JPPIPA 11(8) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Comparative Morphometric Analysis for Flood Risk Assessment in Alo and Molamahu Sub-Watersheds, Gorontalo Regency

Indrawan[1*], Ahmad Syamsu Rijal S[2], Talha Dangkua[2], Risman Jaya[2]

[1] Student in Geography Study Program, Universitas Muhammadiyah Gorontalo, Gorontalo, Indonesia.
[2]Geography Study Program, Universitas Muhammadiyah Gorontalo, Gorontalo, Indonesia.

Received: May 30, 2025
Revised: July 04, 2025
Accepted: August 25, 2025
Published: August 31, 2025

Corresponding Author:
Indrawan
indrawan.indra0299@gmail.com

DOI: 10.29303/jppipa.v11i8.11924

Abstract: This study conducts a comparative morphometric analysis of the Alo and Molamahu sub-watersheds, located in the upstream Limboto Watershed, Gorontalo Province, Indonesia, to assess flood risk. Using the National Digital Elevation Model (DEMNAS) with an 8-m spatial resolution, classical morphometric parameters were derived through remote sensing and Geographic Information System (GIS) techniques. Both sub-watersheds share a maximum stream order of 4 and exhibit relatively high drainage density and stream frequency, indicating rapid surface runoff. However, the Molamahu sub-watershed is larger, steeper, and has a higher ruggedness number than Alo, suggesting greater erosion potential and higher susceptibility to landslides and flash floods. In contrast, Alo shows gentler slopes but remains flood-prone due to short overland flow paths. The analysis demonstrates that morphometric characteristics directly influence flood dynamics, highlighting the need for tailored watershed management. Recommended strategies include erosion control and slope stabilization in Molamahu, and water retention measures in Alo, supported by broader reforestation efforts across the Limboto system.

Keywords: Morphometric Analysis; Flood Risk; Sub-watershed Comparison; Watershed Management

Introduction

The Alo and Molamahu sub-watersheds lie within the larger Limboto watershed in Gorontalo Province, Sulawesi, Indonesia. The Limboto basin drains into Lake Limboto and is a national priority watershed due to severe sedimentation and flood hazards (S. Eraku et al., 2019) . Gorontalo's topography is basin-shaped (lowlands surrounded by hills) and has a tropical monsoon climate, making it prone to erosion and floods. Studies report that Limboto Watershed suffers very heavy erosion over much of its area. For instance, soil loss modeling estimates that Alo, Molamahu, and neighboring sub-watersheds collectively deliver on the order of millions of tonnes of sediment per year into the Limboto Lake (Dunggio & Ichsan, 2022). The Alo River in particular is noted for high sediment loads and channel aggradation, with its width narrowing to only a few meters in places due to delta formation. This rampant sedimentation not only degrades soil and water quality but also reduces channel capacity and exacerbates flooding downstream (Mosi, Lihawa, et al., 2024; Mosi, Warow, et al., 2024; Virgota et al., 2024).

Local hydrometeorological studies confirm that flood risk is high across the Limboto basin. A spatial flood- hazard assessment found that nearly all alluvial plains in the Limboto watershed fall into high or very-high flood vulnerability zones. Rapid assessment of climate-related risks in Gorontalo Regency likewise identifies extensive flood-prone areas (especially in low-

How to Cite:
Indrawan, Dangkua, T., S, A. S., & Jaya, R. (2025). Comparative Morphometric Analysis for Flood Risk Assessment in Alo and Molamahu Sub-Watersheds, Gorontalo Regency. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 535–545. https://doi.org/10.29303/jppipa.v11i8.11924

lying district centers). Intense rainfall events under climate change further increase this hazard. In sum, the Limboto watershed (and by extension its sub-basins, including Alo and Molamahu) is highly susceptible to floods, driven by both climatic and geomorphic factors (Nusi et al., 2023).

Classical geomorphology teaches that watershed form influences flow. Horton (1945) and later Strahler (1964) formalized drainage topology (stream orders, length distributions) to describe basin geometry. Recent research has empirically linked morphometry to flood susceptibility in varied environments. Obeidat et al. (2021) applied morphometric analysis in Jordan's Wadi Easal basin and found that sub- watersheds with higher Dd, steeper basin relief, and larger Rn accounted for the vast majority of flood- prone area. In that study, 71% of sub-basins were ranked high-to-very-high flood-susceptible, and the underlying parameters identified included drainage density, stream frequency, basin relief and slope, ruggedness number, and related shape factors. Similarly, other works (Sutradhar & Mondal, 2023; Taha et al., 2017) have shown that indices like bifurcation ratio, form factor, and slope correlate with flood hazard levels. In general, studies consistently find that parameters implying rapid runoff and channel concentration (high Dd, high Rr, high Rn) tend to dominate in flood-sensitive basins. Thus, integrating classical theory with these modern findings provides a robust justification for using morphometric metrics as proxies for flood risk.

Given this framework, it is crucial to characterize the morphometry of the Alo and Molamahu sub-watersheds specifically. Both sub-basins lie in the Limboto system and share the broader flood drivers of the region, but they may differ in form and function. A comparative analysis will reveal whether, for example, one watershed has a much higher drainage density or relief ratio than the other, which in turn could explain any differences in flood timing or magnitude.

While the Limboto watershed has been extensively studied for sedimentation processes and downstream flood hazards, limited attention has been given to how its individual sub-watersheds differ in morphometric structure and how these differences translate into distinct hydrological risks. This study addresses that gap by conducting a comparative morphometric analysis of the Alo and Molamahu sub-watersheds. Although both sub-basins lie within the same hydrological system, they are shaped by different geomorphic and topographic features that may produce contrasting hydrological responses. By systematically analyzing these parameters, this research highlights how neighboring sub-watersheds can exhibit different kind of flood susceptibility despite their close geographic proximity.

