Journal of Engineering Science and Technology
Special Issue on AASEC2022, August (2022) 69 - 76

MORPHOMETRIC AND MORPHOTECTONIC CHARACTERISTICS OF THE WATERSHEDS IN PALELEH REGION, BUOL, INDONESIA

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Abstract

Sulawesi Island, Indonesia, was formed due to tectonic activities from the collision of terranes of three plates, which resulted in typical tectonic-affected landforms. The main objective of this study was to characterize tectonic activity, as it acts as a controlling factor in the development of landforms in tectonically active areas. Digital analysis of remote sensing data was determined using the Advanced Spaceborne Thermal Reflection and Emission Radiometer (ASTER). 30m Digital Elevation Model (DEM) and landform development were carried out to understand the morphometric and morphotectonic characteristics. There were a number of morphometric indices of bifurcation ratio (Rb = < 3), drainage density (Dd = < 4), and mountain front sinuosity (Smf = < 1.52). The low value of bifurcation ratio and mountain front sinuosity indicated that the area is tectonic active. The geomorphic index calculated in this study revealed considerable variations in relief, topography, and the dominance of tectonic activity over erosional processes in forming the watersheds.

Keywords: Geomorphic indices, Morphometric, Morphotectonic, Sulawesi.

1. Introduction

Morphometric investigations reveal geographic diversity in a tectonic activity [1]. Landscape morphometrics can be measured and calculated by quantitative assessment, and it is the fastest and most reliable way to generate basic tectonic knowledge [2]. The calculation of morphometry is a tool for analysing and evaluating landscapes [3-5]. Geologically, Sulawesi Island was formed due to tectonic activity and the collision of three major world plates: the Hindi-Australian, Pacific, and Eurasian and is located in the middle of Indonesia and looks like the letter "K" [6]. Therefore, the island of Sulawesi has become a study for assessing morphometric aspects in which the area at the research site is affected by active tectonics [7]. The rock lithology and its complex tectonics affect the watershed, making the West Paleleh an interesting area for research, especially in morphometric and morphotectonic.

Landscape changes to deformation processes are usually used to investigate active tectonics [8]. The implications of active tectonics in geodynamic processes change the landscapes and are used as a method to identify zones of active tectonic deformation [9]. Landscapes, such as mountain directions, valley directions, and flow patterns, are geomorphic indices [10]. These regional geomorphic indices are very helpful for determining the character of an area [11]. Another factor affecting the geomorphic index, apart from tectonic influences, is surface erosion resulting in landform changes [12, 13]. The Geographic Information System (GIS) can be used to determine morphometric and morphotectonic values in the analysis of geological structures [14]. In addition, GIS can be utilized to map geomorphic indices, initial identification, and analysis of tectonic characteristics [15]. The morphometric and morphotectonic analyses are used to make spatial characterization of rivers and watersheds. These analyses, which provide clues about the aerial, linear, and relief characteristics of the drainage basins and flows analysed, are considered fundamental and essential [2].

This study focused on the watersheds in the West Paleleh area, Buol Regency, Central Sulawesi Province, Indonesia, particularly in the Butakio Bodi and Butakio Butagidun watersheds. In general, no research on the morphometric and morphotectonic of the West Paleleh area has been examined in detail. Therefore, this study aimed to determine the characteristics of the morphometric and morphotectonic variables of the watersheds with regional geological structures. Therefore, watersheds play a vital role in the development of science. In addition to its role as a reservoir as well as a provider of water for humans, watersheds are also very closely related to geological processes, especially morphotectonic aspects [16].

