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Digital elevation model based-morphometric characterization of Pambujan River Basin in Northern Samar, Philippines

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Abstract

This study analyzed the morphometric characteristics of the Pambujan River Basin in Northern Samar, Philippines, to address the limited data on its linear, areal, and relief aspects essential for hydrological analysis and flood management. A Digital Elevation Model (DEM)-based morphometric analysis was conducted using a Geographic Information Systems (GIS) framework to characterize the basin and provide scientific insights for flood risk mitigation. The analysis employed Shuttle Radar Topography Mission (SRTM) DEM data, the Digital Soil Map of the World, and Sentinel-2 10-meter Land Use/Land Cover data processed in Quantum GIS to delineate watershed boundaries, extract drainage networks, and compute morphometric parameters. Results revealed that the Pambujan River Basin covers an area of 587 km², with a perimeter of 213 km and a main channel length of 139.4 km. The basin, classified as a fourth-order stream system with 94 streams totaling 498 km, exhibited an average bifurcation ratio of 4.3, indicating a dendritic and structurally undisturbed drainage pattern with moderate flood susceptibility. Areal parameters, including a low drainage density (0.75 km/km²) and stream frequency (0.16 km^{-2}), suggest limited drainage efficiency and delayed hydrologic response, increasing floodplain inundation risk during extreme rainfall. The elongation ratio (0.51) characterizes the basin as elongated, implying longer concentration and lag times (17 hours) and lower but prolonged peak discharge. Relief analysis indicates a maximum basin relief of 397 m, a relief ratio of 0.0073, and a ruggedness number of 0.29, reflecting gently sloping terrain with minimal erosion potential. However, its elongated form may prolong floodwater retention during extended rainfall, requiring continuous monitoring. Upstream soil and water conservation practices such as reforestation and contour farming are recommended. The estimated lag time can guide DRRM offices and local planners in improving community-based flood management and early warning systems. Integrating morphometric results with hydrological models like HEC-HMS, alongside climate and land use data, is encouraged for better flood prediction. The study's outcomes can support water resource planning for irrigation, domestic use, and power generation. Overall, the findings emphasize the importance of morphometric analysis in sustainable watershed management and disaster risk reduction for the Pambujan River Basin.

Keywords: River Basin, QGIS Basin Model, Drainage Morphometry, Watershed Characteristics, Geomorphology

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1. Introduction

A watershed, or drainage basin, is a natural hydrological unit that collects rainfall and channels surface runoff into a common outlet such as a river, lake, or ocean (Sarker & Leta, 2025). Defined by topographic divides, it integrates terrestrial and aquatic ecosystems and forms a foundation of the hydrological cycle. Watersheds regulate surface flow, recharge groundwater, and sustain ecological and agricultural systems (Borrelli et al., 2020).

However, watersheds worldwide are increasingly threatened by anthropogenic pressures such as deforestation, agricultural intensification, mining, and unplanned urban expansion, which disrupt flow regimes and accelerate degradation (Booth et al., 2002). Diminished vegetation cover promotes erosion and sedimentation, while pollutants from agricultural and industrial sources deteriorate water quality (Sun et al., 2021). Climate change further alters rainfall patterns and intensifies extreme events, heightening ecosystem vulnerability.

Addressing these challenges requires an integrated framework that combines hydrological, geomorphological, and land-management perspectives. Sustainable watershed management coordinates the use of land, water, and biological resources to meet developmental goals without compromising environmental integrity (GWP, 2000). The integration of Geographic Information Systems (GIS), remote sensing, and Digital Elevation Models (DEMs) has revolutionized watershed studies by enabling spatial analysis of terrain, drainage networks, and flow accumulation (Reddy et al., 2018). GIS-based tools allow the delineation of watershed boundaries, quantification of morphometric parameters, and simulation of runoff, establishing a scientific basis for hydrological modeling and flood assessment.

Hydrological modeling integrated with remote sensing has greatly enhanced the accuracy of watershed-scale analyses. Process-based models simulate rainfall–runoff behavior and floodplain inundation with high spatial and temporal precision (Nag et al., 2024). Widely used examples include the Topography-based Hydrological Model (TOPMODEL; Beven et al., 2021), Système Hydrologique Européen (SHE; Abbott et al., 1986), Gridded Surface Subsurface Hydrologic Analysis (GSSHA; Downer et al., 2006), Soil and Water Assessment Tool (SWAT; Neitsch et al., 2011), and the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) (United States Army Corps of Engineers, 2021). These models, once calibrated and validated, can reproduce observed hydrographs and predict inundation for multiple rainfall return periods, supporting flood-risk mapping and watershed management (Downer et al., 2006; Neitsch et al., 2011; United States Army Corps of Engineers, 2021).

Despite these advances, hydrological modeling has inherent limitations that affect performance, such as data dependency and calibration uncertainty. Hydrological models often rely on extensive time-series data for calibration and validation, which are scarce in many developing regions (Sarker & Leta, 2025). Another limitation is the lack of process insight in purely statistical or calibrated hydrological models. While models can reproduce observed hydrographs, they often do not explain how basin shape, slope, and drainage organization control hydrological response (Beven & Freer, 2001; Gao et al., 2019). This means that model performance remains sensitive to physical descriptors such as slope, basin shape, and drainage density. This underscores the value of morphometric analysis as a complementary approach that provides the physical context for interpreting model outputs. Recent studies highlight that integrating GIS-derived morphometric parameters with hydrological modeling improves watershed assessment and flood prediction. For example, El-Bagoury and Gad (2024) developed a GIS–HEC-HMS workflow that uses morphometric indicators such as slope and basin area to simulate runoff and inundation. Abdelgawad et al. (2024) and Herbei et al. (2024) found strong links between morphometric indices and runoff behavior, while Ganie et al. (2024) emphasized the importance of DEM-derived features in constructing and calibrating HEC-HMS models. In ungauged catchments, morphometric-based regionalization techniques have proven effective for estimating model parameters and predicting peak flows (Demisse et al., 2021).