This paper presents a detailed morphometric comparison of the Alo and Molamahu sub-watersheds to support flood-sensitive management. The results will identify how each watershed's shape and drainage network contribute to runoff characteristics and sediment yields. This study aims to assess the flood risk of the two sub-watersheds based on their morphometry. The findings will have practical implications since highlighting which watershed exhibits more acute flood potential, resource managers can prioritize interventions in the most sensitive areas. Through this approach, we hope to demonstrate that even neighboring sub-watersheds within a single watershed can behave differently, and that tailored flood-risk strategies must be grounded in quantitative terrain analysis.

The novelty of this research lies in its dual contribution. First, it provides new empirical evidence on the spatial heterogeneity of flood risk drivers within a single watershed, emphasizing that effective management requires moving beyond a one-size-fits-all approach. Second, it demonstrates how morphometric analysis can serve as a rapid diagnostic tool for identifying high-risk sub-watersheds in data-limited tropical regions. Such an approach is not only cost-effective but also transferable to other watersheds facing similar flood and erosion challenges.

Method

Study Area

The Alo and Molamahu sub-watersheds are two among several sub-basins located in the upstream region of the Limboto Watershed in Gorontalo Province. Administratively, the Alo Sub-watershed is situated in Tibawa District, Gorontalo Regency, while the Molamahu Sub-watershed lies in the surrounding areas within the same regency. These two sub-watersheds play a vital role in the hydrological system of Lake Limboto, serving as major contributors of surface runoff and sediment flow into the lake (Alfianto & Cecilia, 2020; S. S. Eraku & Permana, 2020).

The Alo Sub-watershed covers an area of approximately 69,736,900 m² (around 69.7 km²), while the Molamahu Sub-watershed spans about 127.7 km². Both sub-watersheds have been identified as among the largest sediment contributors to Lake Limboto. Based on WaTEM/SEDEM modeling, the estimated sediment volume from the Alo Sub-watershed reaches 115,204 m³ per year, while the Molamahu Sub-watershed contributes around 73,058 m³ per year (Alfianto & Cecilia, 2020). The geomorphological conditions of these sub-watersheds are influenced by complex geological structures, land cover dominated by shrubs, declining forest areas, and increasing land conversion for agriculture and settlements. These sub-watersheds are located within active sediment production zones, with very high erosion potential and soil types exhibit moderate to high erodibility. This is further supported by WaTEM/SEDEM simulations, which show that rivers in the Alo and Molamahu sub-watersheds consistently transport large amounts of sediment annually, especially during 50-year return period flood events (Alfianto & Cecilia, 2020). The map of study area is presented in Figure 1.

