JPPIPA 11(8) (2025)

Jurnal Penelitian Pendidikan IPA

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

Morphometric Characteristics and Their Relation to Flood Events in Paguyaman Watershed, Gorontalo

Karina Meiyanti Maulana[1,4*], Ahmad Syamsu Rijal S[2], Talha Dangkua[2], Risman Jaya[2], Andrew Mulabbi[3]

[1] Student in Geography Study Program, Universitas Muhammadiyah Gorontalo, Gorontalo, Indonesia.
[2] Geography Study Program, Universitas Muhammadiyah Gorontalo, Gorontalo, Indonesia.
[3] School of Education, Uganda Christian University, Besania Hill, Mukono, Uganda.
[4] Geography Study Program, Universitas Negeri Manado, North Sulawesi, Indonesia.

Received: June 28, 2025
Revised: July 27, 2025
Accepted: August 25, 2025
Published: August 31, 2025

Corresponding Author:
Karina Meiyanti Maulana
karinameiyanti@unima.ac.id

DOI: 10.29303/jppipa.v11i8.11909

Abstract: The Paguyaman Watershed represents a strategically significant and essential water resource for the surrounding region. In recent years, this area has become increasingly vulnerable to environmental pressures, including heightened sedimentation, changes in land use, declining water quality, and more frequent flooding events. This study aims to evaluate the morphometric characteristics of the Paguyaman Watershed and their relationship to flood vulnerability observed over the past five years. Morphometric analysis was conducted using quantitative methods within GIS and remote sensing approach. The primary dataset utilized was DEMNAS. The analyzed morphometric parameters include drainage density (3.95), stream frequency (8.61), bifurcation ratio (8.41), form factor (0.13), elongation ratio (0.40), and ruggedness number (8.20). These parameter values indicate that the Paguyaman Watershed possesses an elongated concave shape, steep topography, high surface runoff intensity, and low infiltration capacity. The findings reveal that the watershed exhibits characteristics of high flood susceptibility, as evidenced by recurrent flood events in the villages of Totopo, Tolite, and Juria over the last five years. The spatial pattern of flood vulnerability within the watershed is closely linked to morphological features, such as steep slopes, low soil infiltration capacity, and excessive surface flow accumulation—particularly within the Bilato and Boliyohuto sub-districts.

Keywords: Flood; Morphometric; Paguyaman River; Paguyaman Watershed.

Introduction

Indonesia Government Regulation Number 37 of 2012 concerning Watershed Management explains that a Watershed is a land area that is a single unit with rivers and their tributaries, which functions to accommodate, store and channel water originating from rainfall to lakes or to the sea naturally, where the boundaries on land are topographical separators and boundaries at sea to water areas that are still affected by land activities. Watersheds can be seen as a system, so that watersheds have inputs, processes occur, and produce outputs (Asdak, 2020). The processes occurring within watersheds are influenced by natural inputs like rainfall, as well as by human activities that result in outputs such as water discharge (Mosi, Y., Lihawa, F., Dunggio, I., 2024).

A watershed is a naturally defined hydrological area, bounded by topographic features, that collects and channels precipitation runoff through a network of streams, ultimately converging at a single outlet point (Rahaman et al., 2015). A watershed, as a complex system, requires effective management to ensure its proper functionality. As mandated by Indonesia

How to Cite:
Maulana, K. M., S, A. S. R., Dangkua, T., Jaya, R., & Mulabbi, A. (2025). Morphometric Characteristics and Their Relation to Flood Events in Paguyaman Watershed, Gorontalo. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 476–488. https://doi.org/10.29303/jppipa.v11i8.11909

Government Regulation No. 37 of 2012, watershed management is defined as human efforts to regulate the reciprocal relationship between natural resources and human activities within the watershed. The objective is to achieve ecological sustainability and harmony while enhancing the long-term benefits of natural resources for human welfare. Strategic watershed management is crucial in addressing a range of environmental challenges, including drought, food insecurity, and suboptimal water retention conditions. These issues manifest in excessive surface runoff, diminished agricultural productivity, soil erosion, and inefficient infiltration processes (Raja Shekar & Mathew, 2024). The concept of watershed management emphasizes the interconnected relationships between soil, slope, upland and lowland areas, land use, and geomorphological features. In defining watershed boundaries, the primary focus is on conserving soil and water resources, which are fundamental to effective watershed management (Meshram & Sharma, 2017).

Morphometric analysis of a watershed offers a quantitative assessment of the drainage system, examining its structural attributes while integrating size and shape as essential factors in watershed characterization (Mohammed et al., 2018). Morphometric analysis plays a crucial role in watershed classification, offering quantitative insights into stream network characteristics and supporting hydrological investigations (Raja Shekar & Mathew, 2024). A comprehensive morphometric analysis of a catchment significantly improves the understanding of how drainage patterns shape landforms and their attributes. It offers essential insights into the interactions between the drainage network and the broader landscape, supporting researchers and land managers in making well-informed decisions related to watershed management, land use planning, and environmental conservation (Raja Shekar & Mathew, 2024). Advancements in geospatial analytical techniques, including Geohraphy Information System and Remote Sensing, along with other tools, facilitate the measurement and computation of morphometric parameters. These fundamental aspects are integrated with mathematical equations to determine linear, area, and relief characteristics (Prasannakumar et al., 2013); (Jaya et al., 2024).

As a watershed that supplies water to these three regencies, the Paguyaman Watershed plays a crucial role in regional water provision. The Paguyaman Watershed currently faces several challenges, as identified from various sources. These include sedimentation issues (Adam et al., 2022), land-use conversion, which is presumed to contribute to increased river discharge and heightened flood occurrences (Djiko et al., 2022), water quality degradation based on physical and chemical parameters exceeding threshold limits (Lahili et al., 2023), indications of land degradation, soil erosion, or unsustainable land conversion (Faridawaty et al., 2024) and several events of flood caused by Paguyaman River which is the main river in Paguyaman Watershed. Previous research conducted on the Paguyaman Watershed has described the various challenges faced within the watershed and examined its characteristics, primarily from a biogeophysical perspective (Faridawaty & Rauf, 2025). However, these studies have not yet incorporated an analysis of the watershed's morphometric characteristics. Morphometric analysis of a basin is essential for watershed planning and development, contributing to sustainable land and water resource utilization. It serves as a valuable foundation for planners and policymakers in formulating effective management strategies for the catchment area (Salunke & Wayal, 2023).

