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IDENTIFICATION OF TECTONIC DEFORMATION USING MORPHOMETRICAL ANALYSIS OF LAMONGAN VOLCANO COMPLEX

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ABSTRACT: The objective of this research is to determine the level of tectonic activity based on morphometric and morphotectonic analysis in the selected case study area is located around the Lamongan Volcano Complex which covers the watershed sub-basin of the Lecari, Bondoyudo, Dilem, Jatiroto, Rondoningu, and Banyubiru Rivers. Administratively, the area is within the region of Lumajang, Jember, and Probolinggo Regencies, East Java Province, Indonesia. For this purpose, a set of parameters namely, drainage pattern, morphometry, morphotectonics, and geological structure were considered as an effective platform to clarify the existence of tectonic activity. The analyzed morphometric variables consisted of the dimensions of the sub-watershed area, stream segment azimuth, landform azimuth, stream length, drainage density (Dd), bifurcation ratio (Rb), and mountain-front sinuosity (Smf). As for the data analysis, this research used a quantitative descriptive approach. The results show that the Dd value ranged from 3.4 to 4.7 with Rb ranging from 1.0 to 9.2, and the Smf value ranges from 1.2 to 3.4, hence based on those values indicated that the study area has an ascendancy of tectonic activity. Since the Lamongan Volcano Complex is a volcanism-prone area, therefore, tectonic deformation monitoring is needed to reduce the impact of disasters, as the effects are more complicated when the volcano is located in a densely populated area.

Keywords: Morphometry, Lineament, Tectonic activity, Lamongan Volcano Complex

1. INTRODUCTION

The activity of tectonic plates on the earth's surface can affect the forms of landscapes resulting from the movement of geological structures, and consequently, affect the morphotectonic characteristics [1]. According to spesific geological conditions, the soil's ability is reflected in the characteristics of the landscape which can be analyzed quantitatively, including the dimensions of the watershed, drainage patterns, morphology lineaments, flow density, and stream order ratio [2].

The research location was conducted in the Lamongan Volcano Complex, in the central part of East Java (Fig. 1). Gunung Lamongan (8.00°S, 113.342°E, and 1625 m above sea level) is one of several active volcanoes located in East Java. During the nineteenth century, Gunung Lamongan (last eruption in 1898) was among the most active volcanoes in Indonesia. Little is known of the tectonic structure underlying the volcanoes, although synoptic radar imagery shows evidence for regional ~NW–SE and ~NE–SW faulting [3]. Based on the geologic map of Lamongan Volcano [4], the study area consists of Pandan Pyroclastic Deposits (Pdp), Lamongan Old Lava (Llt), Lamongan Volcano's Old Flank Eruption Lava (Llst), Lamongan Young Lava (Llm), Geni Pyroclastic Deposits (Gp), Parang Lava (Pl), Lamongan Pyroclastic Deposits (Lp), Lamongan Volcano's Young Flank Eruption Lava (Llsm), and Young Lahar Deposits (lhm). Lamongan Volcano Complex has resided in a densely populated area.

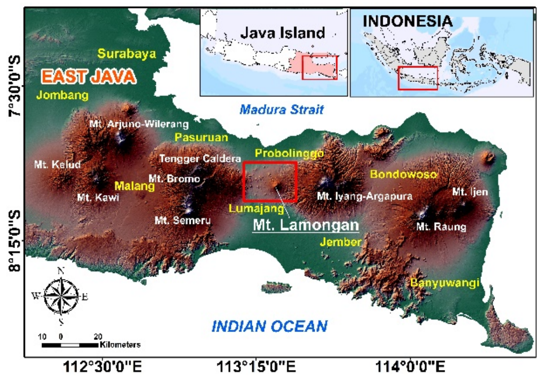

Fig. 1 The research location was conducted in the Lamongan Volcano Complex.

2. METHODS

This research considers the use of morphometry and morphotectonic analysis to investigate the level of tectonic activity. The object of research includes morphographic variables, which consist of morphometric and morphotectonic aspects of sub-watersheds. The quantitative descriptive approach is used for data analysis, for example, by measuring and calculating morphometric and morphotectonic variables.