Morphometric analysis quantitatively characterizes the geometry of a watershed through linear, areal, and relief parameters (Horton, 1945; Strahler, 1964). Linear parameters (e.g., stream order, bifurcation ratio) describe drainage structure; areal parameters (e.g., form factor, elongation ratio, circularity ratio) reflect basin shape and hydrological efficiency; and relief parameters (e.g., basin relief, relief ratio, ruggedness number) express terrain energy and erosional potential (Hamad, 2020; Mesa, 2006). These parameters influence the timing and magnitude of surface runoff and sediment transport. Basins with high drainage density and steep relief produce rapid runoff and flash floods, while elongated basins with gentle slopes exhibit slower flow. Morphometric analysis thus provides a physical basis for understanding hydrological response and supports flood-susceptibility mapping and watershed planning (Gajbhiye et al., 2014).

In the Philippine context, the Pambujan River Basin (PRB) in Northern Samar is a significant hydrological system that drains northward into the Pacific Ocean and supports extensive agricultural and residential communities. Situated in the northern portion of Samar Island along the eastern seaboard of the central Philippines, the basin is highly exposed to Pacific typhoons and monsoonal rains that frequently cause flooding across its low-lying floodplains.

Previous hydrological modeling and flood-mapping studies have been conducted for watersheds in the Philippines (Sarmiento et al., 2017), but limited attention has been given to their morphometric interpretation, particularly for the Pambujan River Basin. Therefore, morphometric analysis bridges this gap by providing physically based indicators that explain variations in flow concentration, lag time, and peak discharge among sub-basins. Studies by Rao (2020) and El-Bagoury et al. (2024) confirm that morphometric parameters improve model calibration, especially in data-scarce regions. Parameters such as drainage density, basin shape, and relief ratio directly inform model components defining loss rate, transform, and baseflow methods (United States Army Corps of Engineers, 2021). Empirical equations for lag time and time of concentration (Kirpich, 1940; NRCS, U., 2004b) also rely on slope and flow length derived from morphometry, ensuring that model calibration remains physically meaningful. Aside from these, morphometric characterization also enhances the identification of hydrologically sensitive zones, supports flood hazard prioritization, and informs land-use and reforestation planning (Musaed et al., 2022). In this way, morphometric analysis contextualizes hydrological simulations and strengthens decision-making for watershed sustainability.

For the Pambujan River Basin, morphometric analysis extends understanding beyond model calibration toward geomorphological interpretation. By quantifying morphometric attributes, this study examines how watershed structure influences runoff generation, infiltration, and flood vulnerability. Integrating morphometric results with hydrological outputs deepens the interdisciplinary foundation for watershed management. While hydrological models predict the magnitude and timing of flows, morphometric parameters explain why certain sub-basins respond more quickly and intensely. This combined interpretation supports the design of flood mitigation strategies, optimized land-use zoning, and conservation planning (Gajbhiye et al., 2014; Patel et al., 2012).

This study aims to supplement existing hydrological and flood-modeling outputs with a comprehensive morphometric analysis of the Pambujan River Basin. Using high-resolution DEM data and GIS-based spatial techniques, it quantifies linear, areal, and relief parameters to examine how watershed structure influences runoff generation, infiltration, lag time, and concentration time. The results aim to complement hydrological model parameters and support science-based watershed management and policy planning.

2. Materials and Methods

2.1 Study area

Pambujan River Basin is situated in the northern part of Samar Island in the Eastern Visayas Region, Philippines (Fig. 1b). It is geographically located at 12°08’04” to 12°34’05” North latitude and 124°41’22” to 125°00’06” East longitude. Pambujan River Basin covers almost entirely the municipalities of Pambujan and Silvino Lobos and parts of San Roque and Mondragon in Northern Samar, and Calbayog City, Samar (Fig. 1a).

The province of Northern Samar, where the Pambujan River Basin is located, falls under the Type II climate classification of the Modified Corona Climate Classification System, which is typical of municipalities along the eastern seaboard of the Philippines. According to the Philippine Atmospheric, Geophysical and Astronomical Services Administration, Type II is characterized by the absence of a distinct dry season and the occurrence of a pronounced maximum rainfall during November to December. In terms of hydrometeorological conditions, Northern Samar receives an annual average rainfall of 3,750.7 mm, with approximately 185 rainfall days per year, indicating a highly humid and wet climate regime. The mean annual temperature in the area is around 27.5°C. The relative humidity averages 86%, reflecting the strong maritime influence on the region, while the mean sea-level atmospheric pressure is about 1,010.1 millibars. Furthermore, the prevailing wind direction is northeast, with an average wind speed of 2 meters per second.