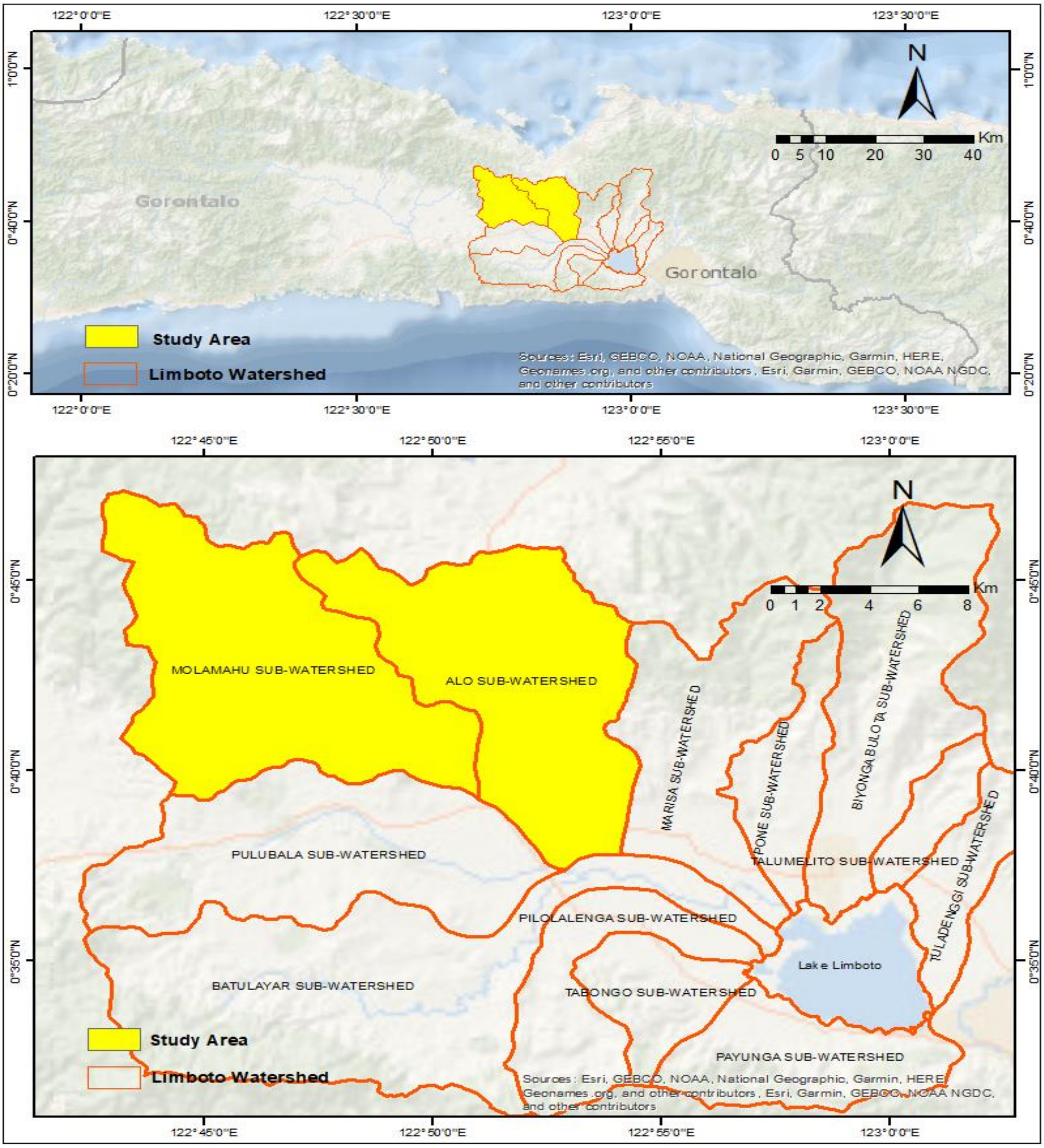

Figure 1. Map of study area

Data Management and Analysis

The main dataset employed for analyzing the morphometric characteristics of the sub-watersheds was DEMNAS (National Digital Elevation Model) obtained from https://tanahair.indonesia.go.id/ demnas. With a spatial resolution of 8 meters, DEMNAS is considered more accurate than other elevation data sources such as ALOS PALSAR and SRTM (Jaya et al., 2024). The method employed follows classical morphometric analysis principles developed by Horton (1945), Strahler (1964), and Nag (1998). The analysis procedure involved several main stages. First, DEM-based hydrological methods, to determine flow direction and flow accumulation. River networks formed from the flow accumulation were then classified using the Strahler method to determine stream order. Morphometric parameters were then calculated across four major aspects: basic (area, perimeter, stream length, segment count), linear (drainage density, stream frequency, bifurcation ratio, stream length ratio, mean stream length), areal (form factor, circularity ratio, elongation ratio, drainage texture, length of overland flow, maintenance constant), and topographic (relief, relief ratio, ruggedness number). All parameters were systematically calculated using standard formulas widely adopted in previous morphometric studies. Parameters for the morphometric calculation in this research is presented in Table 1.

A literature review was then conducted to support the interpretation of the morphometric results. This review focused on identifying key relationships between morphometric parameters and flood risk, drawing from both classical geomorphological theory and contemporary case studies. By aligning the study's findings with this existing body of work, the interpretation of morphometric indicators in relation to flood vulnerability was strengthened and contextualized. The flowchart of stages and methods employed is presented in Figure 2.

Table 1. Morphometric parameters

Morphometric aspects	Parameter	Methods/formulas	References
Basic	Basin area (A)	DEMNAS Analysis	Strahler (Munoth & Goyal, 2020)
	Perimeter (P)	DEMNAS Analysis	Horton (Nasir et al., 2020)
	Stream order (U)	DEMNAS Analysis	Strahler (Nasir et al., 2020)
	Number of stream segments (Nu)	DEMNAS Analysis	Horton (Nasir et al., 2020)
	Stream length (Lu)	DEMNAS Analysis	Horton (Obeidat et al., 2021)
	Basin length (Lb)	DEMNAS Analysis	Horton (Obeidat et al., 2021)
Linear	Mean stream length (Lms)	$Lms = \frac{Lu}{Nu}$	Strahler (Munoth & Goyal, 2020)
	Stream length ratio (Rl)	$Rl = \frac{Lu}{Lu - 1}$	Horton (Munoth & Goyal, 2020)
	Bifurcation ratio (Rb)	$Rb = \frac{Nu}{Nu + 1}$	Strahler (Bharath et al., 2021)
	Drainage density (Dd)	$Dd = \frac{Lu}{A}$	Horton (Bharath et al., 2021)
	Stream frequency (Fs)	$Fs = \frac{Nu}{A}$	Horton (Albaroot,et al, 2018)
Area	Texture ratio (T)	$T = \frac{Nu}{P}$	Horton (Choudhari et al., 2018)
	Form factor (Rf)	$Rf = \frac{A}{Lb^2}$	Horton (Waikar & Nilawar, 2014)
	Circularity ratio (Rc)	$Rc = \frac{4 \, x \, \pi \, x \, A}{P^2}$	Schumn (Obeidat et al., 2021)
	Elongation ratio (Re)	$Re = \frac{2 \, x \sqrt{\frac{A}{\pi}}}{Lb}$	Schumn (Waikar & Nilawar, 2014)
	Length of overland flow (Lg)	$Lg = \frac{1}{2} x \frac{1}{Dd}$	Horton (Albaroot,et al, 2018)
	Constant channel maintenance (Mc)	$Mc = \frac{1}{Dd}$	Schumn (Munoth & Goyal, 2020)
Topography	Basin relief (R)	$R = H - h$ H = Maximum relief h = Minimum relief	Horton (Obeidat et al., 2021)
	Relief ratio (Rr)	$Rr = \frac{R}{Lb}$	Schumn (Choudhari et al., 2018)
	Ruggedness number (Rn)	$Rn = R \, x \, Dd$	Strahler (Sutradhar & Mondal, 2023)

The literature review was conducted to strengthen the interpretation of the results. This process involved several stages. Firstly, identification of key sources was conducted where literature was gathered from reputable international journals, accredited national journals, as well as classic hydrology and geomorphology textbooks. The databases consulted included Google Scholar and ScienceDirect, using keywords such as morphometric analysis, flood risk, drainage density, ruggedness number, watershed management and Limboto watershed.

Secondly, selection of relevant literature was conducted where the selected references met the following criteria: (i) they examined the relationship between morphometric parameters and watershed risk to floods; (ii) they provided empirical case studies at both global levels and local contexts; and (iii) they provided watershed management strategies derived from morphometric findings.