Several flood events occurring in the vicinity of the Paguyaman Watershed require special attention, given the high frequency of flooding over the past five years, with primary caused by the overflowing Paguyaman River. These recurring floods are strongly linked to the physical characteristics of the upstream river and the watershed characteristics (Supiyati et al., 2024). The identification of morphometric characteristics can serve as a key parameter in determining appropriate methods or policy directions for disaster mitigation within the Paguyaman Watershed. The physical attributes of a watershed—including its size, shape, gradient, and drainage system—play a crucial role in determining its hydrological response to precipitation. Consequently, analyzing watersheds at a broad scale is essential for assessing flood risks. Flood-prone areas are locations with a significant likelihood of experiencing flooding, determined either by the historical frequency of previous flood events or by physical factors that indicate the area's environmental conditions (Aditama et al., 2025). Morphometric analysis, which quantitatively examines these physical characteristics, has been widely recognized as an effective approach for understanding and forecasting hydrological behavior (Bashir & Alsalman, 2024). Monitoring can involve identifying and mapping regions susceptible to flood disasters, offering a comprehensive view of the area's current conditions based on the contributing factors of flooding (Virgota et al., 2024). Given the complexity of these issues, this study aims to identify the key factors (morphometric characteristics) and its relation to flood events that must be understood before implementing conservation measures or further solutions, ensuring effective watershed management. This study introduces an approach by conducting an in-depth morphometric analysis of the Paguyaman Watershed, a vital hydrological unit in Gorontalo Province, Indonesia, which has not previously been examined through this method. Although prior studies have assessed its biogeophysical attributes (Faridawaty & Rauf, 2025), this research uniquely quantifies the watershed's structural characteristics and investigates their connection to recurring flood occurrences.

Method

Study Area

The Paguyaman Watershed is one of the largest watersheds in Gorontalo Province, encompassing three regencies: Gorontalo Regency, Boalemo Regency, and a small portion of Pohuwato Regency. Administratively, the Paguyaman Watershed (DAS Paguyaman) is located within Gorontalo Regency (42.33%), Boalemo Regency (48.57%), Pohuwato Regency (8.95%), and a small portion of North Gorontalo Regency (0.13%), covering a total area of approximately 241,787.37 ha. Astronomically, located at 122,02^0 - 122,73^0 East and 0,88^0 - 0,66^0 North. Spatially, Paguyaman Watershed is presented in Figure 1.

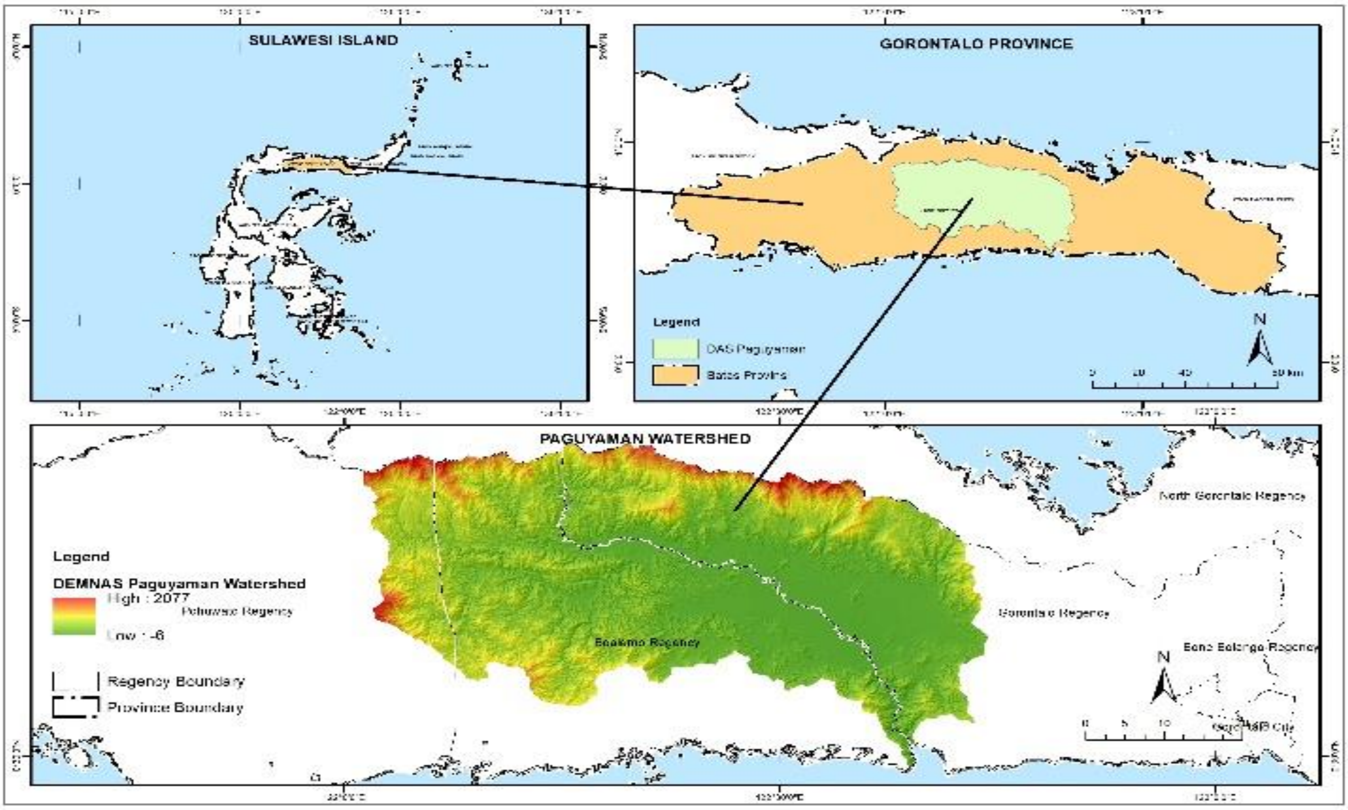

Figure 1. Paguyaman Watershed in Gorontalo

The topographic conditions of the Paguyaman Watershed (DAS Paguyaman) are predominantly characterized by highlands and mountainous terrain, extending across the northern, western, and part of the southern regions of the watershed. The dominant slope gradient ranges from 15% to 40%, covering approximately 31.77% of the area, the dominant soil type is Latosol covering approximately 51,35% of Paguyaman Watershed (Faridawaty & Rauf, 2025). Land use within the Paguyaman Watershed is also primarily dominated by forested areas.