2. Methods

The morphometric and morphotectonic of the Butakio Bodi and Butakio Butagidun watersheds were examined in this research. 12.5-m contour lines were digitized from a 1:50,000 topographic map of the Indonesian Topographical Map using MapInfo software and then were used to assess the dynamic tectonic characteristics of the morphology. The assessment included using the value of the area, length, width, and shape of the sub-watershed, stream order and bifurcation ratio, drainage density, and flow patterns. The streams were then digitized and sequenced according to Schumm [10] the flow length calculation, watershed area, and stream order. The division of 56 sub-watersheds was delineated from the two watersheds located in the study area. The calculated variables were the morphotectonic characteristics such as the straightness of the valleys, mountains, rivers, the mountain front sinuosity (Smf), the mountain front's length (Lmf), and a straight line along the front of the mountain (Ls). The geological formations and their areas were obtained from the geological map scale 1:100,000, the geological map scale of the Tilamuta sheet. Based on the regional geological map, the type of formation in the study area determined the strength of the bedrock and played an essential role in morphometric and morphotectonic. The response of tectonic activity was reflected in the morphology of the landform and drainage network. Although most of the study areas (80%) were composed of the same lithology, lithological characteristics with different strengths in all study areas could influence the morphometric and morphotectonic values.

3. Results and Discussion

3.1. Morphometrics of the Butakio Bodi and Butakio Butagidun watersheds

The geomorphology of the Butakio Bodi watershed varies from upstream to downstream and is dominated by hilly and mountainous relief. Accordingly, this affects the slope. The boundary of the Butakio Bodi watershed, from studio analysis, is divided into 28 sub-watersheds. The morphology of the Butakio Butagidun watershed is not much different from that of the Butakio Bodi because the locations of the two watersheds are next to each other and have hilly and mountainous relief. For the analysis results, the Butakio Butagidun watershed has 28 sub-watersheds. Butakio Bodi and Butakio Butagidun are the main rivers flowing from the Paleleh Mountains, which are in the south of the study site and downstream to the north in the sea of Sulawesi. The results of processing the morphometric aspects using MapInfo software showed that the Butakio Bodi watershed has the main river length of 14.91 Km from upstream to downstream and a watershed area of 63.3 Km^2. On the other hand, the Butakio Butagidun watershed has the main river length of 17.88 Km from upstream to downstream and a watershed area of 59.65 km^2.

The determination of a watershed or sub-watershed shape was closely related to the aspect of the area, length, and width of the related watershed or sub-watershed. The Butakio Bodi watershed is a type of parallel watershed, while the Butakio Butagidun watershed is a bird-feather watershed. Both shapes of the two watersheds can be seen in Fig. 1.

The bifurcation ratio (Rb) is the first step in drainage basin analysis. It is based on the flow hierarchy ranking proposed by Schumm [10]. The bifurcation ratio is the ratio of the total number of flows of one order to the number of flows of the next higher order [10]. In the Butakio Bodi watershed, the number of Rb is less than 3.0, which means that the bifurcation ratio generally ranges between 3.0 and 5.0, where the geological structure does not distort the drainage pattern [10]. Thus, it can be interpreted that a value less than 3.0 indicates that the area is affected by tectonic structures. However, sub-watershed B14 Rb 2-3 shows a value of 3.0, meaning that this value does not indicate that it is exposed to tectonic deformation. The condition is an anomaly in the Sub-watershed B14 area, which has impermeable or erosion-resistant bedrock. In other words, it can be said that the lithology in the area is not affected by tectonic structures [17]. Still, the Rb of the Butakio Bodi watershed generally showed that it is not deformed by tectonics. The

Butakio Butagidun watershed obtained the calculation result of an Rb value less than 3.0. A high average value of Rb indicates a strong structural control in watershed development, while a lower value indicates less structural disturbance [10, 18-20]. Based on the Rb data in the two watersheds in the research location, it can be interpreted that the structure or tectonic activity is affected but not so significantly as presented in Table 1.

The value of drainage density (Dd) is an essential indicator of the linear scale of landform elements in river eroded topography [21]. The elements that govern watershed dissection could be reflected in the drainage density. Many studies have associated this indicator with climate, vegetation, and lithology [8, 10, 16, 22]. Referring to each sub-watershed in the Butakio Bodi, the ten largest sub-watersheds in the Butakio Bodi show various values but based on the drainage density value; they are not too dense. Therefore, this value reflects that the watershed has an impermeable subsurface, apparently minimal vegetation cover, and mountains in its relief [23]. Likewise, the Dd Butakio Butagidun watershed has a moderate drainage density, which indicates that, generally, the river flow in the watershed passes through rocks with medium to stiff resistance so that the intensity of the drainage density is not too dense.

