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RESEARCH ARTICLE

Stream Morphometry as Response to the Level of Tectonic Deformation on Sorowako and Surrounding Areas, Indonesia

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Abstract

Sorowako and surrounding areas are geologically influenced by Sulawesi's microcontinent movement, which has produced several geological phenomena. Morphometry is one of the parameter that can reveal geological condition of particular area. Morphometric analysis of water catchment area in Sorowako and surrounding areas using Bifurcation Ratio (Rb) and Drainage Density (Dd) can provide comprehensive information on level of deformation in Sorowako region. Analysis result of Bifurcation Ratio Index (Rb) on water catchment area reveals that Rb<3 value is dominant and equally spread in Sorowako region, it varies from 0.094 to 2.888. However in several place the value of Bifurcation Ratio (Rb) index is more than 5 (Rb>5) with varies from 5.142 to 10.250. Drainage Density (Dd) value ranges from 0.907 to 8.422 with an average value is 4.125 describes impact of erosion and tectonic on Sorowako region. Based on morphometric analysis of two parameters, Sorowako and surroundings area have been heavily impacted by tectonic activity on Sulawesi island. In western, eastern and northern regions on water catchment area, level of deformation tends to be higher compared to southern region. This can be seen on analysis result of water catchment area 43, water catchment area 196, and water catchment area 302 that have relatively larger number of stream orders, and also have Bifurcation Ratio's value less than three (Rb<3). Information of tectonic deformation level on Sorowako region through morphometric analysis is important to further use as a basis for water catchment area management planning, so that it can identify areas prone to geological disasters. This fairly high level of tectonic deformation also believed to be a controlling factor for nickel grade contained in Sorowako and surrounding areas which allow supergene enrichment to occurs in rocks.

Keywords: Morphometry, Tectonic, Deformation, Water Catchment Area, Sorowako

1. Introduction

Morphometry is a quantitative measurement of geological aspects characteristics on a particular area. Morphometry of water catchment area is a term used to describe the condition of the stream channel network quantitatively. Water catchment area is an area that functions as a water reservoir area which has important benefits in maintaining sustainability of water sources function in an area. Water catchment area is a land area that collects and stores water from rain and channels it directly into lakes or through rivers. All the rain that falls in a water catchment area will fills the river in areas. Water catchment area is a rain catchment area. All water that flows through the river moves to leave river catchment area with or without considering it's path before reach the run off. In Sorowako's water catchment area, there are three large lakes which are; Matano lake, Mahalona lake and Towuti lake. Each water catchment area can describe characteristics of an area related to geological processes that have taken place. Tectonic activity intensively occurred in this region thus forming Banggai-Sula microcontinent. Low density continental crust causes uplift of deep sea rocks from the oceanic crust and mantle.

The complexity of tectonic history during the forming of Sulawesi island causing many geological structures formed. In central part of Sulawesi island, a left-hand strike slip fault system was formed which consist of two main fault zones thats are Palukoro fault and Matano fault (Fig.1) (Soehaimi et al., 2025).

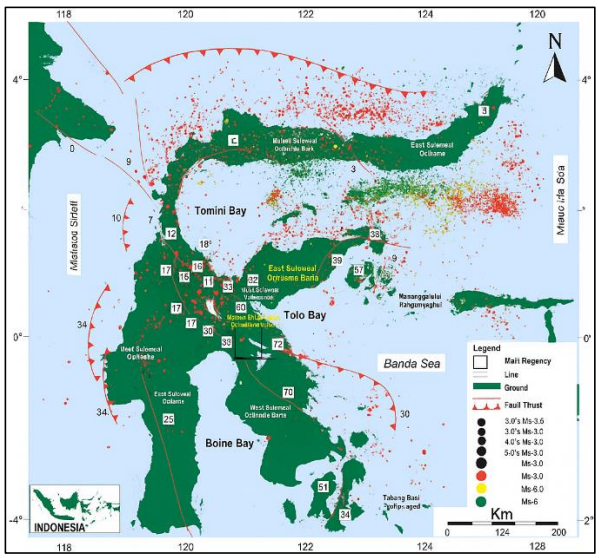

Fig. 1. Geological structure map of Sulawesi (Soehaimi et al., 2025).