Morphometry can be measured by calculating quantitative variables on the surface of land formation which consists of aspects of dimensions (area, circumference, length, width), elevation and angle of slope [5]; also, requires the measured of river segment length, segment azimuth river, straightness azimuth, drainage density, river order, and river branch ratio. The results of measurements and calculations by using morphometry can be used to determine the geomorphic index value and tectonic activity level of the study area.

The importance of using high-quality data cannot overstate, so it is necessary to obtain data from reputable sources. The data used in this research was collected from survey and verification activities in the field, as well as supplemented by satellite images extraction and topographic maps with a scale of 1: 25,000 processed in the studio by using the ArcGIS software.

The analysis process uses a simple grid method to facilitate the calculations [6]. Then the analyzed data will be converted into digital data and then be processed using GIS software.

The value of the geomorphic index obtains by using a specific formula. Based on the obtained values, it is then used for analysis to investigate the existence of tectonic activity. The density value or drainage density (Dd) obtains by calculating the total length of river flow compared to the total area of the sub-watershed. The high Dd value represents the river network on the drainage basin is either large or tight.

The ratio of river branches (Rb) is the result of a comparison of the number of certain order river segments with the number of the next order river segments. If the ratio value of the river branch (Rb) is less than three or more than five, it implies that there has been deformation due to the influence of tectonic activities [6].

Mountain-front sinuosity (Smf) is the result of the comparison between the surface length to the straight length of the mountain-front (Fig. 2). Smf approaches a value of 1 reflects increase straightness indicating active uplift. Sinuosity increased reflecting the workflow of water (river) which bypass mountain-plains boundary. Based on the index, the author developed the classification of the degree of tectonic activity (Table 1).

The used equations to determine morphometric and morphotectonic values are given below,

$$Dd = \frac{\Sigma Ls}{A} \quad (1)$$

where Dd is the index ratio of river density, ΣLs is a total length of river drainage, and A is a total area of the watershed.

$$Rb = \frac{\Sigma n}{n+1} \quad (2)$$

where Rb is the ratio of river branches, Σn is the number of river orders of certain segments, and $n + 1$ is the number of the next order river segments.

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

where Smf is mountain-front sinuosity, Lms is the surface length of the mountain-front, and Ls is the straight length of the mountain-front.

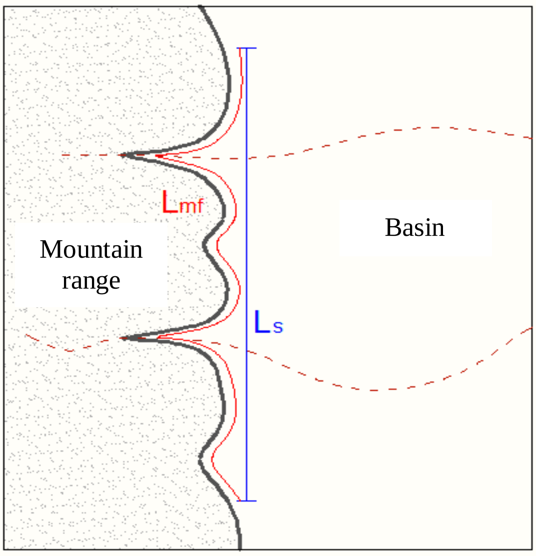

Fig. 2 Illustration method of mountain-front sinuosity (Smf). [5]

Table 1 Classification of tectonic activity based on mountain-front sinuosity. [1]

Class	Smf	Tectonic activity	Description
1	1.2 – 1.6	Active tectonism	Associated with alluvial landforms, longitudinal watershed patterns, narrow valley floor, sloping slopes
2	1.8 – 3.4	Moderate to slightly active tectonism	Associated with alluvial plains, the watershed extends, the valley floor wider than the floodplain
3	2.0 – 7.0	Tectonically Inactive	Associate with pedimentary forms and embayments on the mountain front, slopes in resistant rock layers, wide and integrated hills

3. RESULT AND DISCUSSION

The morphometry and morphotectonic processing data are using digital elevation model data from the Arc-Second Global Shuttle Radar Topography Mission (SRTM) with a 30-meter spatial resolution, to determine tectonic activity in the southern part of Lamongan Volcano, East Java. The usage of the image was carried out on Quaternary volcanic deposits which show variations in landform, lithological resistance, changes in the river flow direction, and geological structure. An indication parameter regarding the existence of the geological structure and the effect of active tectonic activity [6] is briefly described as (1) Lineaments of the valley, ridge or hill in the DEM-SRTM data; (2) Lineaments of drainage patterns and watershed segments; (3) Extreme curvature and presence of stocky structures around the watershed; (4) Interpretation of topographic maps showing lineaments of river segments; (5) There is indication of broad depression zones filled with alluvial deposits.