Data Management and Analysis

The primary data utilized in the analysis of watershed morphometric characteristics is DEMNAS, or the National Digital Elevation Model, provided by the Geospatial Information Agency, which is accessible through its official website. DEMNAS has a spatial resolution of 8 meters, which is considered superior compared to other elevation data sources such as ALOS PALSAR and SRTM (Jaya et al., 2024). Remote sensing and Geographic Information Systems (GIS) offer advanced tools for transforming diverse spatial data into a cohesive and well-organized database. These technologies enable the efficient management of large volumes of spatially diverse information, both at detailed (micro) levels and across entire watersheds. A key strength of GIS lies in its ability to overlay multiple thematic layers, making it highly valuable for hydrological modeling and comprehensive land-use planning (Rai et al., 2024). In the early stages of morphometric analysis, researchers depended on manual techniques to determine key morphometric parameters. These included measurements of stream lengths, the number of streams, catchment areas, perimeters, and other related factors. Significant advancements in this field were made by Horton (1945), Smith (1950), and Strahler (1957), whose pioneering work established the foundation for the quantitative evaluation of drainage systems (Raja Shekar & Mathew, 2024). The parameters for the morphometric calculation of the Paguyaman watershed can be observed as Table 1.

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 morphometric analysis of the Paguyaman watershed was conducted using spatial analysis based on DEMNAS data, focusing primarily on fundamental morphometric aspects, including Basin Area (A), Perimeter (P), Stream Order (U), Number of Stream Segments (Nu), Stream Length (Lu), and Basin Length (Lb). Furthermore, other morphometric aspects such as Linear, Area, and Topographic characteristics were analyzed using mathematical formulations, as presented in Table 1, which was compiled from various sources.

The relationship between morphometric characteristics and flood occurrences in the Paguyaman watershed can be assessed after interpreting the morphometric parameters. The interpretation results provide insights into whether the watershed exhibits flood-prone characteristics. If the watershed is determined to be flood-prone, this finding aligns with the high frequency of flood events, necessitating the selection of appropriate conservation methods. Conversely, if the watershed does not exhibit flood-prone characteristics, further analysis is required to understand the underlying causes of the frequent flooding events in the Paguyaman watershed. The stages and analytical methods used in this study are presented in Figure 2.

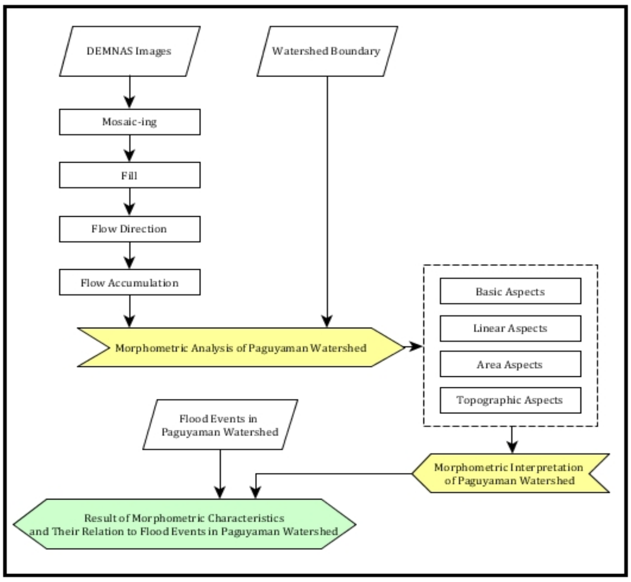

Figure 2. Flow chart of stages and methods used

Result and Discussion

Morphometric Analysis

Morphometric analysis was conducted by measuring four key aspects: fundamental aspects, linear aspects, area aspects, and topographic aspects. The results of the calculations and analyses are presented in Table 2 and Table 3.

Table 2. Results (1)

Morphometric Aspects	Parameter	Results
Basic	Basin Area (A)	2401,28 km²
	Perimeter (P)	279,27 km
	Stream Order (U)	5
	Number of stream segments (Nu)	20678
	Stream Length (Lu)	9479,56 km
	Basin Length (Lb)	138,30 km
Linear	Mean Stream Length (Lms)	0,46
	Stream Length Ratio (Rl)	Table 4
	Bifurcation Ratio (Rb)	Table 4
	Drainage Density (Dd)	3,95
	Stream Frequency (Fs)	8,61
Area	Texture Ratio (T)	74,04
	Form Factor (Rf)	0,13
	Circularity Ratio (Rc)	0,39
	Elongation Ratio (Re)	0,40
	Length of Overland Flow (Lg)	0,25
	Constant Channel Maintenance (Mc)	0,25
Topography	Basin Relief (R)	2,076 km
	Relief Ratio (Rr)	0,02
	Ruggedness Number (Rn)	8,20

Table 3, some of the results needs to explain based on stream order, such as Number of Segments (Nu), Stream Length (Lu), Mean Stream Length (Lms), Stream Length Ratio (Rl), and Bifurcation Ratio (Rb).

Table 3. Results (2)

Stream Order (U)	Number of Segments (Nu)	Stream Length (Lu)	Mean Stream Length (Lms)	Basin Area (A)
1	16094	4694,22	0,29	
2	4349	3519,82	0,81	
3	215	936,79	4,36	2401,28
4	14	190,43	13,60	
5	6	138,30	23,05	
Total	20678	9479,56		
Stream Order (U)	Stream Length Ratio (Rl)	Bifurcati-on Ratio (Rb)	Drainage Density (Dd)	Stream Frequenc y (Fs)
1	-	3,70		
2	2,77	20,23		
3	5,38	15,36	3,95	8,61
4	3,12	2,33		
5	1,69	0,43		
Mean		8,41		

Basin Area (A) and Perimeter (P)

Basin Area (A) represents the total land surface contained within the defined watershed boundary, playing a crucial role in determining the volume of runoff generated within the watershed (Bharath et al., 2021). The watershed or basin area was determined based on the watershed boundaries obtained from the Ministry of Environment and Forestry of Indonesia in the form of spatial data. The Paguyaman watershed was identified as having an area of 2,401.28 km². The perimeter (P) of a basin represents the total length of its outer boundary, reflecting both the shape and overall dimensions of the drainage basin (Bharath et al., 2021). The Perimeter of Paguyaman watershed is 279.27 km.

Stream Order (U)

Stream ordering follows the classification system introduced by Strahler, in which the smallest tributaries are assigned as first-order streams. When two first-order streams converge, they form a second-order stream. Similarly, the merging of two second-order streams results in a third-order stream, continuing this pattern progressively. The primary channel responsible for transporting the total water discharge within the basin is classified as the highest-order stream (Munoth & Goyal, 2020). In this study, total Stream Order can be identified with 5 order (Table 3). Spatially, Stream Order can be seen in Figure 3.