Thirdly, analysis and synthesis were conducted, where the collected literature was then analysed to identify consistent patterns linking morphometric parameters with flood risks. These insights were compared with the morphometric results of the Alo and Molamahu sub-watersheds to ensure that interpretations were not merely descriptive but supported by scientific evidence and finally, the literature review served as an interpretative framework for differentiating management strategies between the Alo and Molamahu sub-watersheds.

Table 2. Summary of Literature Reviewed

Category	Number of Literature	Examples	Relevance
Classical theories of geomorphology and hydrology	8	(Chow, 1965; Horton, 1932, 1945; Strahler, 1964)	Basic morphometric calculations and hydrological response theory for watersheds
Global empirical studies of floods and morphometry relations	10	(Arabameri et al., 2020; Obeidat et al., 2021; Sutradhar & Mondal, 2023; Taha et al., 2017)	Confirm the relationship between morphometric characteristics with flood risk
Local studies	6	(Alfianto & Cecilia, 2020; Dunggio & Ichsan, 2022; S. Eraku et al., 2019; Nusi et al., 2023)	Provide local context
Watershed conservation and flood mitigation strategies	6	(Mitsch & Gosselink, 2015; Morgan, 2009; Stallard, 1988; Wischmeier & Smith, 1978)	Recommendations on sub-watershed management strategies

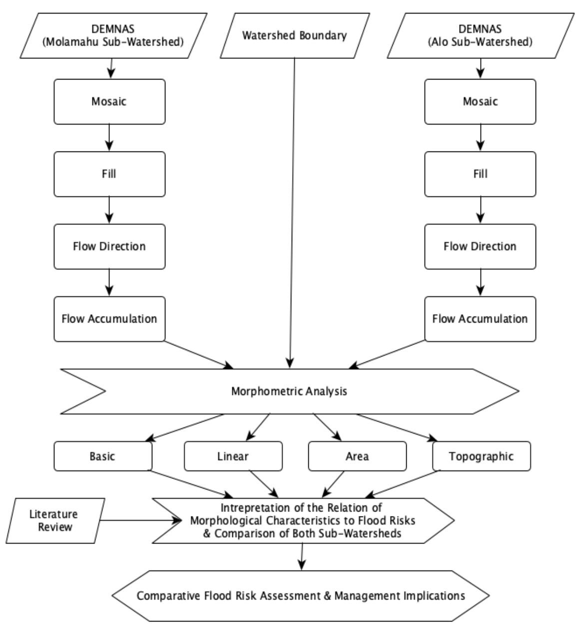

Figure 2. Flowchart detailing the stages and methods employed

Result and Discussion

Results

Alo Sub-watershed

The Alo Sub-watershed covers an area of 112.70 km² and has a perimeter of 55.40 km, with a maximum stream order of 4. It contains 231 stream segments, indicating a relatively dense river network. The main channel is 21.016 km long, and the total stream length across all orders is 96.73 km. The drainage density is 0.86 and the stream frequency is 2.05, both of which indicate a dense drainage network and efficient surface water conveyance.

The bifurcation ratio is 1.00, suggesting a uniform stream branching pattern without major anomalies. The mean stream length is 0.42 km, reflecting a large number of short tributaries, which aligns with the high stream frequency. The stream length ratio is 1.01 km, indicating that the change in stream length between orders is minimal. In terms of shape, the watershed exhibits a strongly elongated form. The form factor is 0.26, and the circularity ratio is 0.46, both pointing to an elongated, non-circular basin. The elongation ratio is 0.67, making overall shape isl best interpreted as elongated.

The length of overland flow is 0.58 km, indicating that rainfall runoff travels a relatively short distance overland before reaching a stream channel. This implies fast surface flow and an increased risk of flash flooding. The channel maintenance constant is 1.24, a low value showing that even a small land area is sufficient to support 1 km of stream, reinforcing the dominance of surface runoff. Topographically, the elevation difference between the highest and lowest points is approximately 0.534 km (e.g., ~550 m at the peak and ~16 m at the outlet), and the total watershed length is 96.73 km. This gives a relief ratio of 0.025, indicating a gentle slope. The ruggedness number is 0.46, suggesting moderate relief and a medium level of erosion potential.

Overall, while the watershed's slopes are not excessively steep, the combination of high drainage density, short overland flow paths, and dense stream networks leads to increased surface runoff potential especially if vegetation cover is reduced. Hydrologically, Alo is highly responsive to rainfall, making it prone to rapid flooding.

Molamahu Sub-watershed

The Molamahu Sub-watershed is larger, covering 127.97 km² with a perimeter of 59.99 km. The highest stream order in Molamahu is also 4. The number of stream segments reaches 288, higher than Alo due to the larger catchment area. The main channel length is 24.5km, while the total length of all stream orders is 94.27 km. The drainage density (Dd) is approximately 0.74, and the stream frequency (Fs) is 2.25, both indicating a relatively dense river network. The bifurcation ratio (Rb) is 1.00, similar to Alo, suggesting a uniform stream branching pattern. The mean stream length (Lms) is 0.33, which is shorter than in Alo, implying a higher density of low-order streams per unit area. The stream length ratio (RL) is 1.01, showing minimal variation in stream length across stream orders, and is consistent with the Alo watershed.

In terms of shape, the Molamahu Sub-watershed is elongated. The form factor (Rf) is 0.21, a very low value, and the circularity ratio (Rc) is 0.45, both pointing to a highly elongated basin shape. Due to the much lower Rf and Rc values, the watershed is more accurately described as elongated. Lg is slightly shorter than in Alo, suggesting that rainfall runoff reaches stream channels quickly. This short Lg implies a short time of concentration and high potential for rapid runoff. Thus, Molamahu is also susceptible to flash flooding under intense rainfall due to its dense drainage system and short surface flow paths.