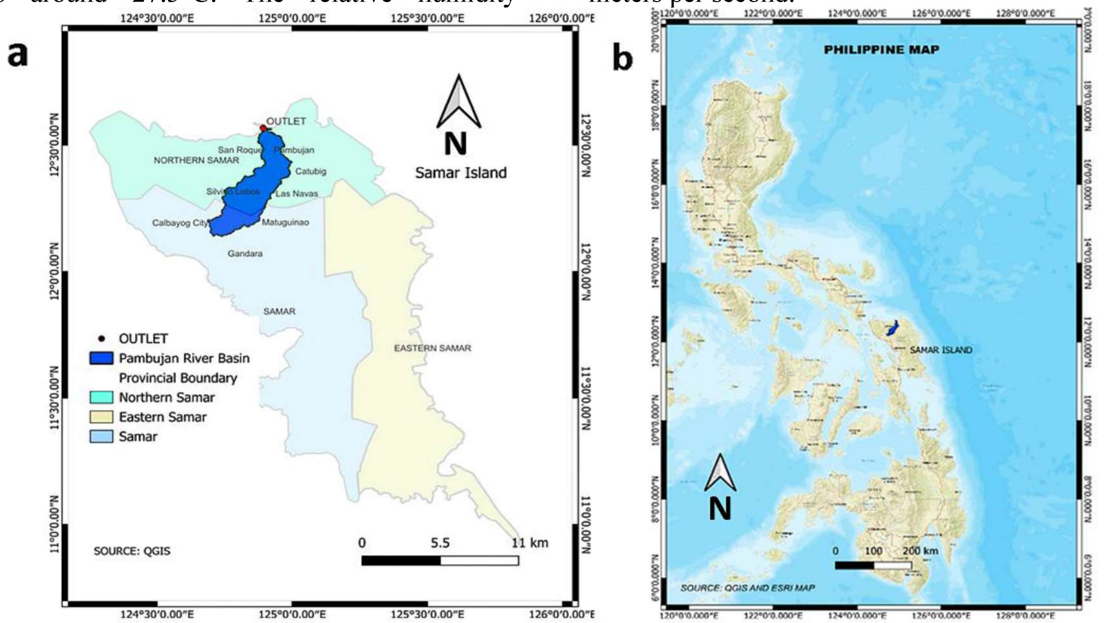

Figure 1. Location Map of the Pambujan River Basin in (a) Samar Island, and (b) the Philippines

2.2. Materials

The study employed a combination of geospatial tools and datasets to derive essential morphometric parameters and analyze the characteristics of the Pambujan River Basin.

2.2.1. Quantum Geographic Information System (QGIS)

QGIS version 3.22.9 was used as the primary platform for data integration, visualization, and spatial analysis. QGIS was selected because its open-source capabilities allowed efficient processing of multiple datasets, including terrain, soil, and land cover information, thereby facilitating the delineation of drainage boundaries, slope analysis, stream length measurement, and overlay of thematic maps (QGIS Development Team, 2022).

2.2.2. Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM)

SRTM-DEM was used to extract the morphometric parameters of the Pambujan River Basin, such as elevation profile, drainage area, perimeter, basin length, slope, and stream lengths. SRTM-DEM is a nearly global, high-resolution topographic dataset of the Earth's surface, created from radar data collected in February 2000 by the National Aeronautics and Space Administration Space Shuttle Endeavour (NASA, 2021). This free and openly available digital elevation model provides elevation information with 30-meter (~1 arc-second) resolutions, making it invaluable for various applications in geosciences, from hydrological modeling to terrain analysis (Yang et al., 2011)

2.2.3. Digital Soil Map of the World (DSMW)

DSMW was used to assess the soil types and their distribution across the Pambujan River Basin. DSMW is a global-scale geographic information system dataset that represents the distribution of soils across the globe. It shows 4931 mapping units consisting of soil associations, which are mixtures of different soil types. It was originally developed by the Food and Agriculture Organization of the United Nations (FAO) in collaboration with the United Nations Educational, Scientific, and Cultural Organization (UNESCO) as part of the FAO/UNESCO Soil Map of the World project, initiated in 1961. The DSMW has since been digitized, updated, and used for various applications, including agriculture, environmental monitoring, land-use planning, and climate change modeling (FAO, 1995).

2.2.4. Sentinel-2 10-Meter Land Use/Land Cover Map (LULC)

The LULC map used in this study is a high-resolution global dataset developed by Environmental Systems Research Institute (ESRI) in partnership with Impact Observatory and Microsoft that provides detailed land cover classifications derived from ESA's Sentinel-2 satellite imagery (ESRI, 2021). This data set was used to identify the fine-scale features of the river basin, such as trees, crops, as-built areas, and water bodies.

2.3. Methodology

The methodological framework for this research is summarized in Figure 2, which outlines the sequential processes involved from data collection to data analysis.