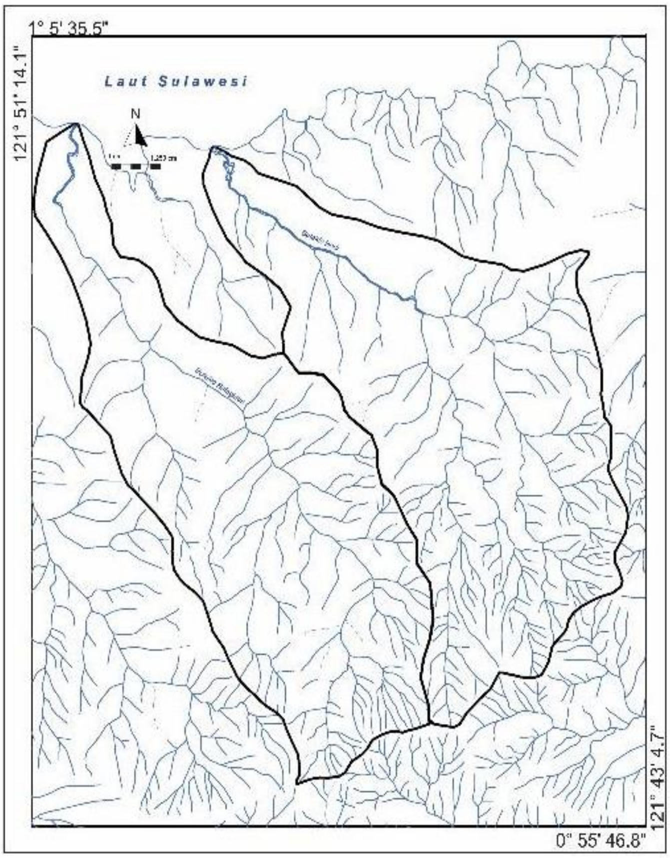

Fig. 1. The Butakio Bodi watershed (right) and Butakio Butagidun watershed (left).

Table 1. The area, width, and length of the Butakio Bodi and Butakio Butagidun watersheds.

Watershed Name	Sub-watershed Name	Area of Watershed (Km^2)	Width of Watershed (Km)	Basin Length (Km)
The Butakio Bodi	B8	23,830	2,446	9,742
	B14	5,248	1,992	2,634
	B19	5,205	0,963	5,407
	B4	3,205	1,186	2,703
	B18	1,968	0,853	2,308
	B22	1,248	0,684	1,825
	B6	1,223	0,655	1,868
	B5	1,047	0,577	1,814
	B12	0,958	0,602	1,593
	B15	0,873	0,460	1,897
The Butakio Butagidun	G16	18,810	2,200	8,550
	G5	8,099	1,265	6,400
	G12	2,173	0,577	3,769
	G14	1,581	0,641	2,466
	G8	1,569	0,877	1,790
	G15	1,311	0,923	1,421
	G19	1,024	0,621	1,650
	G6	0,876	0,620	1,412
	G13	0,783	0,359	2,182
	G10	0,516	0,544	0,949

There are various river flow patterns in the Butakio Butagidun watershed, such as sub-dendritic, parallel, subparallel, and rectangular. However, the dominant pattern is the sub-dendritic pattern when viewed more broadly. Afterward, in the middle of the Butakio Butagidun watershed, there is a river bend nearly 90^o and the direction of the river flow. The direction change of the river flow in the southern part indicates a geological structure that develops in this area in the form of a fault that changes the river flow direction. The evidence shows that geological structures influence the flow patterns developing in this area (see Fig. 2).