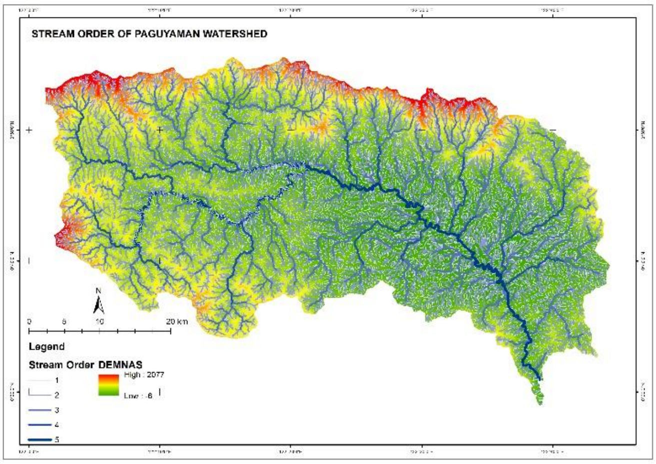

Figure 3. Stream Order Map of Paguyaman Watershed

Number of Stream Segments (Nu)

Strahler describes stream number as the total count of streams within various orders in a specific drainage basin. Watersheds with a high stream number tend to experience greater runoff and quicker peak flow compared to those with fewer streams (Bhat et al., 2019; Obeidat et al., 2021). Total number of stream segments can be seen in Table 4. Paguyaman Watershed contains of 5 stream orders, with total number of all segments 20.678. 77,83% of all these number of segments are the number of segments for 1st order of stream in Paguyaman Watershed. A high number of streams and stream frequency typically signify steep terrain and an impermeable surface (Mahmood & Rahman, 2019). An increased stream count often accelerates water discharge from the basin, leading to a faster runoff process (Bashir & Alsalman, 2024). The high number of streams in Paguyaman Watershed indicates that That Paguyaman Watershed is have steep terrain, impermeable survace, and fast runoff process, that can be leading to the high potential of prone to flood.

Stream Length (Lu)

Stream length refers to the measured length of streams across various orders, determined using Horton's methodology. According to Strahler, longer streams suggest reduced infiltration and an increased capacity for runoff generation within a watershed (Obeidat et al., 2021). A high concentration of streams within a basin suggests that the topography is actively experiencing erosion. Conversely, a lower stream count signifies a more developed and stable landscape (Munoth & Goyal, 2020). Paguyaman Watershed has high number of stream length especially in the lower number of stream order, that can be indicates that Paguyaman Watershed are experiencing erosion, shaping the landscape through continuous surface wear and sediment displacement. However, this finding does not align with the research conducted by Faridawaty et al. in 2024. The majority of the Paguyaman Watershed (75.13%) exhibits low to moderate erosion levels. This indicates that the soil condition in most areas remains relatively stable, considering that a significant portion of the upstream region of the Paguyaman Watershed is still forested, with minimal intervention from socio-economic activities.

Basin Length (Lb)

Basin length is determined by measuring along the primary channel, extending from the main boundary of the watershed to the point of watershed division (Jaya et al., 2024; Patel et al., 2012). Basin Length in Paguyaman Watershed is 138,30 km same as the primary channel (stream order number 5) that can be seen in Table 4. Basin length serves as a key measure of surface runoff characteristics, with extended stream lengths typically signifying gentler slope gradients (Christopher et al., 2010; Obeidat et al., 2021; Taha et al., 2017). According to the study conducted by Faridawaty et al. (2023), the main river in the Paguyaman Watershed is situated on a slope gradient of 0–8%. This finding is consistent with the previous statement that longer stream flows generally indicate gentler slope gradients. Such characteristics can serve as an indicator of the hydrological properties of the region, particularly in relation to surface flow patterns and water infiltration rates.

Mean Stream Length (Lms)

According to Strahler, the stream length is a characteristic property related to drainage network components of drainage basins. Generally, it shows higher the stream order, longer the length of stream and lower the stream order shorter the length of stream (Choudhari et al., 2018). The average stream length in the Paguyaman Watershed, when calculated as the total stream length divided by the total number of stream segments, is 0.46 km (as presented in Table 3). However, when assessed based on individual stream orders, the values differ (Table 4). For instance, in order 1, the mean stream length value is 0.29 km, which corresponds to the highest number of segments and a relatively longer stream length. Conversely, in higher stream orders, such as order 5, the mean stream length value is the largest at 23.04 km, due to a lower number of segments and shorter individual stream lengths.

Stream Length Ratio

Horton explain the stream length ratio (Lur) values serve as a key metric for assessing the relative permeability of rock formations within a basin (Munoth & Goyal, 2020). The stream length ratio of Paguyaman Watershed can be seen in Table 4. The stream length ratio of Paguyaman Watershed is variate based on the stream order. The calculation of stream length ratio is dividing mean stream order with mean stream (order – 1). Stream length ratio for order 3 is the highest from all the other order, and the lowest stream length ratio is order 5. Variations in stream length ratio values between successive stream orders arise due to differences in slope gradients and topographic characteristics (Magesh et al., 2012; Munoth & Goyal, 2020).

Bifurcation Ratio

Horton considered the bifurcation ratio as an indicator of relief and landscape dissection. Strahler found that, apart from regions with significant geological influence, bifurcation ratio values exhibit relatively slight variations across different environmental conditions. A catchment with a lower bifurcation ratio generally indicates minimal structural disruptions, preserving its original drainage pattern. Additionally, the bifurcation ratio helps characterize basin morphology—circular basins tend to exhibit lower bifurcation ratio values, whereas elongated basins typically show higher bifurcation ratio values. Strahler classifies bifurcation ratio into three categories. When the bifurcation ratio is less than 3, it represents an idealized theoretical basin with a hierarchical drainage network that experiences minimal distortion. A bifurcation ratio between 3 and 5 suggests that the drainage pattern remains largely unaffected by geological influences, though a moderate increase in branching complexity is observed. Conversely, a bifurcation ratio greater than 5 indicates an elongated basin in which geological structures play a significant role in shaping the basin, leading to a high degree of branching complexity (Raja Shekar & Mathew, 2024). Bifurcation ratio in Paguyaman Watershed based on the result of calculation shows in Table 4. The average value of bifurcation ratio in Paguyaman Watershed is 8,41 which greater than 5. This indicate shape of Paguyaman Watershed is elongated basin.

Drainage Density

Drainage density is an essential hydrological parameter that quantifies the proportion of a basin's total stream and river length relative to its surface area, originally introduced by Horton. This metric is heavily influenced by various factors, including soil permeability, the composition of underlying rock formations, geological structure, vegetation coverage, and the topographical relief of the watershed. A higher drainage density typically indicates lower water infiltration capacity, resulting in an increased likelihood of surface runoff (Bashir & Alsalman, 2024; Dube et al., 2022). Drainage density can be interpreted based on watershed texture classification, which consists of five categories: values greater than 4.97 indicate very fine texture, values between 3.73 and 4.97 represent fine texture, values ranging from 2.49 to 3.73 correspond to moderate texture, values between 1.24 and 2.49 indicate coarse texture, and values below 1.24 fall into the very coarse category (Raja Shekar & Mathew, 2024). The general drainage density of the Paguyaman Watershed shows in Table 3, is 3.95, placing it within the second category (3.73–4.97), classified as fine texture. this value indicating the stream network remains relatively compact, the density is slightly lower than the previous category. Watersheds with fine texture typically appear in areas with moderately steep slopes and a well-developed drainage network as in Paguyaman Watershed. Spatially, the drainage density of the Paguyaman Watershed can be observed in Figure 4.