The research area is located in East Luwu district, South Sulawesi province with total rain catchment area estimated around 2,050 km^2 (Fig.2). This research is intended to obtain morphometric characteristic data for each water catchment area in Sorowako and surrounding areas, and related to level of deformation or tectonic that occurs.

Sorowako and surrounding areas are eastern part of Sulawesi island which characterized by ophiolite and metamorphic rocks that have estimated age between late Cretaceous - late Oligocene, which in several place overlain by Mesozoic sediments (Golightly, 1979). Eastern part of Sulawesi island was composed of two subduction melange zones that were uplifted in pre and post Miocene. Melange that aged Miocene to post-Miocene occupies on central and the northern arm of the island.

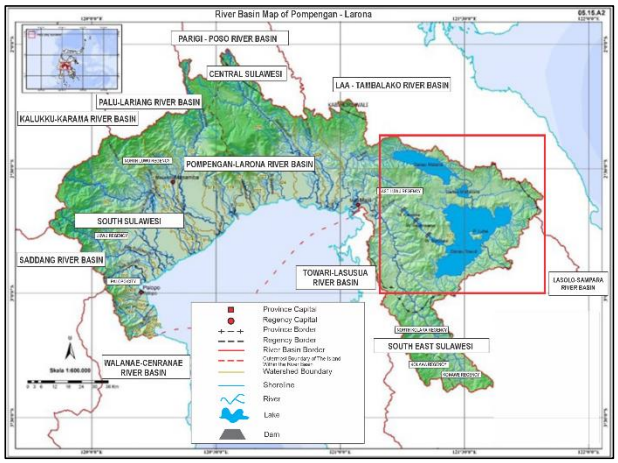

Fig. 2. Water catchment area of Sorowako region.
**Regulation of the Minister of Public Works and Public Housing No 04/PRT/M/2015 related to Criteria for Determining River Basins*

2. Methods

In general, this research examines rivers morphometric characteristics in Sorowako and surrounding areas. The equipment and materials used in this research include Digital Elevation Model (DEM) image (to get general overview of water catchment area profile), camera, stationery and geographic information system (GIS) software namely ArcGIS 10.7 for studio data processing. The morphometric parameters analyzed in this research are bifurcation ratio (Rb) and drainage density (Dd) value. Determining of stream orders, calculating of total stream length on water catchment area, and calculating of total large area of water catchment area are the first step that must be taken in analyze stream morphometry based on the hierarchy of stream formation by Strahler, 1964 in Sukiyah, 2017. From data obtained through determining stream orders, the next step is calculating bifurcation ratio (Rb) and drainage density (Dd) value on each water catchment area with the intention to ascertain deformation due to tectonics activity that occured in Sorowako and surrounding areas.

2.1 Stream Order

Stream channels in a water catchment area can be divided into several stream orders. Stream order is the position of stream channel branching in it's sequence relative to the main stream in water catchment area.

As the number of stream order grows, the number of total large area and total stream length of water catchment area will become wider. Based on the Strahler, 1964 method, in Sukiyah, 2017, a river flow that has no stream branches (in upstream) is called stream order 1, then the combination of two order 1 is called order 2, and the combination between two orders 2 is called order 3, so until reach the main downstream which is marked by largest stream order number (Fig.3).

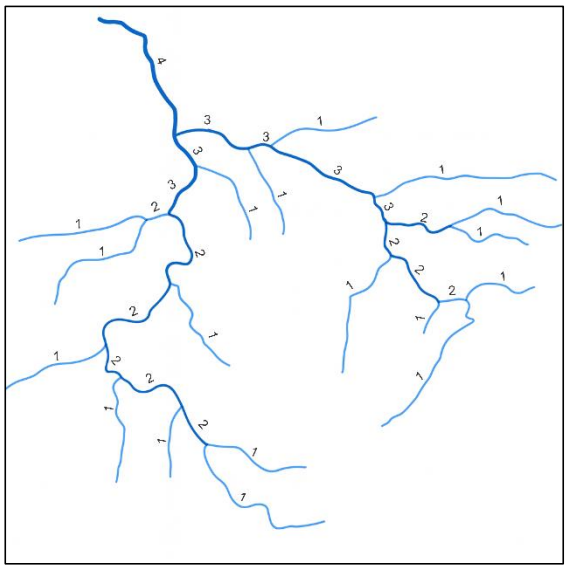

Fig 3. Stream order based on segmentation method according to Sukiyah, 2017 in Almira et al, 2025.