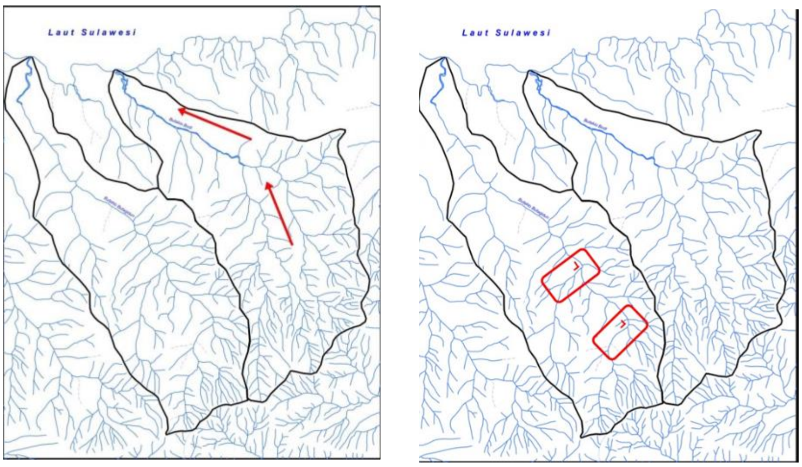

Fig. 2. Changes in the direction of river flow in the Butakio Bodi watershed (left) and the angled shape of the river in the Butakio Butagidun watershed (right).

3.2. Morphotectonics of the Butakio Bodi and Butakio Butagidun watersheds

The morphotectonic characteristics of the downstream Butakio Bodi watershed landscape in river flow deflection could indicate active tectonic influences. The Mountain-Front Sinuosity (Smf) value obtained from calculations (Table 2) ranges from 1.18 - 1.52, so tectonic activities in the Butakio Bodi watershed are active tectonic [8]. Based on this classification, the Butakio Bodi watershed is affected by active tectonic activity, so that the tectonic activity will produce output in the form of natural features on the DEM. These natural features can be a continuous ridge and deflection of the river flow direction. This interpretation is corroborated by the evidence of faults found in the Butakio Bodi watershed on the Regional Geological Map of the Tilamuta sheet.

Table 2. Smf values of the Butakio Bodi and Butakio Butagdun watersheds.

Watershed Name	Length of Sinuous (Km)	Horizontal Length (Km)	Smf Value
The Butakio Bodi	10.37	8.154	1.27
	9.126	7.717	1.18
	5.33	4.243	1.26
	2.29	1.511	1.52
	2.699	1.978	1.36
The Butakio Butagidun	6.553	5.765	1.14
	3.586	2.634	1.36
	6.936	5.983	1.16
	3.634	2.538	1.43
	4.439	3.342	1.33

The landscape's morphotectonic characteristic of the Butakio Butagidun watershed, especially the middle part, is a river bend of almost 90^{o}, indicating that the area is experiencing tectonics. Based on the results of the Smf calculation, it ranges from 1.14 to 1.43, so tectonic activity in this area is categorized as active tectonic [8]. The tectonic activity will produce output in the form of landscape features on DEM. The landscape can be continuous ridges, deflection of river flow, and intrusion domes. The interpretation is corroborated by the evidence of faults and igneous rock intrusions found in the Butakio Butagidun watershed area on the Regional Geological Map of the Tilamuta sheet.

4. Conclusion

The geomorphic index calculated in this study includes linear morphometric parameters, area, relief, and geomorphic index. Morphotectonic and geomorphic indices are important tools for understanding the tectonic activity of a site. Morphometric and morphotectonic parameters have shown their usefulness in inferring valuable information about the tectonic activity of the study area. The analysis and calculation of the parameters, namely Rb, Dd, and Smf, showed that the watersheds on the research site at the Paleleh, Buol, Indonesia, are strongly influenced by active tectonic activity. It is reflected in the flow pattern of the river, the value of bifurcation ratio, drainage density, and mountain front sinuosity, whose values indicate the effect of active tectonics at the location of the study area. The influence of tectonics on geomorphology can be explained and observed well based on the relief from the ASTER DEM form and the morphology of the research area. Thus, it is hoped that this research will help draw conclusions about tectonic activity, the factors causing major landslides, earthquakes, and floods, as well as the development of the area.

Acknowledgment

The author is very grateful to Sukardan Tawil for funding and facilitating site-to-site surveys and to Buol research team colleagues for their endless support. This research is part of a thesis completed at Universitas Padjadjaran, which Mrs. Emi Sukiyah supervised. I am very grateful to the editor for providing a helpful review in writing this article.

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