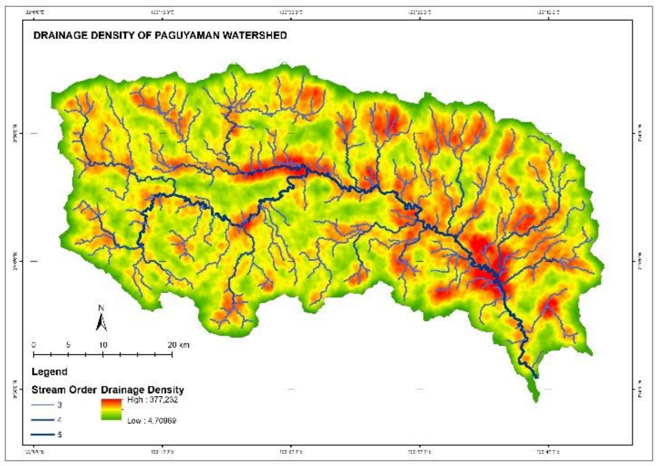

Figure 4. Drainage Density Map of Paguyaman Watershed

Stream Frequency

Horton defines stream frequency as represents of total count of stream segments across all orders within a given unit area. It maintains a positive correlation with drainage density, meaning that as drainage density increases, the number of stream segments within the watershed also rises (Waikar & Nilawar, 2014). Stream frequency is classified into five categories based on its distribution per square kilometer: 0–5 streams per km² fall into the low stream frequency category, 5–10 streams per km² are categorized as moderate stream frequency, 10–15 streams per km² are considered moderately high, 15–20 streams per km² belong to the high category, and 20–25 streams per km² are classified as very high (Raja Shekar & Mathew, 2024). The calculated stream frequency for the Paguyaman Watershed is 8.61, placing it in the moderate category. Assessing stream frequency distribution per unit area is crucial for multiple applications, including land management, ecological evaluations, and water resource planning. This metric aids in understanding hydrological dynamics within a basin, particularly the density of drainage networks and their impact on surface water flow (Raja Shekar & Mathew, 2024).

Texture Ratio

Drainage texture, also known as the texture ratio, refers to the relative distribution and spacing of drainage lines within a given area. Regions with lower permeability tend to exhibit a greater density of drainage lines compared to areas with higher permeability, where water infiltration reduces the extent of surface drainage networks (Munoth & Goyal, 2020). Smith categorized drainage density into five distinct texture classifications. A drainage density below 2 is defined as very coarse, while values ranging from 2 to 4 correspond to a coarse texture. Densities between 4 and 6 are classified as moderate, those between 6 and 8 fall under the fine texture category, and values exceeding 8 indicate a very fine drainage texture (Munoth & Goyal, 2020). The drainage texture of the Paguyaman Watershed exhibits a significantly high value of 74.04, indicating that it falls within the very fine drainage texture classification. Drainage texture serves as an important indicator for assessing permeability and groundwater recharge potential. A higher drainage texture typically signifies increased permeability, allowing for more efficient groundwater replenishment (Choudhari et al., 2018).

Form Factor (Rf)

Horton described the form factor (Rf) as a dimensionless ratio of basin area (A) to the square of basin length (Lb), widely used to characterize basin shapes. Form factor values below 0.78 indicate an elongated basin, whereas values above 0.78 suggest a circular basin (Albaroot et al., 2018). The Paguyaman Watershed has a form factor value of 0.13, signifying an elongated shape. This characteristic suggests that the watershed will experience a more gradual peak flow over an extended period. As a result, flood management in such elongated basins tends to be more manageable compared to circular basins, where peak flows occur more abruptly (Albaroot et al., 2018).

Elongation Ratio (Re) and Circularity Ratio (Rc)

The elongation ratio (Re) and circularity ratio (Rc) are essential parameters for analyzing basin morphology, as they help assess erosion intensity and the likelihood of flooding within a watershed. Their values range from 0 to 1, with lower values indicating an elongated basin and higher values signifying a more circular shape (Munoth & Goyal, 2020). As presented in Table 3, the elongation ratio of the Paguyaman Watershed is 0.40, while the circularity ratio is 0.39. Since both values are closer to 0 rather than 1, it can be inferred that the Paguyaman Watershed exhibits a more elongated shape rather than a circular form. The circularity ratio and elongation ratio serve as an indicator of drainage efficiency and potential flash flood risk. In a circular basin, runoff generally follows similar travel distances, leading to simultaneous arrival at the basin outlet and resulting in a pronounced peak discharge. Conversely, in elongated basins where the outlet is positioned at one end of the primary stream, runoff tends to disperse over a longer duration, producing a lower and more gradual peak discharge (Nasir et al., 2020).

Length of Overland Flow (Lg)

Overland flow and surface runoff represent two distinct types of water movement. Overland flow describes precipitation that moves across the land surface before entering stream channels, whereas surface runoff refers to the water flowing within these channels as it drains out of the watershed (Raja Shekar & Mathew, 2024). The length of overland flow of Paguyaman Watershed value is 0,13. The length of overland flow exhibits an inverse relationship with flood susceptibility. In the Paguyaman Watershed, the length of overland flow is measured at 0.13, classifying it within the high susceptibility to flood category (Obeidat et al., 2021).

Constant Channel Maintenance (Mc)

Schumn describes the constant of channel maintenance as the reciprocal of drainage density. In general, lower Mc values in a watershed suggest that the underlying rocks have lower permeability, while higher values indicate greater permeability (Choudhari et al., 2018). The constant channel maintenance value in the Paguyaman watershed is 0.25. This value falls into the category of low constant channel maintenance (Munoth & Goyal, 2020), indicating a lower likelihood of percolation or infiltration, which consequently results in increased surface runoff.

Basin Relief (R)

Schumm defines the relief ratio as the proportion of maximum basin relief to the horizontal distance along its longest dimension, which runs parallel to the main drainage line. This ratio serves as an indicator of the overall steepness of the basin (Albaroot et al., 2018). The highest point in the Paguyaman watershed is recorded at 2076 meters above sea level (or 2,076 km). In contrast, the lowest point corresponds to the river mouth, which flows into the sea, resulting in an elevation of 0 meters above sea level. Consequently, the basin relief is calculated as 2,076 km. This significant elevation difference is attributed to the geographical position of the Paguyaman watershed, which drains into the sea (Tomini Bay) in its southern region. The elevation of the relief basin influences the drainage pattern, which in turn determines the extent of surface runoff (Jaya et al., 2024).