2.2 Bifurcation Ratio (Rb)

Bifurcation ratio (Rb) is an index number that determined based on number of stream channels for an order. To be able to find out the bifurcation ratio (Rb) value, it will be necessary to determine stream order on each water catchment area firstly. A stream order is a branching part of a stream channel seen from it's position relative to the main stream. The stream order system has been explained by several experts, one of them is Strahler (1964). This method explains that if two of the same stream order meet, then on the next segment a higher stream order will be formed. The bifurcation ratio (Rb) value can be more than 10 for very elongated basins where there are intercalations between low and high resistance rock layers. Based on Verstappen (1983) in Sukiyah (2017), bifurcation ratio (Rb) value usually ranges between 3.0 to 5.0 for a water catchment area that is not significantly affected by tectonics, and (Rb>5) when it has undergone significant active tectonic deformation in region. According to Strahler (1964), characteristically bifurcation ratio values range between 3.0 to 5.0 for water catchment area which is not much influenced by structural geology.

In calculating the bifurcation ratio (Rb) value can using following formula :

$$Rb = \frac{Nu}{Nu+1} \quad \text{..... (1)}$$

Information :
- *Rb* : Bifurcation ratio index
- *Nu* : Number of stream channel order - u
- *Nu*+1 : Number of stream channel order - u+1

Table 1. Bifurcation ratio index according to Strahler, 1964 in Gupta., K.L et al., 2019.

Bifurcation Ratio (Rb) Index	Explanation
(Rb) < 3	Indicate that the sub-basins are less affected by structural disturbances
(Rb) 3 - 5	Drainage basin in which the geological structures do not disturb the drainage pattern.
(Rb) > 5	Indicate a strong structural control in the drainage pattern

2.3 Drainage Density (Dd)

Drainage density (Dd) is an index number that provides a numerical measure of how densely rivers and streams are distributed across a drainage basin. It is an expanded function of the size of infiltration capacity and resistance to erosion (Horton, 1945). The drainage density value on water catchment area usually influenced by various factors, generally is the ability of rocks against weathering, rocks permeability, climate, vegetation, etc. (Javed, 2009). Drainage density value also as an indication of deformation due to tectonics in a region.

In calculating the drainage density (Dd) value, using the following formula :

$$Dd = \frac{L}{A} \quad \text{..... (2)}$$

Information :
- *Dd* : Drainage density index (km/km^2)
- *L* : Total stream length on water catchment area (km)
- *A* : Total of large area on water catchment area (km^2)

Table 2. Drainage density index according to (Rama., V.A, 2014)

Drainage Density (Dd) Index	Texture	Explanation
< 1.24	Very Coarse	Very coarse rock texture with low erosion and tectonic affected
1.24 – 2.49	Coarse	Coarse rock texture with low erosion and tectonic affected
2.49 – 3.73	Moderate	Medium rock texture with topography affected by tectonics
3.73 – 4.97	Fine	Fine rock texture with topography affected by erosion and tectonics
> 4.97	Very Fine	Very fine rock texture with topography affected by erosion and tectonics

3. Discussion

Morphometric characteristics of water catchment area in Sorowako and surrounding areas that analyzed through digital elevation model (DEM) data processing. From results of studio analysis, 370 water catchment area's data were obtained which spread on Sorowako and surrounding areas. The highest stream order is the 8th stream order identified on water catchment area 119. Topographic condition of Sorowako and surrounding areas are characterized by hill area, relatively low hill in the southern and quite steep on the northern, western and eastern areas. Most of surface land is still covered by vegetation as tropical rainforest.

Fig 4. Morphology at eastern area of Sorowako.

3.1 Stream Order and Bifurcation Ratio (Rb) Value

Based on result of stream morphometry data processing on water catchment area, bifurcation ratio (Rb) value that obtained from identification and calculation of stream order, which identified from 370 water catchment areas scattered in Sorowako and surrounding areas.

Table 3. Numbers of stream order in Sorowako region.

Numbers of stream order on water catchment area in Sorowako (stream channel)							
Orde I	Orde II	Orde III	Orde IV	Orde V	Orde VI	Orde VII	Orde VIII
22,727	13,530	7,342	4,097	1,827	1,334	189	146

From data obtained, it's proven that many stream channel found in water catchment area show tendency have been affected by tectonic activity then forming stream channel pattern. Stream order 1 is the river with largest number found in Sorowako region, that is 22,727 rivers in stream order 1 category which spread on water catchment area in Sorowako and surrounding areas.