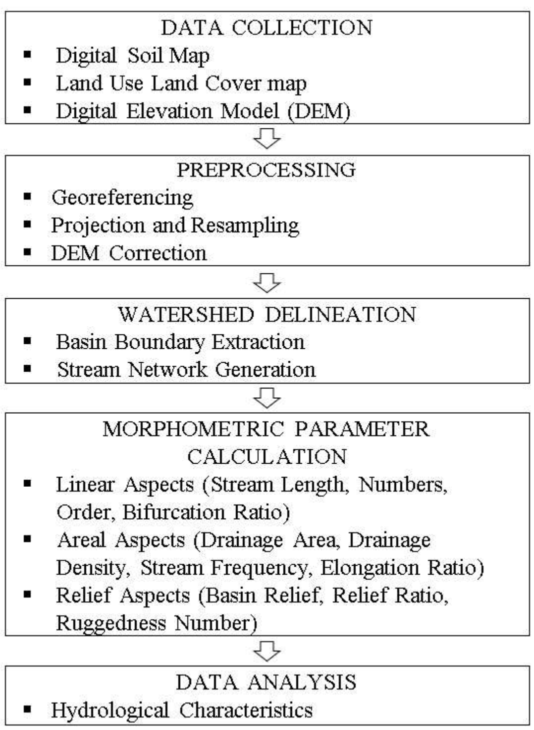

Figure 2. Flow Chart of the Study

2.3.1. Data Collection

Data collection commenced with the acquisition of the SRTM-DEM, which was retrieved via the USGS EarthExplorer platform by specifying the geographic coordinates of the Pambujan River Basin as the Area of Interest, then selecting "Digital Elevation → SRTM 1-ArcSecond Global" under the Data Sets tab, and downloading the DEM tiles in GeoTIFF format (USGS, 2023). For the DSMW, the data were accessed through FAO's Soils Portal in raster format (FAO, 2003). The Sentinel-2 10-meter Land Use and Land Cover (LULC) data were obtained via the website of the ESRI. ESRI is a leading international supplier of geographic information system (GIS) software, web-based GIS, and geodatabase management applications (ESRI, 2021). All datasets were downloaded in compatible formats (GeoTIFF), then imported into the QGIS software.

2.3.2. Preprocessing

In QGIS, the SRTM-DEM was preprocessed by reprojecting to the World Geodetic System 1984 (WGS 84) / UTM Zone 51N coordinate reference system. The reprojected data were clipped to the extent of the Pambujan River Basin. Then the voids and depressions in the DEM were corrected using the "Fill Sinks" algorithm available in QGIS, based on the method of Wang & Liu (2006). This process ensured a hydrologically consistent DEM by eliminating artificial pits and enabling continuous water flow across the terrain surface.

2.3.3. Stream Extraction

Before extracting the stream network, the flow direction and flow accumulation grids were first generated from the filled DEM to model surface water movement. The "Flow Direction" tool was used to compute the direction of the steepest descent from each grid cell, creating a raster that represents how water would flow across the terrain. The "Flow Accumulation" tool was applied to count the number of upstream cells draining into each cell. Then the stream networks were extracted through the "channel network" tool in SAGA.

2.3.4. Watershed Delineation

Afterward, an outlet point was then created and positioned in a location where the watershed drains. The point is created using the "new shapefile layer" tool. Then, using this outlet point, the terrain analysis "upslope area" tool was utilized to derive rasters that contribute flow to the outlet point. Finally, the upslope area rasters were converted to a vector layer using the "polygonize" tool (Conrad et al., 2015). The resulting polygon represents the basin boundary. The polygons were validated by overlaying them manually with the stream network to ensure outlet alignment. The final polygon was integrated with the extracted channel network, DSMW, and LULC data sets, and a digital map format was derived to visualize the drainage network, elevation profile, soil classification, and land use and land cover map of the Pambujan River Basin.

2.3.5. Calibration and Validation

The extracted streams were examined and calibrated manually to ensure alignment of the inlet-outlet points of the streams. Observation through ground-truthing and OpenStreetMap were used as references for comparing, trimming, and adjustments of the generated coordinates and stream segments.

2.3.6. Morphometric Parameter Calculation

Morphometric parameter calculations were conducted to quantitatively describe the geometry of the Pambujan River Basin and its drainage network. The parameters were classified into two groups: basic and derived. The basic parameters include the drainage area, basin length, basin perimeter, stream length, stream number, highest elevation, and outlet elevation, which were extracted from the processed DEM datasets using the QGIS platform.

*Stream lengths (Lu)***.** Stream lengths are the total length of all streams within the river basin measured from inlet to outlet in kilometers (Horton, 1945).

Stream Number (Nu). Stream number refers to the number of counts of all order streams within the basin (Horton, 1945). Nu and Lu for each order are computed directly from the DEM-derived drainage network.

Drainage Area (A). The drainage area refers to all the land surface that drains runoff to the outlet of the river basin. The QGIS program determined the boundaries of the basin and computed the surface area measured in square kilometers.

On the other hand, the derived parameters were calculated using classical morphometric equations originally proposed by Horton (1945), Strahler (1957), and Schumm (1956). These derived parameters were structured into three domains: linear aspects, areal aspects, and relief aspects.

2.3.6.1. Linear Aspects

The linear aspects of basin morphometry were calculated using stream order and bifurcation ratio. These parameters were used to describe the configuration of the stream network and assess the degree of drainage dissection, stream distribution, and structural control within the basin (Schumm, 1956).

Stream orders (U). Stream ordering followed Strahler's hierarchical system, where the headwater streams that received no tributaries are called the first-order streams. Two first-order streams unite to form a second-order stream. Two second-order streams unite to form a third-order stream and so on. Where two streams of different orders join, the order of the higher-order stream will prevail (Strahler, 1957).

Bifurcation ratio (Rb). The bifurcation ratio (Rb) was calculated by getting the ratio of the number of stream segments of specified order and the number of streams in the next higher order. Rb was calculated using equation 1 (Schumm, 1956).

$$\text{Rb} = \frac{N_U}{N_{U+1}} \tag{1}$$

Where: N_U = Total number of stream segments of order 'u', and N_{U+1}= Number of stream segments of the next higher order.

2.3.6.2. Areal Aspects

Areal morphometric parameters describe the spatial characteristics of the basin, integrating both drainage patterns and basin geometry. Key indices include drainage density, stream frequency, and elongation ratio.

Drainage Density (Dd). Drainage density defines the coarseness or fineness of drainage of the river basin. It is the ratio of the total stream length and the total area of the river basin measured in km/km². Dd was calculated using equation 2 (Horton, 1945).

$$\text{Dd} = \frac{Lu}{A} \tag{2}$$

Where: Lu = total stream lengths (km) and A = drainage area (km^2).