Ratio Relief (Rr)

Schumm describes the relief ratio as the ratio of the basin's maximum elevation difference to the horizontal distance along its longest dimension, which runs parallel to the main drainage line. This metric serves as an indicator of the basin's overall steepness (Albaroot et al., 2018). This fundamental metric offers crucial insights into the basin's overall steepness and topographic diversity. By measuring the relationship between relief and length, it helps reveal the intensity of erosion processes shaping the basin's gradient. Consequently, the relief ratio is an important analytical tool for studying and interpreting the geomorphological features and drainage basin dynamics (Raja Shekar & Mathew, 2024). The relief ratio of the Paguyaman watershed is 0.02. A higher relief ratio generally corresponds to steep slopes and significant elevation differences, while a lower relief ratio indicates more gradual slopes and lower overall relief (Albaroot et al., 2018). This suggests that the Paguyaman watershed is characterized by gentle slopes and low relief. This observation aligns with the findings of Faridawaty et al. (2024), which indicate that slopes ranging from 0% to 15% account for a substantial portion 30% of the total area of the Paguyaman watershed.

Ruggedness Number (Rn)

Strahler defines the ruggedness number (Rn) as a metric that integrates slope steepness with basin length (Munoth & Goyal, 2020). A high ruggedness number signifies steep terrain, which increases the likelihood of flash floods and erosion (Obeidat et al., 2021; Patton & Baker, 1976). Additionally, Strahler notes that the ruggedness number tends to rise when drainage density and relief are exceptionally high, leading to not only steeper slopes but also extended slope lengths. The ruggedness number of the Paguyaman watershed is 8.20, which falls within the high category. This indicates that the watershed features relatively steep terrain, contributing to an increased risk of flooding and erosion.

Relation to Flood Events

Flood events in the Paguyaman watershed, particularly in its main river, the Paguyaman River, have been consistently observed in the same areas over the past five years, based on data collected from various online news sources and local community reports. These recurring floods are attributed to the same underlying factors: high rainfall as the primary input and the overflowing of the Paguyaman River as the output. The morphometric analysis conducted in this study aims to characterize the Paguyaman watershed, providing insights that should be understood to effectively manage or mitigate these persistent flood occurrences through appropriate conservation measures. A summary of flood events in the Paguyaman watershed over the past five years is presented in Table 4.

Table 4. Flood Events in Paguyaman River over the past five years

Month/Year	Village	Sub-District	District
Apr-25	Bongo Dua	Wonosari	Boalemo
Apr-25	Permata	Paguyaman	Boalemo
Apr-25	Totopo	Bilato	Gorontalo
Feb-25	Rejonegoro	Paguyaman	Boalemo
Feb-25	Kualalumpur	Paguyaman	Boalemo
Jun-24	Tolite	Boliyohuto	Gorontalo
Jun-24	Totopo	Bilato	Gorontalo
Jun-24	Juria	Bilato	Gorontalo
Jul-23	Totopo	Bilato	Gorontalo
Jul-23	Juria	Bilato	Gorontalo
Dec-22	Juria	Bilato	Gorontalo
Dec-22	Totopo	Bilato	Gorontalo
Nov-22	Saritani	Wonosari	Boalemo
Nov-22	Pangeya	Wonosari	Boalemo
Jul-22	Tolite	Boliyohuto	Gorontalo
Sep-21	Tolite	Boliyohuto	Gorontalo
Aug-20	Motoduto	Boliyohuto	Gorontalo
Aug-20	Tolite	Boliyohuto	Gorontalo
Mar-20	Diloniyohu	Boliyohuto	Gorontalo
Mar-20	Tolite	Boliyohuto	Gorontalo
Mar-20	Bongo Ayu	Boliyohuto	Gorontalo

Table 5 presents a chronological record of flood occurrences within various villages in the Paguyaman watershed and surrounding regions, categorized by month and year of the event. Table 5 providing a comprehensive spatial distribution of flood-affected areas. The dataset illustrates recurring flood incidents in specific locations, particularly within the sub-districts of Bilato, Boliyohuto, Paguyaman, and Wonosari. The temporal pattern indicates flood events spanning multiple years, highlighting persistent hydrological challenges within these regions. This information serves as a critical reference for assessing flood frequency, spatial distribution, and potential contributing factors, thereby aiding hydrological and geomorphological analyses aimed at flood mitigation and watershed management strategies. The points and locations of flood events in each village within the Paguyaman watershed over the past five years are presented in Figure 5.

Morphometric parameters like circularity ratio, form factor, elongation ratio, drainage texture, and compactness coefficient exhibit an inverse relationship with flood susceptibility (Jothimani et al., 2021). The morphometric characteristics of the Paguyaman Watershed strongly influence the occurrence of flooding in various villages within the region, as documented in the table. The high drainage density (3.95) and stream frequency (8.61) indicate an extensive network of water channels that, in combination with impermeable surfaces and steep terrain, contribute to rapid runoff processes. Sub-watersheds characterized by high drainage density, stream frequency, and relief ratio, combined with a low elongation ratio, exhibited a greater susceptibility to flooding, primarily as a result of reduced infiltration capacity and increased surface runoff (Narendra et al., 2024). This condition exacerbates flood susceptibility, particularly in areas with fine-textured drainage patterns.

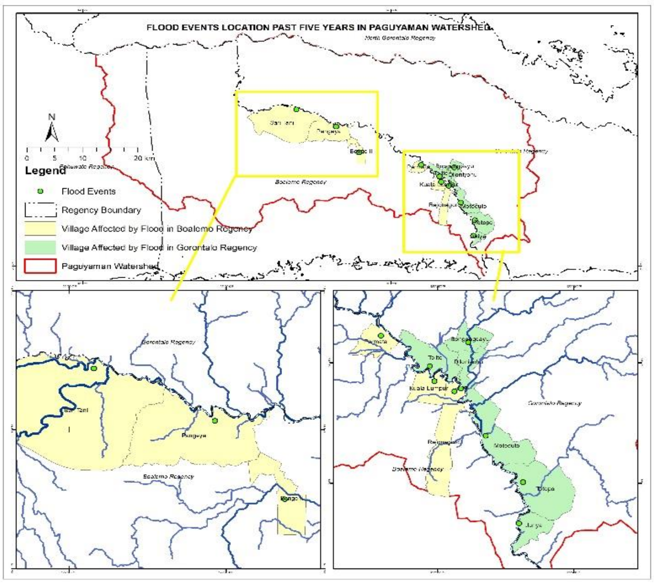

Figure 5. Flood Events location over the past five years

The elongated morphology of the watershed—evident from morphometric parameters such as a high bifurcation ratio (8.41), low form factor (0.13), elongation ratio (0.40), and circularity ratio (0.39)—contributes to delayed peak discharges, which typically reduce the likelihood of sudden flood surges. However, this flood-mitigating effect is counterbalanced by the watershed's high ruggedness number (8.20), which indicates pronounced topographic variation. This rugged terrain accelerates runoff and enhances erosion potential, ultimately heightening flood vulnerability. Additionally, the short length of overland flow (0.13) points to a reduced capacity for water infiltration, aligning the basin with a high flood susceptibility classification.