Table 4. Recapitulation of bifurcation ratio which has value (Rb)<3 and (Rb)>5 at each level of bifurcation ratio index in Sorowako area.

Rb 1-2	Rb 2-3	Rb 3-4	Rb 4-5	Rb 5-6	Rb 6-7	Rb 7-8
327	201	78	33	9	1	1

Bifurcation ratio (Rb) index on Sorowako and surrounding areas shows the dominance of bifurcation ratio that have value less than 3.0 (Rb<3) (approximately 95% of total area). Rb 1-2 which have value less than 3.0 is the most numerous numbers, that is 327 in total from recapitulation data of bifurcation ratio value that have value less than 3.0. The analysis result of bifurcation ratio (Rb) on water catchment area shows (Rb<3) has value range 0.094 to 2.888 which is the (Rb<3) value really dominates on water catchment area and spread comprehensively on Sorowako and surrounding areas. Meanwhile on several place, bifurcation ratio (Rb) that have value more than 5.0 (Rb>5) were also found in Sorowako region with value ranging from 5.142 to 10.250 (on water catchment area 365 and water catchment area 277).

It is clear that Sorowako and surrounding areas have been heavily impacted by tectonic activity of Sulawesi island, especially on western, eastern and northern regions of water catchment area, level of deformation tends to be higher than southern region. This can be seen in water catchment area 43, water catchment area 196 and water catchment area 302 with a relatively higher number of stream orders as well as bifurcation ratio (Rb) value that have value less than 3.0 (Rb<3) which are massively distributed on water catchment area. So it can be concluded in general that stream channel on water catchment area in Sorowako region mostly have rapid increases and decreases in flood water levels, and this is closely related to tectonic influences that occur. As well as the intensity of erosion in Sorowako and surrounding areas.

Geological condition of research area show heterogeneous conditions. One of them can be identified as various drainage patterns and branches of river in water catchment area and this condition has generally experienced by quite intense tectonic deformation (Verstappen, 1983, in Sukiyah, 2021). This heterogeneous geological condition is also evidenced by appeareance of joints and ultramafic rocks outcrops as well as melange formation that scattered in Sorowako and surrounding areas.

3.2 Drainage Density (Dd) Value

Drainage density (Dd) index on Sorowako and surrounding areas varies from 0.907 (on water catchment area 233) to 8.422 (on water catchment area 314). The average value of drainage density (Dd) in water catchment area is 4.125. This can be interpreted that condition of Sorowako and surrounding areas is very affected and impacted by erosional events and tectonic activity of Sulawesi island.