According to Horton (1945), a poorly drained basin has a drainage density of 0.73, while a well-drained basin is 2.74. High drainage density indicates high run-off and low infiltration rate, whereas low drainage density implies low run-off and high infiltration (Prasad, 2008)

Elongation ratio (Re). The elongation ratio (Re) was determined by calculating the ratio of the diameter of a circle of the same area as the basin to the maximum basin length (Schumm, 1956). Re values were divided into three groups: circular (>0.9), oval (0.9–0.8), and less elongated (<0.7) (Magesh et al., 2011). Re values approaching 1 means the shape of the basin approaches a circle (Abdel-Lattif & Sherief, 2012). Circular shape basins have shorter concentration time than elongated basins (Chaithong, 2022). The elongation ratio was computed using equation 3 (Schumm, 1956).

$$\mathrm{Re} = \left(\frac{2}{\mathrm{Lb}}\right)\left[(A/\pi)^{0,5}\right] \quad (3)$$

Where: Lb = basin length in km and A = basin area in km^2

Stream frequency (Fs). Fs is defined as the number of stream segments per unit basin area. It is computed using equation 4 (Horton, 1945).

$$\mathrm{Fs} = \frac{Nu}{A} \quad (4)$$

Where: Nu = number of mapped stream segments and A = basin area in km^2

Fs are categorized into very high (20-25), high (15-20), moderately high (10-15), moderate (5-10), and low (0-5) (Shekar and Mathew, 2024).

2.3.6.3. Relief Aspects

Basin relief, relief ratio, and ruggedness number were used to analyze the relief aspects of the Pambujan River Basin. These parameters helped describe the vertical dimension of the basin and analyze its erosional potential.

Basin Relief (Bh). Basin relief, also known as absolute relief, is the elevation difference between the highest point on the watershed divide and the basin outlet measured in meters. It is computed using equation 5 (Schumm, 1956).

$$\mathrm{Bh} = \mathrm{H} - \mathrm{h} \quad (5)$$

Where: H = highest elevation (m) and h = elevation (m) at the outlet points

Basin relief is an essential factor in understanding the denudational characteristics of the watershed, landforms, and drainage networks development, overland flow, through-flow, and erosional properties of the terrain (Farhan et al., 2015).

Relief Ratio (Rr). Rr is a dimensionless morphometric parameter defined as the ratio between basin relief and the maximum basin length measured parallel to the principal drainage line (Schumm, 1956). This ratio provides an index of the overall slope of the basin surface (Strahler, 1957). Rr was computed using equation 6 (Schumm, 1956).

$$\mathrm{Rr} = \mathrm{Rb}/\mathrm{Lb} \quad (6)$$

Where: Lb = basin length in km and Rb = basin relief in km.

Ruggedness Number (Rn). The Ruggedness Number (Rn) is a composite morphometric parameter that integrates basin relief (Bh) and drainage density (Dd) into a single index. Rn is computed using equation 7 (Strahler, 1964).

$$\mathrm{Rn} = (\mathrm{Bh} \times \mathrm{Dd})/1000 \quad (7)$$

Where: Bh = maximum basin relief (m) and Dd = drainage density (km/km^2).

Rn values are categorized as very low for subdued morphology (<0.1); low for slight morphology (0.1-0.4); moderate for moderate morphology (0.4 - 0.7); high for sharp morphology (0.7 - 1.0); and very high for extreme morphology (>1.0), modified from the suggestion of Farhan et al. (2015). Higher Rn values represent longer and steeper slopes, while lower values represent flatter or gently undulating terrains.

2.3.7. Hydrological Analysis

Concentration Time (Tc). Time of concentration is the time required for water to travel from the most hydraulically distant point of a watershed to the outlet. It represents the period after which all areas of the watershed contribute to runoff at the outlet. Tc was computed using equation 8 (Kirpich, 1940).

$$\mathrm{Tc} = 0{,}00663\, L^{0,77} So^{-0,385} \quad (8)$$

Where: L = main channel length (km) and So = main channel slope (m/m).

Lag Time (Lt). Lag time (Lt) is the time difference between the centroid of rainfall (excess rainfall) and the peak of the resulting hydrograph. It reflects how quickly runoff from a catchment responds to rainfall. Lt was computed using equation 9 (NRCS, U., 2004b).

$$\mathrm{Lt} = 0{,}6\ \mathrm{Tc} \quad (9)$$

Where: Lt = lag time (hr) and Tc = concentration time (hr).

3. Results and Discussion

3.1 River Basin Characteristics

3.1.1. Soil Classification

Pambujan River Basin is dominated by two types of soil, the Distric Nitosols (92%) covering the upstream portion and Orthic Luvisols (8%) covering the downstream portion. Distric Nitosols and Orthic Luvisols differ markedly in texture, slope position, and hydrological behavior. Distric Nitrosols are fine-to-medium-textured soils, typically clay to clay loam, with slow permeability and high runoff potential. They occur predominantly in upland and mountainous areas with moderate to steep slopes. In contrast, Orthic Luvisols are medium-textured soils (mostly loam to clay loam) with moderate permeability and better structural development. They are commonly found on gently undulating to nearly level terrains, such as lowlands or river terraces (FAO, 1979). These types of soils have low to moderate infiltration rate (<15 mm/hr - 50 mm/hr) and have water holding capacity of 100-250 mm water depth per meter depth of soil (Brouwer et al., 1985).