These findings are consistent with observations in mountainous catchments, where high drainage density (Dd), relief ratio (Rr), and drainage texture (Rt) are positively associated with flash flood occurrences (Víg et al., 2022). Conversely, lower elongation ratio (Re) and form factor—characteristics also present in the studied watershed—are inversely related to flood severity (Narendra et al., 2024). The alignment of these morphometric indicators highlights the critical role of watershed shape, slope, and drainage configuration in influencing flood dynamics, underscoring the need for targeted watershed management strategies in topographically complex regions.

Table 5 presents recurring flood events in several villages, such as Totopo, Tolite, and Juria, indicating that these locations are consistently affected by hydrological disturbances over multiple years. These patterns align with the watershed's geomorphological characteristics, as villages situated within sub-districts like Bilato and Boliyohuto experience repeated flooding due to steep slopes, high runoff intensity, and reduced infiltration potential. For additional information, these villages is located near from the end of Paguyaman River, which is the estuarine area or the downstream area. The regions most impacted by flooding typically feature flat or gently sloping terrain, indicating a flood-prone landscape that includes floodplains, coastal terraces, swamps, and backswamps (Purwanto & Paiman, 2023). The Paguyaman River's tendency to overflow is a direct consequence of these interconnected factors, with flood events frequently recorded in sub-districts such as Paguyaman and Wonosari.

By analyzing both the morphometric parameters and historical flood data, it is evident that villages within areas characterized by steep gradients, high drainage density, and impermeable surfaces exhibit increased flood vulnerability. Slope and elevation emerged as key contributors to flood generation, as regions with steep terrain typically experience reduced infiltration capacity and increased surface runoff (Desalegn & Mulu, 2021). The findings of this research provide a critical foundation for developing flood mitigation strategies and land-use planning policies in the Paguyaman Watershed. The identified morphometric indicators—such as high drainage density, stream frequency, ruggedness number, and elongated basin shape—highlight specific areas with heightened flood vulnerability. These insights can support government agencies and local stakeholders in prioritizing flood-prone sub-districts like Bilato, Boliyohuto, Paguyaman, and Wonosari for immediate intervention. Understanding these relationships is essential for implementing strategic flood mitigation measures, optimizing watershed management approaches, and developing conservation practices tailored to the region's hydrological dynamics.

Conclusion

The morphometric analysis of the Paguyaman Watershed reveals a strong relationship between watershed characteristics and flood susceptibility. High drainage density (3.95) and stream frequency (8.61) indicate a well-developed drainage system that facilitates rapid surface runoff, particularly in areas with steep slopes and low permeability. The elongated basin shape, evidenced by a high bifurcation ratio (8.41), low form factor (0.13), elongation ratio (0.40), and circularity ratio (0.39), suggests delayed peak discharge but sustained flood flows, which may increase inundation duration. The ruggedness number (8.20) and high length of overland flow (0.13) further reflect a landscape prone to high erosion rates and reduced infiltration, amplifying flood risk. These geomorphological conditions are consistent with the observed recurrence of flood events in villages such as Totopo, Tolite, and Juria, as well as the sub-districts of Bilato, Boliyohuto, Paguyaman, and Wonosari. The findings align with previous studies that demonstrate the predictive value of morphometric parameters in identifying flood-prone sub-watersheds. From a practical standpoint, this study offers a valuable framework for flood risk assessment and watershed planning. The insights can inform spatial zoning regulations, prioritize reforestation or land cover restoration efforts in critical zones, and guide infrastructure development such as retention basins and flood control barriers. Incorporating morphometric indicators into flood early warning systems and integrated watershed management strategies can enhance climate resilience and reduce disaster vulnerability in the Paguyaman Watershed and similar tropical river basins.

Acknowledgments
The authors would like to express their deepest gratitude to Universitas Muhammadiyah Gorontalo for the continuous support, facilities, and academic guidance provided throughout the completion of this research.

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

Funding
This research received no external funding

Conflicts of Interest
The authors declare no conflict of interest.

References

Adam, E. Z., Rijal, A. S., Tisen, T., Matalapu, I., & Hendra, H. (2022). Estimasi Besaran Sedimentasi Di Sub Das Paguyaman Yang Berada Di Kabupaten Gorontalo. *Social Landscape Journal*, *3*(2), 9–18.

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., Al-Areeq, N. M., Aldharab, H. S., Alshayef, M., & Ghareb, S. A. (2018). Quantification of Morphometric Analysis using Remote Sensing and GIS Techniques in the Qa' Jahran Basin, Thamar Province, Yemen. *International Journal of New Technology and Research*, *4*(8), 11. https://www.scirp.org/reference/referencespapers?referenceid=3305986

Asdak, C. (2020). *Hidrologi dan Pengelolaan Daerah Aliran Sungai* (VII). UGM Press.

Bashir, B., & Alsalman, A. (2024). Morphometric Characterization and Dual Analysis for Flash Flood Hazard Assessment of Wadi Al-Lith Watershed, Saudi Arabia. *Water (Switzerland)*, *16*(22). https://doi.org/10.3390/w16223333

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*(August), 100277. https://doi.org/10.1016/j.envc.2021.100277

Bhat, M. S., Alam, A., Ahmad, S., Farooq, H., & Ahmad, B. (2019). Flood hazard assessment of upper Jhelum basin using morphometric parameters. *Environmental Earth Sciences*, *78*(2), 0. https://doi.org/10.1007/s12665-019-8046-1

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/10.1080/24749508.2018.1452482

Christopher, O., Idowu, A. O., & Olugbenga, A. S. (2010). Hydrological Analysis of Onitsha North East Drainage Basin Using Geoinformatic Techniques. *World Applied Sciences Journal*, *11*(10), 1297–1302.