The channel maintenance constant (Mc) is 1.36, a low value meaning that a relatively small area is sufficient to support 1 km of stream. This is similar to Alo and further indicates a dominant surface runoff pattern in the watershed. Topographically, the Molamahu watershed is steeper than Alo. The elevation difference is 0.803 km (803 m), greater than that of Alo. The relief ratio (Rr) is 0.033, indicating a steeper average slope. The ruggedness number (Rn) is 0.59, significantly higher than Alo's. This high Rn reflects steeper terrain and denser drainage, leading to faster surface runoff and higher erosive energy. These conditions increase the risk of landslides and flash floods. The morphometric characteristics comparison of both sub-watershed is presented in Table 3.

Table 3. Morphometric characteristics comparison of both sub-watershed

Morphometric aspects	Parameter	Alo	Molamahu,
Basic	Basin area (A)	112.70 km²	127.97 km²
	Perimeter (P)	55.40 km	59.99 km
	Stream order (U)	4	4
	Number of stream segments (Nu)	231	288
	Basin length (Lb)	21.16 km	24.10 km
	Stream length (Lu)	96.73km	94.27 km
Linear	Mean stream length (Lms)	0.42 km	0.33 km
	Stream length ratio (Rl)	1.01 km	1.01 km
	Bifurcation ratio (Rb)	1.00	1.00
	Drainage density (Dd)	0.86 km/ km²	0.74 km/km²
	Stream frequency (Fs)	2.05 km/ km²	2.25 km/ km²
Area	Texture ratio (T)	1.76	1.66
	Form factor (Rf)	0.26	0.21
	Circularity ratio (Rc)	0.46	0.45
	Elongation ratio (Re)	0.67	0.63
	Length of overland flow (Lg)	0.58 km/ km²	0.68 km/ km²
	Maintenance channel constant (Mc)	1.24 km²	1.36 km²
Topography	Basin relief (R)	0.53 km	0.80 km
	Relief ratio (Rr)	0.025	0.033
	Ruggedness number (Rn)	0.46	0.59

Discussion

The comparative analysis of the two sub-watersheds reveals several morphometric similarities as well as distinct differences. Both watersheds share the same highest stream order (4), implying an equivalent branching hierarchy, a fundamental concept in quantitative geomorphology (Horton, 1945; Strahler, 1964). However, Molamahu is larger (127.975 km² compared to 112.704 km²) and has more stream segments (288 compared to 231). Despite differences in scale, both sub-watersheds exhibit relatively high drainage densities and stream frequency (Fs) values are closely matched, suggesting dense and efficient river networks. These high Dd and Fs values indicate that both watersheds are prone to rapid surface runoff, a fact consistently supported by literature linking high Dd values with elevated flood risk and rapid hydrograph rises (Nag, 1998; Pallard et al., 2009).

Topographically, a significant contrast emerges. Molamahu has a greater relief (803 m) compared to Alo (534 m), and a higher ruggedness number (0.46 vs 0.59), suggesting steeper slopes and higher erosion potential in Molamahu (Arabameri et al., 2020; Chow, 1965). While Alo has a slightly denser drainage network, Molamahu is more vulnerable to landslides and sedimentation due to its higher elevation and steeper gradient. Both sub-watersheds are elongated in shape, contributing to extended concentration times. However, the length of overland flow (Lg) in Molamahu is shorter, and its channel maintenance constant (Mc) is also low, similar to Alo, indicating rapid surface water conveyance. Literature also confirms that low Lg values heighten the risk of flash flooding, making both sub-watersheds hydrologically sensitive (Meshram & Sharma, 2017; Portuguez-Maurtua et al., 2023).

From a management standpoint, tailored approaches are necessary. Alo, with gentler slopes, is better suited for water retention strategies such as wetland restoration and sediment traps. In contrast, Molamahu requires more aggressive slope stabilization methods like upstream reforestation, terracing, and retaining walls (Stallard, 1988). Their elongated shapes mean main channels are long and runoff is evenly distributed downstream. These findings are in line with classical geomorphological theories (Horton, 1932; Schumm, 1956; Strahler, 1964) and contemporary research (Khodaei et al., 2025), which emphasize the roles of flow density and relief in flood and erosion susceptibility. Accordingly, watershed planning must account for morphometric differences: runoff reduction and micro-conservation infrastructure in Alo, and erosion control in Molamahu (Pastor et al., 2024)).

Key morphometric parameters directly correlate with flood risk in these sub-watersheds. Drainage Density (Dd) is a primary indicator. High Dd reflects a tightly knit stream network, enabling swift surface runoff convergence. Watersheds with high Dd exhibit rapid hydrograph rises and elevated flood peaks, signaling a short lag time and greater flood vulnerability (Portuguez-Maurtua et al., 2023; Singh, 1992).

Length of Overland Flow (Lg) further affects flood dynamics. A short Lg means water quickly reaches the stream channel, amplifying flash flood potential. Watersheds with short Lg values demonstrate rapid runoff concentration, whereas longer Lg values delay peak flows (Yamazaki et al., 2011). Relief Ratio (Rh) indicates overall slope steepness. Higher Rh values suggest stronger gravitational pull and faster surface flow. Sub-watersheds with high Rh have short response times and high flood peaks, heightening flash flood risk (Enea et al., 2024).