Consequently, the low to moderate infiltration rate of these soils promotes higher surface runoff during intense rainfalls, meaning when rainfall intensity is greater than the infiltration rate of the soil. The spatial distribution of these soil types suggests that the upper catchment contributes to quick runoff generation and shorter lag and concentration times, while the downstream soils may attenuate flow peaks through infiltration and storage effects. Similar findings were reported by Jourgholami & Labelle (2020), who found that watersheds with dominant fine-textured soils exhibit higher runoff coefficients and reduced lag times compared to basins with coarser soils. Likewise, Mishra & Singh (2003) emphasized that soil texture and structure strongly influence hydrological responses by modulating infiltration and subsurface flow.

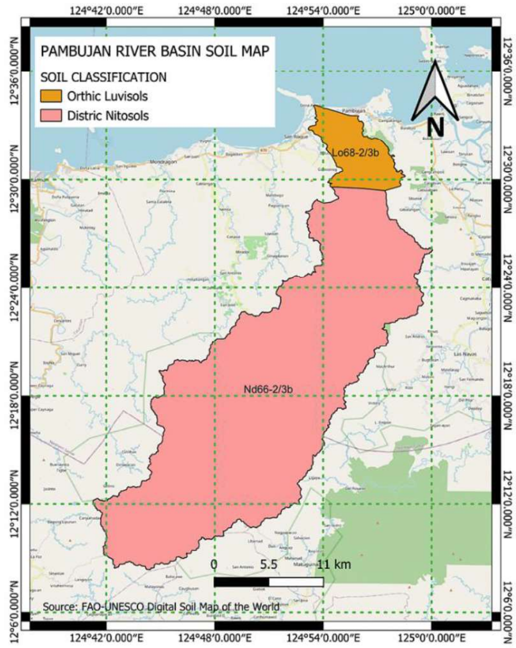

Figure 4. **Pambujan River Basin Soil Map**

3.1.2. Land Use / Land Cover

The Pambujan River Basin is predominated by forest and vegetation cover, accounting for about 95% of the total land area. This condition has significant hydrological implications, particularly for infiltration, lag time, concentration time, and peak runoff. Dense vegetation enhances soil permeability and root-zone absorption, allowing greater infiltration and groundwater recharge while minimizing overland flow (Sadhwani et al., 2022). As a result, runoff is delayed, lengthening both lag and concentration times, which in turn reduces the magnitude and velocity of peak discharge during storm events.

Conversely, the presence of built-up areas and agricultural lands, though minor, can locally increase impervious surfaces and compacted soils, leading to reduced infiltration and faster surface runoff generation (Welde & Gebremariam, 2017). The estimated population of over 50,000 people, based on the Philippine Statistics Authority 2020 Census of Population and Housing, living within these built-up zones introduces additional hydrological stress, as settlements near rivers often contribute to decreased infiltration capacity and higher flood susceptibility.

Overall, the basin's dense vegetation cover serves as a key factor in regulating hydrological behavior, reducing flood hazards, and sustaining ecological balance despite localized human disturbances. Moreover, the land cover data provide a useful basis for estimating the Curve Number (CN) of the Pambujan River Basin. The CN values are derived from the guidelines of the United States Department of Agriculture Soil Conservation Service (SCS, 1972) and the United States Department of Agriculture - Natural Resources Conservation Service (NRCS U., 2004a). The Curve Number is a critical parameter in hydrological modeling, as it indicates the proportion of rainfall that contributes to surface runoff.

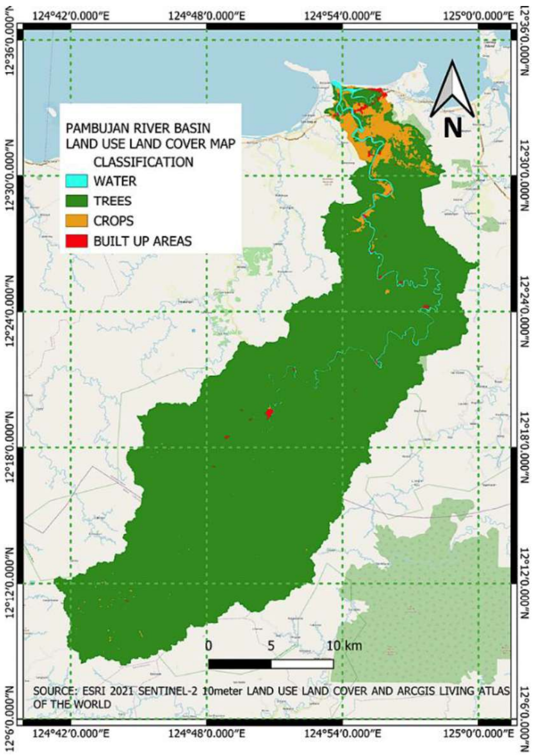

Figure 5. Pambujan River Basin Land Use Land Cover Map

3.1.3. Elevation Profile

The elevation profile of the Pambujan River Basin, with a total relief of 397 m (highest amsl = 397 m; lowest amsl = 0 m) and terrain that rises toward the western portion of Samar and descends northward toward the municipality of Pambujan, has important implications for infiltration, concentration time, lag time, and peak runoff. High basin relief and associated steep slopes generally reduce the time available for infiltration as precipitation is rapidly routed downslope; consequently, effective infiltration rates in steep upper parts of the basin are commonly lower than in gentler, lower-gradient zones, especially during intense storms when soils quickly become saturated. Steep slopes and short flow paths also shorten the basin's concentration time and lag time because surface and shallow subsurface flows reach the channel more rapidly; the basin, therefore, tends to produce a fast hydrologic response to rainfall.