This form signifies the characteristics of floodplain areas that are relatively smaller compared to other forms of watershed patterns [7]. The topographic analysis is carried out to understand the direction, shape of the river, and variations in land shape. The objects analyzed are surface data in the form of elevation from the height, slope to determine the tilt of slope, aspect to determine the direction of the slope, and hillshade to determine the straightness of the topography (Fig. 3 and Fig. 4). Topographic analysis displayed as 3D analysis (three dimensions) that applied to the surface data.

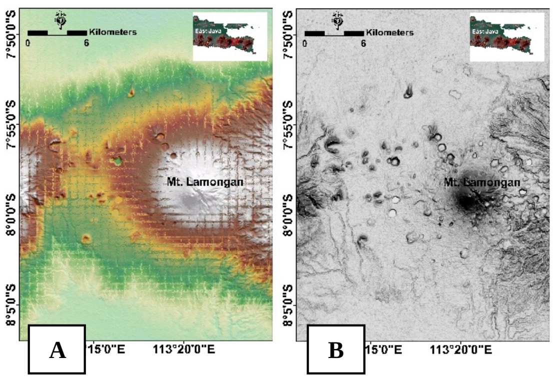

Fig. 3 Processing of DEM-SRTM (A) Elevation and (B) Slope.

The results of DEM-SRTM data processing are used for visual image interpretation of ridge and valley lineaments is intended to observe consistent lineament patterns that can assist in the interpretation of geological structures in the study area.

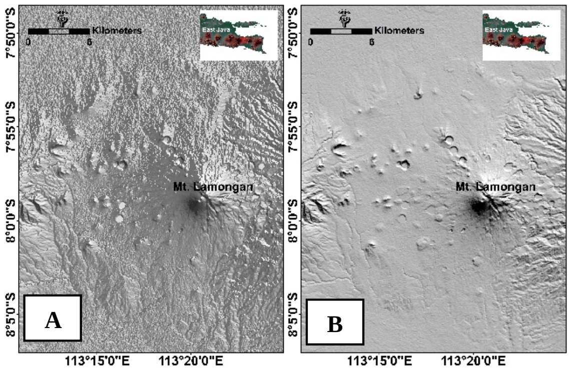

Fig. 4 Processing of DEM-SRTM (A) Aspect and (B) Hillshade.

Based on the results of image interpretation, the study area has a relative direction of NW-SE and NE-SW ridge lineaments, and valley lineaments also have a relative direction of NW-SE and NE-SW (Fig. 5).

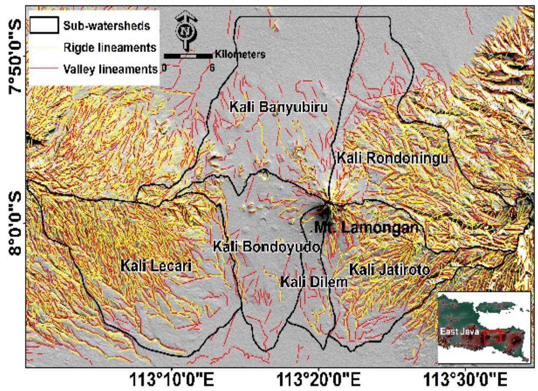

Fig. 5 Lineaments of ridge and valley in the DEM-SRTM data.

