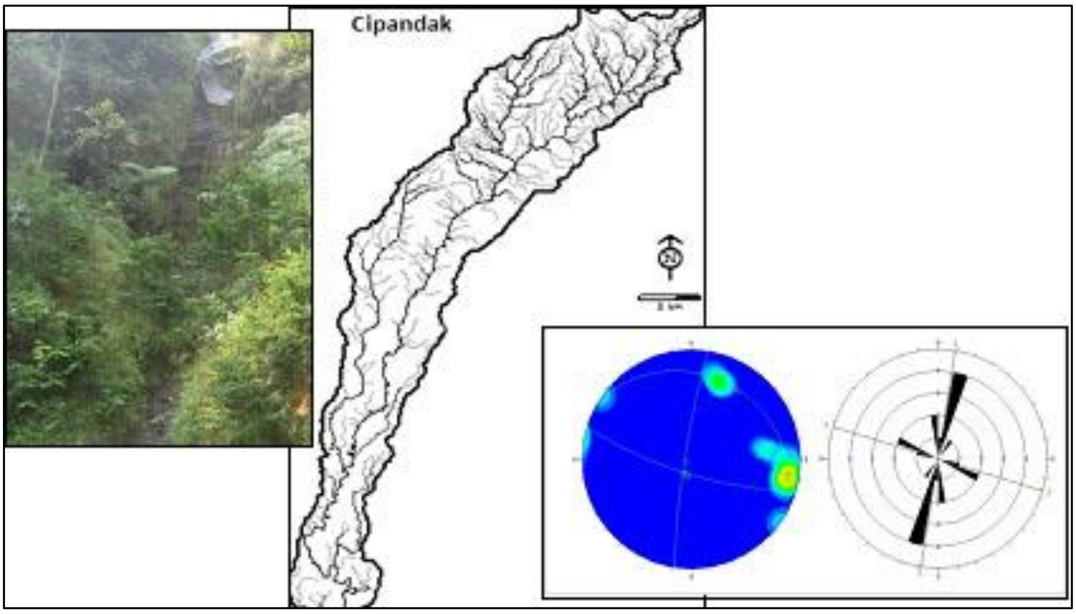

Figure 7. Stereonet and rosette diagram of joints data. Interpretation of results indicates horizontal fault trending southwest - northeast, coincide with Cipandak river. Fault escarpment as well as a waterfall in the Cipandak watershed, South Cianjur

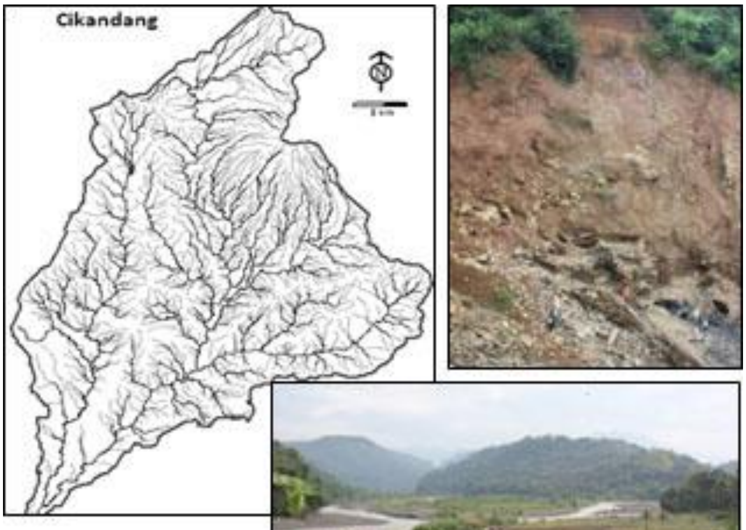

Figure 8. Geomorphology and drainage patterns of the centre part of Cikandang watershed

Based on the analysis in the various clusters, it is known that the southern part of West Java region vulnerable to the threat of geological hazards, including seismicity and ground movement. Seismicity besides caused by the subduction zone in the southern part of Java, also can be caused by fault movement on land. urthermore, the effects of the earthquake is the landslides. Therefore, a detailed classification of areas prone to earthquakes and landslides are very important. A more comprehensive understanding of this will help the sustainability of development in this region, especially the pathways of road infrastructure and other facilities.

4. CONCLUSION

Interpretation of satellite images can help to recognize the existence of fault in southern part of West Java. Spectral appearance can be emphasized by using a combination of appropriate wavelength and filters are available in a variety of image processing software. Visualization fault lines would be clearer if the data integration of satellite imagery and radar imagery is done.

Morphotectonic quantitatively study results support the interpretation that the geomorphology units associated with tectonic benchmark to be able to identify the genetic fault. Some morphometric variables and morphotectonic can be key in determining the presence of quaternary fault. Morphotectonic study results support the interpretation that the units morfografi associated with tectonic referable initial zoning for landslides

Results of field observations indicate the existence of empirical evidence related to the existence of active faults are found along the path of landslides, especially in the southern Sukabumi dan Garut region. Meanwhile, in the southern Cianjur, potential landslides associated with the presence of fault remains to be studied further. Potential earthquake due to shifting fault should also be wary, related to infrastructure development in the South West Java.

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Emi Sukiyah received the Engineering degree in Geology from Padjadjaran University in 1993, Master degree in 2000 from Postgraduate program of Geological Engineering - Institute of Technology Bandung, and Doctor degree in 2009 from Postgraduate program of Geological Engineering - Padjadjaran University. Since 1997 as a lecturer in the Faculty of Geological Engineering – Padjadjaran University, Bandung, Indonesia. Fields of research: Remote sensing application in the field of geology, tectonic geomorphology, renewable energy, the GIS application for spatial analysis, erosion modeling.

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