These findings are consistent with those of Strahler (1952) and Chorley et al. (1984), who noted that basins with high relief and steep gradients exhibit quick hydrologic responses due to shorter flow paths and reduced infiltration time. Jain & Sinha (2006) and Sreedevi et al. (2005) also reported that steep-sloped basins generate flashy hydrographs characterized by high peak discharges and short lag times, while low-relief downstream areas act as natural attenuators, allowing water to spread and reducing flood peaks. Moreover, Ogden et al. (2011) emphasized that elevation gradients strongly influence the timing and magnitude of runoff responses, making relief an important determinant of flood hazard in tropical and monsoon-influenced catchments.

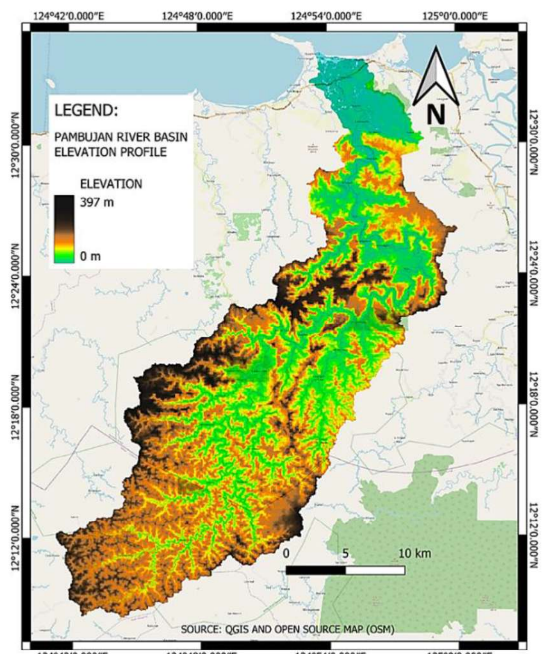

Figure 6. Elevation Profile of the Pambujan River Basin

3.1.3. Drainage Network

The delineation of the Pambujan River Basin and the description of its main channel characteristics have important implications for runoff generation, concentration time, and lag time. The well-defined boundary ensures that all precipitation and surface flow within the basin ultimately converge toward the main outlet, making it a functional hydrologic unit for runoff analysis and flood management (Chow, 2010). The relatively long main channel length of 139.4 km suggests that surface runoff generated from rainfall will take a longer time to reach the outlet, thereby increasing concentration and lag times (Subramanya, 2013). This implies that peak discharge may be delayed, allowing for potential attenuation of flood peaks along the channel, particularly if the basin has substantial vegetation and storage areas. However, the 135-meter average channel width near the outlet indicates a large flow-carrying capacity, which can accommodate higher volumes of runoff during storm events. Conversely, if intense rainfall occurs over upstream areas with steep slopes or reduced vegetation cover, runoff generation may accelerate, shortening concentration time and increasing the potential for flash flooding downstream.

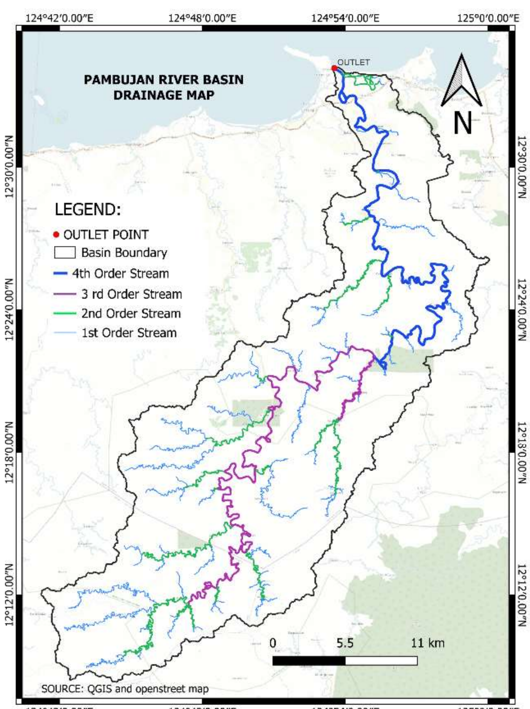

Figure 7. **Drainage Network of Pambujan River Basin**

3.2. Morphometric Characteristics

Linear Aspects. Pambujan River Basin is a 4th-order stream network consisting of 94 streams. The decrease in the number of streams as the rank goes up indicates a tree root pattern, which is an attribute of a dendritic drainage system (Table 1). The Pambujan River Basin's average bifurcation ratio of 4.3 suggests that its drainage pattern is still mostly unaffected by geology, but branching becomes moderately more complex. A bifurcation ratio below 3 indicates a nearly ideal basin with an orderly and undisturbed drainage network, while greater than 5 suggests an elongated basin where geological structures strongly influence its shape, leading to very complex branching (Strahler, 1964). The results of this study differ from those reported by Torrefranca and Otadoy (2024), who classified the Wahig-Inabanga Watershed as a sixth-order stream. Although both basins exhibit nearly the same area and shape, the Wahig-Inabanga Watershed has a substantially higher number of streams (1,108) compared to only 94 in the Pambujan River Basin. This significant discrepancy may be attributed to inadequate validation and calibration, underscoring the importance of manual inspection, trimming, and adjustment through ground-truthing and the use of aerial maps.