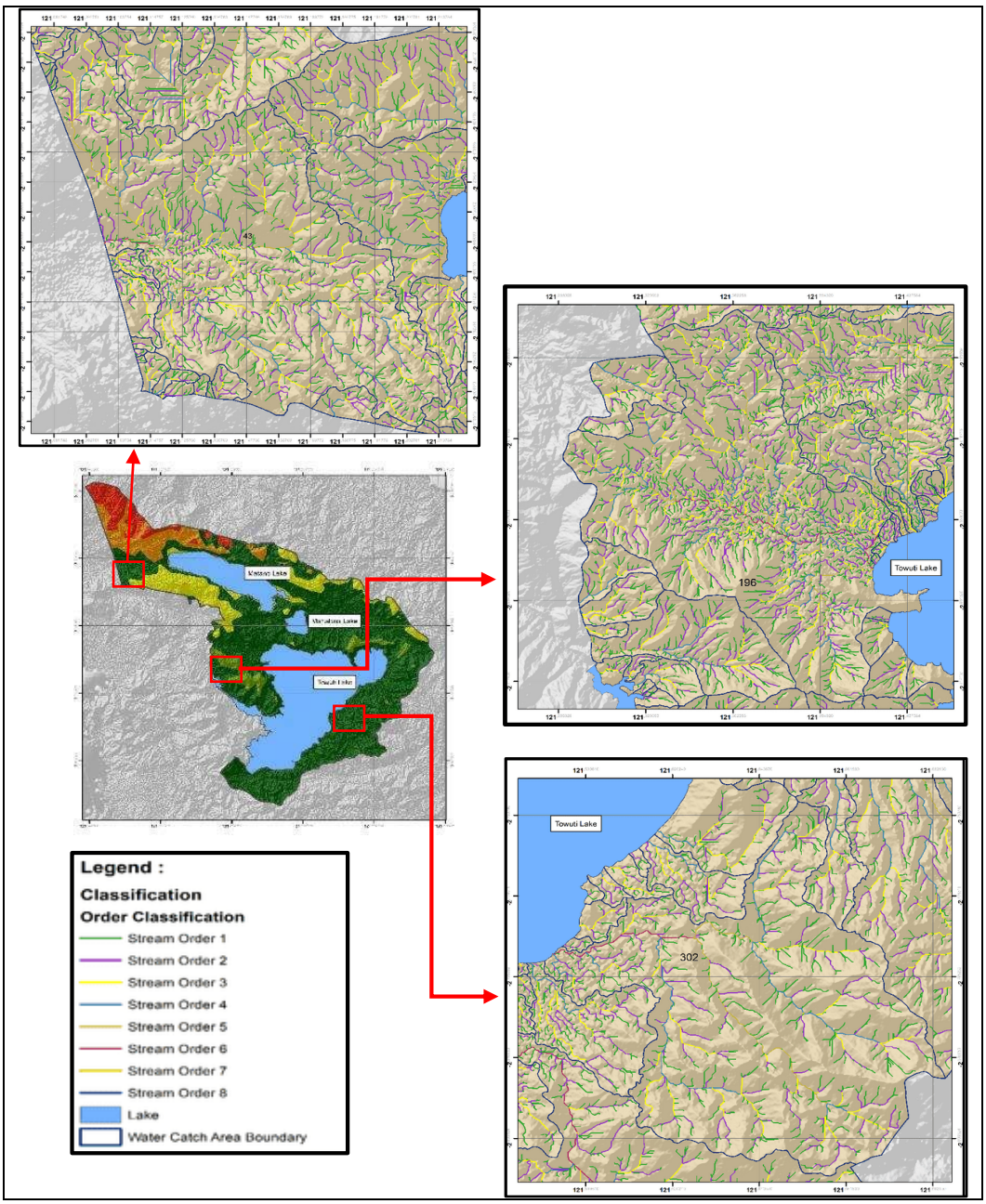

Fig 5. Water catchment area and stream order at northern, western and eastern area of Sorowako.

The drainage density (Dd) index in Sorowako and surrounding areas also describes the rivers flow through rocks with soft resistance and many fracture zones such as joints and faults, thus causing the transport of of sediment material carried by river flow to be greater.

4. Conclusion

Based on morphometric characteristic's analysis results on water catchment area of Sorowako and surrounding areas, which identified from 370 water catchment areas, can be concluded that Sorowako and surrounding areas have a fairly high deformation level due to tectonic activity of micro continent of Sulawesi island. This is proven through analysis of bifurcation ratio (Rb) calculation on water catchment area, which has bifurcation ratio (Rb) value less than 3 (Rb<3), which has an estimated percentage of 95% of total research area. Furthermore, this result confirmed by analysis of drainage density (Dd) value calculated on water catchment area, which has drainage density (Dd) value in the range of 0.907 to 8.422 (with an average drainage density value is 4.125), that describes Sorowako and surrounding areas are affected by quite intense erosion and tectonics. It's can also be interpreted that in Sorowako and surrounding areas are dominated by rocks that have low level resistance or there are many weak zones such as joints and faults which is proven by many evidence of geological structure that found in the field.

Overall, based on morphometric characteristic aspect that analyzed (bifurcation ratio (Rb) index and drainage density (Dd) index), it can be concluded that these two morphometric parameters have relations that interprets tectonic events in Sorowako and surrounding areas. It can be seen that Sorowako and surrounding areas strongly affected by tectonic activity of Sulawesi island especially on the western, eastern and northern regions of water catchment area, the level of deformation tends to be higher than on the southern region. This can be seen on water catchment area 43, water catchment area 196, and water catchment area 302 with relatively larger number of stream order and generally have bifurcation ratio (Rb) value less than 3 (Rb<3). The level of deformation and tectonic events is likely to be one of the controlling factors for nickel grade contained

in Sorowako and surrounding areas which is allowing supergene enrichment occurs in rocks formation.

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