The Ruggedness Number (Rn), a combination of relief and drainage density, signals terrain ruggedness. High Rn values signify steep, dissected landscapes with high runoff and erosion potential (Chorley, 1957). In Alo and Molamahu, high Rn suggests increased susceptibility to sedimentation and flash floods. Additionally, studies suggest that basins with high values for form factor, elongation tend to have low infiltration capacity, corroborating findings from morphometric studies worldwide (Joji et al., 2013)(Purwanto & Paiman, 2023). For example, research in the East Rapti River Basin (Nepal) found that drainage density and topographic relief are key contributors to flash flooding (Sharma et al., 1980).

The morphometric characteristics of Sub-DAS Molamahu and Sub-DAS Alo provide insights for developing targeted and effective watershed management strategies in addressing recurring flood occurences, (Supiyati et al., 2024) within the broader Limboto watershed. Recognizing these inherent geomorphological differences is paramount for moving beyond generic interventions to site-specific solutions (Aditama et al., 2025; Pisupati & PJ, 2025). For Molamahu, with its pronounced relief and high ruggedness number, a strong emphasis on erosion control and slope stabilization is crucial to mitigate sediment transport downstream into Lake Limboto. This necessitates aggressive reforestation and afforestation, particularly on steeper slopes, as forest cover significantly enhances infiltration and reduces surface runoff velocity and soil loss (Wischmeier & Smith, 1978; Asdak 2023). Furthermore, implementing bioengineering techniques like contour planting, terracing, and vegetative gabions, along with strategic structural measures like check dams and sediment traps, can effectively manage water flow and sediment on highly erodible gradients (Morgan, 2009).

Meanwhile, Alo, characterized by its comparatively gentler slopes, presents distinct opportunities for enhancing water retention and groundwater recharge. Despite its slightly denser drainage network implying efficient runoff, the lower relief suggests that strategies like wetland restoration and the creation of small-scale infiltration ponds would be highly effective. These interventions can serve as natural sponges, storing excess water during peak flows, releasing it slowly, and thereby reducing downstream flood impacts while concurrently replenishing groundwater aquifers (Mitsch & Gosselink, 2015).

Conclusion

This comparative morphometric analysis of the Alo and Molamahu sub-watersheds has revealed important differences in their hydrological behavior and flood risks. Both sub-watersheds are characterized by high drainage densities and stream frequencies, which indicate rapid surface runoff and heightened flood sensitivity. However, their topographic and areal characteristics result in distinct levels of risk. Molamahu, being larger and steeper with a higher ruggedness number, shows greater susceptibility to erosion, landslides, and flash s. In contrast, Alo, despite its dense drainage network and short overland flow paths, exhibits gentler slopes that favor rapid runoff but with comparatively lower erosion potential.

These findings highlight two general conclusions. First, morphometric analysis is an applicable tool for identifying flood-prone sub-watersheds within larger basins, especially in tropical environments where detailed hydrological data are often scarce. The study demonstrates that even neighboring sub-watersheds within the same system can display markedly different flood vulnerabilities depending on their geomorphological configuration. Second, tailored watershed management is essential: slope stabilization and erosion control must be prioritized in steeper sub-watersheds like Molamahu, while water retention strategies, including wetland restoration, sediment traps, and infiltration ponds are more effective in gentler sub-watersheds such as Alo.

Beyond the Limboto watershed system, the research provides broader insights for watershed planning in other flood-prone regions of Indonesia and comparable tropical basins. The methodological framework of combining DEMNAS data, GIS techniques, and classical morphometric indices offers a cost-effective and replicable approach to sub-watershed prioritization. Practical implications include the need for local governments and resource managers to integrate morphometric findings into flood mitigation policies, reforestation programs, and land-use planning. More generally, the study underscores the value of linking geomorphological analysis with climate adaptation strategies, particularly as extreme rainfall events become more frequent under climate change. Thus, this research not only clarifies the distinct flood risks of the Alo and Molamahu sub-watersheds but also demonstrates the wider applicability of morphometric analysis for disaster risk reduction and sustainable watershed management.

Acknowledgments
The authors wish to express their sincere gratitude to Universitas Muhammadiyah Gorontalo for its continuous support, provision of facilities, and academic guidance throughout the completion of this research.

Author Contributions
Conceptualization, I, T.D, and A.S.R.S.; methodology, R.J; software, data analyzer and visualization I; writing—review and editing, I; supervision, T.D and A.S.R.S.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

References

Aditama, D. H., Harisuseno, D., & Hendrawan, A. P. (2025). Flood Prone Area Analysis in the Wonosari Sub Watershed, Bondowoso Regency, East Java. *Jurnal Penelitian Pendidikan IPA*, *11*(5), 359–369. https://doi.org/10.29303/jppipa.v11i5.11130

Albaroot, M., Nabil, M. A., Hamdi, S. A., Mohammed, A., & Saleh, A. G. (2018). Quantification of morphometric analysis using remote sensing and GIS techniques in the Qa'Jahran Basin, Thamar Province, Yemen. *Int J New Technol Res (IJNTR)*, *4*(8), 12–22. https://www.scirp.org/reference/referencespapers?referenceid=3305986

Alfianto, A., & Cecilia, S. (2020). Pemodelan Potensi Erosi Dan Sedimentasi Hulu Danau Limboto Dengan Watem/Sedem. *Jurnal Teknik Hidraulik*, *11*(2), 67–82. https://doi.org/10.32679/jth.v11i2.613

Arabameri, A., Tiefenbacher, J. P., Blaschke, T., Pradhan, B., & Tien Bui, D. (2020). Morphometric analysis for soil erosion susceptibility mapping using novel gis-based ensemble model. *Remote Sensing*, *12*(5), 874. https://doi.org/https://doi.org/10.3390/rs12050874