Table 1. **Stream Order, Stream Lengths, Number of Streams, and Bifurcation Ratio of Pambujan River Basin**

Stream Order	Stream Length, km	Number of Streams	Bifurcation Ratio
1st	241.1	74	
			4.63
2nd	122.6	16	
			5.33
3rd	75.1	3	
			3.0
4th	59.2	1	
Total	498	94	12.96

Areal Aspects. Pambujan River Basin is elongated in shape and covers a drainage area of 587 km^2 with approximately 213 km long perimeter. It has a low stream frequency (0.16/ km^2), which complements the low drainage density (0.75 km/km^2) of the river basin. Low drainage density implies low run-off and high infiltration (Prasad et al., 2008). Its elongated shape makes the Pambujan River Basin drain runoff less efficient than a circular basin (Shekar and Mathew, 2024) but promotes longer concentration and lag times. These results are in accordance with the findings of Bogale (2021) that low drainage density basins suggest high permeability and thick vegetation cover in the basin.

Table 2. **Areal Morphometric Characteristics of Pambujan River Basin**

Parameters	Value	Category
Drainage Area (km^2)	587	
Stream Lengths (km)	498	
Drainage Density, (km/km^2)	0.75	low
Equivalent Diameter (km)	27.34	
Maximum Basin Length, (km)	54	
Stream Frequency (km^{-2})	0.16	low
Elongation Ratio	0.51	elongated

Relief Aspects. The results of relief analysis show that the Pambujan River Basin has high basin relief, low relief ratio, and low ruggedness number (Table 3). Watersheds with low ruggedness numbers generally have gentle and stable slopes with less geomorphic activity. They are less prone to soil erosion and mass movement and show a slower, more moderate response to peak discharge events (Farhan et al., 2015). The low relief ratio suggests that the river basin has relatively gentle slopes and minimal elevation differences, while high basin relief is indicative of a high potential energy of a drainage system based on its elevation above a reference level (Strahler, 1964). Consequently, the Pambujan River Basin is likely to experience slower runoff, higher infiltration rates, and lower potential for soil erosion. According to the Philippine Atmospheric, Geophysical, and Astronomical Service, this topographic configuration aligns with the climatic and hydrological regime of Northern Samar, where orographic rainfall and frequent typhoons contribute to substantial seasonal runoff.

These results aligned with the findings of Del-Aguila and Mejía (2021) in two high Andean River basins in Peru, that high topographical factor implies steep slopes and increased erosive processes

Table 3. **Relief Morphometric Characteristics of the Pambujan River Basin**

Parameters	Value	Category
Highest Elevation, H (m)	397	
Lowest Elevation, h (m)	0	
Basin Relief (m)	397	High
Basin Length (km)	54	
Relief Ratio (m/km)	0.0073	Low
Ruggedness Number	0.29	Low

3.3. Hydrological Analysis

The computed time of concentration and its corresponding lag time for the Pambujan River Basin are 28.38 and 17.3 hours, respectively. This indicates that it takes approximately 17 hours from peak rainfall to generate peak discharge at the outlet. These findings suggest that the basin responds moderately slowly to rainfall events, implying that there is a significant delay between intense rainfall and peak discharge at the outlet. This hydrological response can be attributed to the morphometric characteristics of the Pambujan River Basin, such as dense vegetation cover, elongated shape, low relief ratio, and low drainage density, which tend to reduce surface runoff velocity and prolong flow concentration.

These results, however, did not correspond with the findings of Sarmiento et al. (2017), who reported a lag time of approximately 27 hours and 50 minutes for the Pambujan River Basin. The discrepancy between the two estimates may be attributed to differences in data sources, spatial resolution, and computational methods used in the respective analyses. The present study utilized morphometric analysis tools, which allow for a more detailed representation of stream lengths, slopes, and elevations. In contrast, Sarmiento et al. (2017) may have based their computation on coarser elevation data or empirical formulations calibrated for regional catchments, which could yield higher lag time values.

4. Conclusions

The morphometric analysis of the Pambujan River Basin has provided significant insights into its morphological characteristics. By applying GIS-based technologies and methods such as QGIS software, SRTM-DEM data, and open-source maps, and manual validation and calibration, more accurate values of parameters such as stream orders, drainage density, bifurcation ratio, elongation ratio, relief ratio, stream frequency, and ruggedness number were obtained, and we have gained a better comprehensive understanding of the basin's structural and functional attributes, especially on runoff coefficient and the timing of peak runoff.

Pambujan River Basin exhibits favorable morphometric and hydrological characteristics that support flood moderation and soil conservation. The combination of extended vegetation coverage, elongated basin geometry, low drainage density, and low relief ratio enhances concentration and lag time, infiltration, reduces runoff velocity, and moderates peak discharges. Similarly, the low ruggedness number and stream frequency suggest stable terrain conditions with minimal erosional activity. These features underscore the basin's resilience against flash floods and erosion. However, the elongated basin form may prolong floodwater retention during extended rainfall events, highlighting the need for continued hydrological monitoring and localized flood preparedness.

Given the Pambujan River Basin's generally favorable hydrological response, resource management strategies should focus on enhancing soil and water conservation measures at the upstream level, such as reforestation and contour farming.

The estimated lag time can be used by the Disaster Risk and Reduction Management (DRRM), Municipal Planning and Development Office, and the Sangguniang Bayan as a reference in formulating community-based flood management plans and ordinances, such as early warning systems for communities living in the mid and downstream portions of the basin.

Future studies may integrate these morphological characteristics into hydrological models such as HEC-HMS with climatic and land use and land cover data to develop holistic models for predicting hydrological behavior and flood risk assessment of the Pambujan River Basin. The findings may also be used in water resource management for potential applications such as irrigation systems for agriculture, domestic water supply, and power generation. Such integrated approaches will enable more accurate assessments and informed decision-making for the Pambujan River Basin and similar river systems.

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