Morphometry and morphotectonic analysis conducted by calculating the value of each parameter that can be used to prove the tectonic activity effect on landforms and river flow forms. The following section describes the calculation and analysis variables.

a) The drainage density (Dd)

Drainage density value or the distribution value of the classification of drainage density results in a reflection of differences in volcanic rock compilers [6]. The distribution of river flow areas is calculated by recognizing the ratio of river branches and river density to determine the landforms that have undergone deformation and lithological resistance (Fig. 6). Low Dd values were depicted in the Bondoyudo River sub-watershed, Dilem River and Banyubiru River with a range value of 1.39 km/km^2 to 2.11 km/km^2 demonstrate the more resistant rocks. In the three sub-watersheds categorized as the rough texture with the least runoff rate, it can be assume that the area has permeable rocks and low erosion rates. In the sub-watersheds of Lecari, Jatiroto, and Rondoningu Rivers with a Dd value of 3.01 km/km^2 to 3.17 km/km^2 categorized in the medium texture implies that the watershed is of moderate erosion. The calculation results of Dd can be summarized in Table 2.

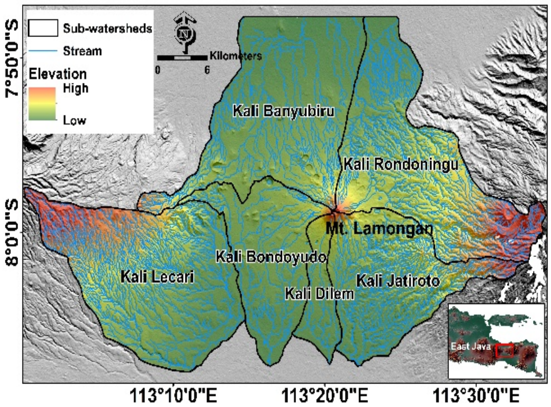

Fig. 6 Maps of the Lecari, Bondoyudo, Dilem, Jatiroto, Rondoningu, and Banyubiru Rivers sub-watersheds are divided into sub-watersheds to determine river densities respectively.

Table 2 The value of distribution based on the classification of drainage density in the data tabulation according to sub-watershed division.

Sub-watersheds	Dd (km/km^2)	Classification
Lecari	3.01	Medium
Bondoyudo	1.48	Rough
Dilem	1.39	Rough
Jatiroto	3.17	Medium
Rondoningu	3.11	Medium
Banyubiru	2.11	Rough

b) The ratio of bifurcation value (Rb)

The ratio of bifurcation value is calculated on the data tabulation based on the division of the watershed, with values less than three or more than five, indicating deformation [6]. The calculated Rb value is ranged between 1 and 11, with the average Rb value for each sub-watershed less than 3, except for the Jatiroto River watershed with an average Rb value of 4.02 as contained in Table 3. Based on the calculation of the average Rb, most of the sub-watersheds in the study area are watersheds that deformed due to tectonics activity which can be shown in Fig. 7.

c) The sinuosity of mountain-front (Smf)

The sinuosity of mountain-front is an analysis from the value of the Smf variable, which implies the relationship between landform, geological structure, level of erosion, and tectonics. The balance between the erosion force and the lifting strength can determine from the value of the sinuosity of the curvature of the mountainous-front. The Smf value ranges from 1.2-1.6 indicates an area with active tectonics and has a broad ridge shape, which leads to magnification and erosion. As for the Smf value range between 1.8-3.4 indicates the level of moderate to slightly active tectonism, and the Smf value of 2.0-5.0 indicates the level of inactive tectonic activity [1]. The results of the analysis show that the class of active tectonic activity is dominated by moderate to active tectonic activity classes in Table 4.

Table 4 Smf index calculated based on the data tabulation based on sub-watershed division.

Sub-watersheds	Smf Index	Classification
Lecari	1.15 – 2.24	Moderate - Active
Bondoyudo	1.16 – 1.51	Active
Dilem	1.12 – 1.93	Moderate - Active
Jatiroto	1.14 – 2.06	Moderate - Active
Rondoningu	1.10 – 2.45	Moderate - Active
Banyubiru	1.25 – 2.18	Moderate - Active

4. CONCLUSION

The morphometry parameters of drainage density, ratio of bifurcation, and the sinuosity of mountain-front used to identify tectonic deformation in Lamongan Volcano Complex.

Dd value shows that the Bondoyudo and Dilem river sub-watersheds pass the rock with rather hard resistance, resulting in small sedimentation. Rb value shows the difference in deformation due to tectonic and non-deformation influences. The sub-watershed of Lecari, Bondoyudo, Dilem, Jatiroto, Rondoningu, and Banyubiru Rivers are deformed.