Bharath, A., Kumar, K. K., Maddamsetty, R., Manjunatha, M., Tangadagi, R. B., & Preethi, S. (2021). Drainage morphometry based sub-watershed prioritization of Kalinadi basin using geospatial technology. *Environmental Challenges*, *5*, 100277. https://doi.org/https://doi.org/10.1016/j.envc.2021.100277

Chorley, R. J. (1957). A new standard for estimating drainage basin shape. *Amer. Jour. Sci.*, *255*, 138–141. https://doi.org/http://dx.doi.org/10.2475/ajs.255.2.138

Choudhari, P. P., Nigam, G. K., Singh, S. K., & Thakur, S. (2018). Morphometric based prioritization of watershed for groundwater potential of Mula river basin, Maharashtra, India. *Geology, Ecology, and Landscapes*, *2*(4), 256–267. https://doi.org/https://doi.org/10.1080/24749508.2018.1452482

Chow, V. Te. (1965). *Bibliography: 1) Handbook of applied hydrology*. Taylor & Francis. https://doi.org/https://doi.org/10.1080/02626666509493376

Dunggio, I., & Ichsan, A. C. (2022). Efektifitas Pembuatan Tanaman Vegetatif dalam Menanggulangi Erosi dan Sedimentasi (Studi Kasus di Daerah Aliran Sungai Limboto Provinsi Gorontalo). *Jurnal Belantara*, *5*(1), 45–58. https://doi.org/10.29303/jbl.v5i1.882

Enea, A., Stoleriu, C. C., Iosub, M., & Niacsu, L. (2024). A GIS automated tool for morphometric flood analysis based on the Horton–Strahler river classification system. *Water*, *16*(4), 536. https://doi.org/https://doi.org/10.3390/w16040536

Eraku, S., Lahay, R. J., & Akase, N. (2019). Utilization of the Storie Method to Analyze the Spatial Distribution of Ground Movement Vulnerability in the Limboto Watershed Area, Gorontalo Province. *International Journal of Innovative Science and Research Technology*, *4*(9). https://www.ijisrt.com/utilization-of-the-storie-method-to-analyze-the-spatial-distribution-of-ground-movement-vulnerability-in-the-limboto-watershed-area-gorontalo-province

Eraku, S. S., & Permana, A. P. (2020). Analisis kemampuan dan kesesuaian lahan di daerah aliran Sungai Alo, Provinsi Gorontalo. *Jukung (Jurnal Teknik Lingkungan)*, *6*(1). https://doi.org/http://dx.doi.org/10.20527/jukung.v6i1.8243

Horton, R. E. (1932). Drainage-basin characteristics. *Transactions, American Geophysical Union*, *13*(1), 350–361. https://doi.org/https://doi.org/10.1029/TR013i001p00350

Horton, R. E. (1945). Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*, *56*(3), 275–370. https://doi.org/https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

Jaya, R., Murti, S. H., Adji, T. N., & Sulaiman, M. (2024). Relation of morphometric characteristics to land degradation in the Biyonga sub-watershed, Gorontalo Regency, Indonesia. *Journal of Degraded & Mining Lands Management*, *11*(2). https://doi.org/10.15243/jdmlm.2024.112.5263

Joji, V. S., Nair, A. S. K., & Baiju, K. V. (2013). Drainage basin delineation and quantitative analysis of Panamaram Watershed of Kabani River Basin, Kerala using remote sensing and GIS. *Journal of the Geological Society of India*, *82*(4), 368–378. https://doi.org/https://doi.org/10.1007/s12594-013-0164-x

Khodaei, H., Nasiri Saleh, F., Nobakht Dalir, A., & Zarei, E. (2025). Future flood susceptibility mapping under climate and land use change. *Scientific Reports*, *15*(1), 12394. https://doi.org/https://doi.org/10.1038/s41598-025-97008-0

Meshram, S. G., & Sharma, S. K. (2017). Prioritization of watershed through morphometric parameters: a PCA-based approach. *Applied Water Science*, *7*, 1505–1519. https://doi.org/https://doi.org/10.1007/s13201-015-0332-9

Mitsch, W. J., & Gosselink, J. G. (2015). *Wetlands*. John wiley & sons. https://books.google.co.id/books?id=-vcwBgAAQBAJ&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Morgan, R. P. C. (2009). *Soil erosion and conservation*. John Wiley & Sons. https://books.google.co.id/books?id=j8C8fFiPNOkC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Mosi, Y., Lihawa, F., Mahmud, M., & Novrizal, F. (2024). Analysis of Non-Point Source (NPS) Pollutant Load and Water Capacity of Bolango River, Gorontalo Province. *Jurnal Penelitian Pendidikan IPA*, *10*(11), 9904. https://doi.org/10.29303/jppipa.v10i11.9582

Mosi, Y., Warow, N., Usman, M., Bahuwa, I. C., Rosalia, N., Kadir, Z. S., Hamidun, M. S., Lihawa, F., & Dunggio, I. (2024). Analisis Erosi dan Sedimentasi di Sub Das Alo-Pohu Kesatuan Pengelolaan Hutan Vi Gorontalo. *Jurnal Sains Teknologi & Lingkungan*, *10*(2), 321–331. https://doi.org/https://doi.org/10.29303/jstl.v10i2.616

Munoth, P., & Goyal, R. (2020). Hydromorphological analysis of Upper Tapi river sub-basin, India, using QSWAT model. *Modeling Earth Systems and*

Environment, *6*(4), 2111–2127. https://doi.org/10.1007/s40808-020-00821-x

Nag, S. K. (1998). Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. *Journal of the Indian Society of Remote Sensing*, *26*, 69–76. https://doi.org/https://doi.org/10.1007/BF03007341