Desalegn, H., & Mulu, A. (2021). Flood vulnerability assessment using GIS at Fetam watershed, upper Abbay basin, Ethiopia. *Heliyon*, *7*(1), e05865. https://doi.org/10.1016/j.heliyon.2020.e05865

Djiko, A., Musa, R., & Ashad, H. (2022). Kajian Perubahan Tata Guna Lahan Terhadap Debit Banjir Sungai Paguyaman Kabupaten Gorontalo. *Jurnal Konstruksi : Teknik, Infrastruktur Dan Sains*, *1*(8), 20–30.

Dube, K., Nhamo, G., & Chikodzi, D. (2022). Flooding trends and their impacts on coastal communities of Western Cape Province, South Africa. *GeoJournal*, *87*(2013), 453–468.

https://doi.org/10.1007/s10708-021-10460-z

Faridawaty, W., Lihawa, F., Wahyuni Baderan, D. K., & Mahmud, M. (2024). Analisis Model Spasial Kondisi Lahan Daerah Aliran Sungai (DAS). *Journal of International Multidisciplinary Research*, *2*(5), 573–585. https://doi.org/10.62504/jimr525

Faridawaty, W., & Rauf, A. (2025). Karakteristik Daerah Aliran Sungai (DAS): Analisis Spasial Biogeofisik DAS Paguyaman. *Journal of International Multidisciplinary Research*, *2019*. https://doi.org/10.62504/jimr1207

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 and Mining Lands Management*, *11*(2), 5263–5277. https://doi.org/10.15243/jdmlm.2024.112.5263

Jothimani, M., Dawit, Z., & Mulualem, W. (2021). Flood Susceptibility Modeling of Megech River Catchment, Lake Tana Basin, North Western Ethiopia, Using Morphometric Analysis. *Earth Systems and Environment*, *5*(2), 353–364. https://doi.org/10.1007/s41748-020-00173-7

Lahili, R., Lihawa, F., & Dunggio, I. (2023). Kinerja Pengelolaan Das Paguyaman Berdasarkan Kondisi Fisika Dan Kimia Air. *Gorontalo Journal of Forestry Research*, *6*(2), 99. https://doi.org/10.32662/gjfr.v6i2.2505

Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N., & Jini, K. V. (2012). GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala, India. *Earth Science Informatics*, *5*(2), 111–121. https://doi.org/10.1007/s12145-012-0101-3

Mahmood, S., & Rahman, A. ur. (2019). Flash flood susceptibility modeling using geo-morphometric and hydrological approaches in Panjkora Basin, Eastern Hindu Kush, Pakistan. *Environmental Earth Sciences*, *78*(1), 1–16. https://doi.org/10.1007/s12665-018-8041-y

Meshram, S. G., & Sharma, S. K. (2017). Prioritization of watershed through morphometric parameters: a PCA-based approach. *Applied Water Science*, *7*(3), 1505–1519. https://doi.org/10.1007/s13201-015-0332-9

Mohammed, A., Adugna, T., & Takala, W. (2018). Morphometric analysis and prioritization ofwatersheds for soil erosion management in Upper Gibe catchment. *J. Degrade. Min. Land Manage*, *6*(1), 1419–1426. https://doi.org/10.15243/jdmlm

Mosi, Y., Lihawa, F., Dunggio, I., N. (2024). Analysis of Non-Point Source (NPS) Pollutant Load and Water Capacity of Bolango River, Gorontalo Province. *Jurnal Penelitian Pendidikan IPA*, *10*(11), 9904–9917. https://doi.org/10.29303/jppipa.v10i11.9582

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

Narendra, B. H., Setiawan, O., Hasan, R. A., Siregar, C. A., Pratiwi, Sari, N., Sukmana, A., Dharmawan, I. W. S., & Nandini, R. (2024). Flood susceptibility mapping based on watershed geomorphometric characteristics and land use/land cover on a small island. *Global Journal of Environmental Science and Management*, *10*(1), 301–320. https://doi.org/10.22034/gjesm.2024.01.19

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*(20). https://doi.org/10.1007/s12517-020-06064-5

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), 1–19. https://doi.org/10.1111/jfr3.12711

Patel, D. P., Dholakia, M. B., Naresh, N., & Srivastava, P. K. (2012). Water Harvesting Structure Positioning by Using Geo-Visualization Concept and Prioritization of Mini-Watersheds Through Morphometric Analysis in the Lower Tapi Basin. *Journal of the Indian Society of Remote Sensing*, *40*(2), 299–312. https://doi.org/10.1007/s12524-011-0147-6

Patton, P. C., & Baker, V. R. (1976). Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls. *Water Resources Research*, *12*(5), 941–952. https://doi.org/10.1029/WR012i005p00941

Prasannakumar, V., Vijith, H., & Geetha, N. (2013). Terrain evaluation through the assessment of geomorphometric parameters using DEM and GIS: Case study of two major sub-watersheds in Attapady, South India. *Arabian Journal of Geosciences*, *6*(4), 1141–1151. https://doi.org/10.1007/s12517-011-0408-2

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

Rahaman, S. A., Ajeez, S. A., Aruchamy, S., & Jegankumar, R. (2015). Prioritization of Sub Watershed Based on Morphometric Characteristics

Using Fuzzy Analytical Hierarchy Process and Geographical Information System – A Study of Kallar Watershed, Tamil Nadu. *Aquatic Procedia*, *4*(Icwrcoe), 1322–1330. https://doi.org/10.1016/j.aqpro.2015.02.172

Rai, R., Pardeshi, S. S., & Prbam, R. (2024). *Watershed Prioritization using Morphometricand Land Use Land Cover Parameters of Kamalang River Watershed using Remote Sensing and GIS Technology*. https://doi.org/10.21203/rs.3.rs-4002429/v1%0ALicense:

Raja Shekar, P., & Mathew, A. (2024). Morphometric analysis of watersheds: A comprehensive review of data sources, quality, and geospatial techniques. *Watershed Ecology and the Environment*, *6*(January), 13–25. https://doi.org/10.1016/j.wsee.2023.12.001

Salunke, K. A., & Wayal, A. S. (2023). Morphometric Analysis of Panjhara River Basin With Use of GIS for Development of Watershed Plan. *Indian Journal Of Science And Technology*, *16*(12), 894–902. https://doi.org/10.17485/ijst/v16i12.2202

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*, 1–11. 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/10.1016/j.rsase.2017.08.007

Víg, B., Fábian, S. Á., Czigány, S., Pirkhoffer, E., Halmai, Á., Kovács, I. P., Varga, G., Dezső, J., Nagy, G., & Lóczy, D. (2022). Morphometric analysis of low mountains for mapping flash flood susceptibility in headwaters. *Natural Hazards*, *114*(3), 3235–3254. https://doi.org/10.1007/s11069-022-05513-6

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. *International Journal of Multidisciplinary and Current Research*, *2*(2014), 179–184. https://doi.org/10.1007/s13201-021-01447-9