The results of the sinuosity of mountain-front (Smf) analysis showed that the class of active tectonic activity was dominated by moderate to active tectonic activity classes. Lamongan Volcano Complex is a volcanism-prone area, so tectonic deformation monitoring is needed to reduce the impact of disasters.

5. ACKNOWLEDGMENTS

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Table 3 Stream order ratio values calculated based on the data tabulation based on sub-watershed division.

Sub-watersheds	Number of stream order segments 1	2	3	4	5	6	Rb 1-2	Rb 2-3	Rb 3-4	Rb 4-5	Rb 5-6	Classification
Lecari	522	242	143	63	25	6	2.16	1.69	2.27	2.52	4.17	Deformed
Bondoyudo	107	57	25	15			1.88	2.28	1.67			Deformed
Dilem	19	10	5	4			1.90	2.00	1.25			Deformed
Jatiroto	466	197	161	71	22	2	2.37	1.22	2.27	3.23	11.00	Deformed
Rondoningu	598	316	142	69	61		1.89	2.23	2.06	1.13		Deformed
Banyubiru	295	173	74	45	9	5	1.71	2.34	1.64	5.00	1.80	Deformed

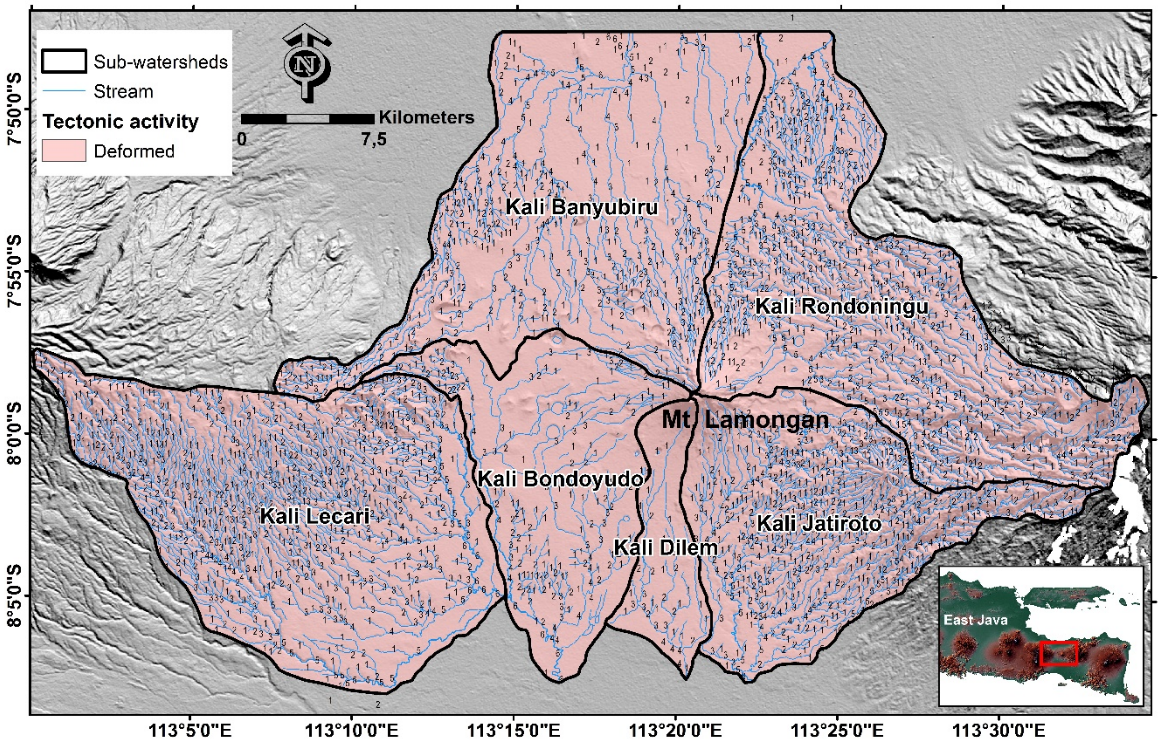

Fig. 7 Stream order ratio maps of the Lecari, Bondoyudo, Dilem, Jatiroto, Rondoningu, and Banyubiru river basins.

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