Nasir, M. J., Iqbal, J., & Ahmad, W. (2020). Flash flood risk modeling of swat river sub-watershed: a comparative analysis of morphometric ranking approach and El-Shamy approach. *Arabian Journal of Geosciences*, *13*, 1–19. https://doi.org/10.1007/s12517-020-06064-5

Nusi, D., Tahir, A., Ilato, R., Abdussamad, J., & Aneta, Y. (2023). Implementation of flood disaster mitigation policy in Gorontalo regency (case study in Tibawa and Limboto districts). *Russian Law Journal*, *11*(2S), 286–293.https://cyberleninka.ru/article/n/implementation-of-flood-disaster-mitigation-policy-in-gorontalo-regency-case-study-in-tibawa-and-limboto-districts

Obeidat, M., Awawdeh, M., & Al-Hantouli, F. (2021). Morphometric analysis and prioritisation of watersheds for flood risk management in Wadi Easal Basin (WEB), Jordan, using geospatial technologies. *Journal of Flood Risk Management*, *14*(2), e12711. https://doi.org/https://doi.org/10.1111/jfr3.12711

Pallard, B., Castellarin, A., & Montanari, A. (2009). A look at the links between drainage density and flood statistics. *Hydrology and Earth System Sciences*, *13*(7), 1019–1029. https://doi.org/https://doi.org/10.5194/hess-13-1019-2009

Pastor, I., Tanislav, D., Nedelea, A., Dunea, D., Serban, G., Haghighi, A. T., Sabau, D., & Bretcan, P. (2024). Morphometric Analysis and Prioritization of Sub-Watersheds Located in Heterogeneous Geographical Units—Case Study: The Buzău River Basin. *Sustainability*, *16*(17), 7567. https://doi.org/https://doi.org/10.3390/su16177567

Pisupati, S. L., & PJ, R. (2025). Morphometric analysis and prioritization of sub-watersheds in the Gosthani River Basin of southern India using PCA-WSM and geospatial techniques. *Journal of Water and Climate Change*, jwc2025727. https://doi.org/https://doi.org/10.2166/wcc.2025.727

Portuguez-Maurtua, M., Arumi, J. L., Stehr, A., Lagos, O., Chávarri-Velarde, E., & Rivera-Ruiz, D. (2023). Mapping of areas vulnerable to flash floods by means of morphometric analysis with weighting criteria applied. *Water*, *15*(6), 1053. https://doi.org/https://doi.org/10.3390/w15061053

Purwanto, A., & Paiman, P. (2023). Flood Risk Spatial Modeling Based on Geographical Information Systems and Remote Sensing in the Pemangkat Regensi. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 9554–9563. https://doi.org/10.29303/jppipa.v9i11.5264

Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological Society of America Bulletin*, *67*(5), 597–646. https://doi.org/https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2

Sharma, M. L., Gander, G. A., & Hunt, C. G. (1980). Spatial variability of infiltration in a watershed. *Journal of Hydrology*, *45*(1–2), 101–122. https://doi.org/https://doi.org/10.1016/0022-1694(80)90008-6

Singh, V. P. (1992). Elementary hydrology. *(No Title)*. https://books.google.co.id/books/about/Elementary_Hydrology.html?id=w7gPAQAAIAAJ&redir_esc=y

Stallard, R. F. (1988). Weathering and erosion in the humid tropics. In *Physical and chemical weathering in geochemical cycles* (pp. 225–246). Springer.https://doi.org/https://doi.org/10.1007/978-94-009-3071-1_11

Strahler, A. N. (1964). Quantitative geomorphology of drainage basin and channel networks. *Handbook of Applied Hydrology*.https://cir.nii.ac.jp/crid/1572824500442828288

Supiyati, Elisa, I., & Halauddin. (2024). The Affect of Physical Parameters on Flood Potential in the Upstream River and the Musi Watershed of Kepahiang, Indonesia. *Jurnal Penelitian Pendidikan IPA*, *10*(10), 7936–7945. https://doi.org/10.29303/jppipa.v10i10.7442

Sutradhar, S., & Mondal, P. (2023). Prioritization of watersheds based on morphometric assessment in relation to flood management: A case study of Ajay river basin, Eastern India. *Watershed Ecology and the Environment*,*5*, 111.https://doi.org/https://doi.org/10.1016/j.wsee.2022.11.011

Taha, M. M. N., Elbarbary, S. M., Naguib, D. M., & El-Shamy, I. Z. (2017). Flash flood hazard zonation based on basin morphometry using remote sensing and GIS techniques: A case study of Wadi Qena basin, Eastern Desert, Egypt. *Remote Sensing Applications: Society and Environment*, *8*, 157–167. https://doi.org/https://doi.org/10.1016/j.rsase.2017.08.007

Virgota, A., Farista, B., Suripto, Gunawan, L. A., & Ernawati. (2024). Identification and Mapping of Flood Vulnerability in the Meninting Watershed, West Lombok. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 3759–3769. https://doi.org/10.29303/jppipa.v10i7.8201

Waikar, M. L., & Nilawar, A. P. (2014). Morphometric analysis of a drainage basin using geographical information system: a case study. *Int J Multidiscip Curr Res*, *2*(2014), 179–184.

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: a guide to conservation planning* (Issue 537). Department of Agriculture, Science and Education Administration.https://www.researchgate.net/profile/Heriansyah-Putra-2/post/Which-formula-is-correct/attachment/59d64d4e79197b80779a6e2c/AS%3A487650378424321%401493276318482/download/USLE.pdf

Yamazaki, D., Kanae, S., Kim, H., & Oki, T. (2011). A physically based description of floodplain inundation dynamics in a global river routing model. *Water Resources Research*, *47*(4). https://doi.org/https://doi.org/10.1029/2010WR009726