Aplication Of GIS Based Morphometric And Land Cover Analysis to Evaluate Flood Potential in The Wai Batu Gantung Watershed, Ambon City, Indonesia.

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Abstract

The Wai Batu Gantung Watershed is one of the areas with high settlement density locates in the downstream part of Ambon City which is particularly vulnerable to localized flooding. The steep morphological condition and rapid coastal development make flood potential analysis crucial to support sustainable watershed management. This study aims to assess the flood potential of the Wai Batu Gantung watershed based on morphometric characteristics and land cover, utilizing Geographic Information System (GIS) application. The analysis was conducted on six sub-watersheds (BGt1 – BGt6) using digital elevation model (DEM) data to determine the parameters of bifurcation ratio (Rb), drainage density (Dd), and texture ratio (Rt), which were the ingrated with land cover maps derived from satellite image interpretation. The result indicate that the Wai Batu Gantung Watershed covers an area of approcimately 8.18 km^2 and is classified as a third – order river system. The Rb values range from 1.3 to 2.0 indicating that the development of the drainage network is strongly influenced by geological and lithological structures, particularly Ambon volcanic rocks, coral limestone, and the Kanikeh Formation. The Dd values, ranging from 3.1 to 4.4 km/km^2 are considered high, suggesting a dense drainage system and rapid hydrological response to rainfall events. Meanwhile, the texture ratio (Rt) balues fall between for suface runoff and erosion. Land cover analysis shows that the upstream area is predominantly covered by shrubs, while the middle to downstream regions especially in sub-watersheds BGt4 and BGt6 have experienced significant increases in residential development. The combination of high drainage density (Dd), coarse texture ratio (Rt), and the expansion of non vegetative land cover in the downstream areas indicates that the Wai Batu Gantung watershed has a moderate to high flood potential. The application of GIS has proven effective in integrating morphometric analysis with spatial data to identify flow patterns, flood-prone zones, and relationships among hydrological parameters. The findings of this study provide a basis for planning watershed conservation strategies, spatial planning for coastal areas, and morphometry based flood mitigation efforts.

***Keywords**: Watersheds, Morphometric, Land Cover, Flood Potential, GIS.*

1. Introduction

A watershed is a terrestrial area that forms an ecological unit consisting of a main river and its tributaries functioning to collect, store, and channel rainfall to lakes or the sea through natural processes. The land boundary is defined by topographic divides, while the ocean boundary extends to the area influenced by terrestrial hydrological activity (Government Regulation No. 37 of 2012 on Watershed Management). Uncontrolled land cover changes particularly in densely populated urban areas, have significantly increased pressure on watershed carrying capacity. Ambon City located in Maluku Province, faces complex hydrometeorological challenges. One of the watersheds vulnerable to flooding is the Wai Batu Gantung Watershed, which has a relatively small area (8.18 km^2) but is situated in a densely populated downstream zone. The high intensity of land conversion in this area has amplified surface runoff and flood potential (Rakuasa et al., 2024). The conversion of natural land into residential and infrastructure areas has reduced infiltration capacity, consequently increasing surface runoff and flood risks (Kayitesi et al., 2022).

To understand the relationship between watershed form, land cover change, and hydrological response, morphometric analysis provides a relevant quantitative approach. Morphometric analysis offers a numerical understanding of watershed shape, size, and drainage pattern which influence hydrological behavior. Parameters such as bifurcation ratio, stream length, drainage density, texture ratio, and watershed form have been widely used to assess flood susceptibility and environmental degradation (Strahler, 1964; Horton, 1945). With the advancement of geospatial technology, Geographic Information Systems (GIS) and Digital Elevation Models (DEM) enable faster and more accurate morphometric analyses integrated with land cover data (Javed & Khanday, 2009). Although several studies in Indonesia have evaluated watershed morphometry in Java (Sukiyah et al, 2015; Sukiyah et al., 2018; Gentana et al., 2018; Haryanto et al., 2019; Raja et al., 2020; Riswandi et al., 2020; Rendra et al., 2021; Siahaan et al., 2002; Sukiyah et al., 2023), quantitative assessments in eastern Indonesia particularly in Ambon remain limited. Research related to the eastern context such as the morphometric and hydrological analysis of the Wai Samal Watershed in Maluku (Ningkeula, 2016), urban flood hazard modeling in Ambon’s watersheds (Rakuasa et al., 2024), land cover change and water availability studies (Barkey et al., 2017), hydrodynamic based urban drainage simulations (Leuhery et al., 2018), and morphometric characteristics of the Wairuhu watershed (Tuanany et al., 2024), have contributed to the understanding of regional hydrology. However, these studies have not explicitly linked morphometric characteristics with land use dynamics. Other research, such as the urban hydrogeological study by (Matrutty et al, 2024), focuses more on groundwater potential. Most of these studies emphasize general hydrological or drainage aspects rather than detailed morphometric land cover relationships, highlighting the need for small scale watershed morphometric studies integrated with land cover analysis in Ambon.

Previous studies discussed above form the foundation for this research, which integrates morphometric analysis and land cover assessment to evaluate flood potential in the Wai Batu Gantung Watershed. Based on these gaps, this study aims to analyze the morphometric characteristics of the Wai Batu Gantung Watershed using a GIS-based approach by integrating topographic, DEM, and land cover data. This analysis is expected to provide an understanding of watershed morphology and its relationship to hydrological risks particularly flood potential, which can serve as a foundation for sustainable watershed management strategies in Ambon City.

2. Methodology

a. Data Collection

The data used in this study include a Digital Elevation Model (SRTM DEM)**,** topographic maps, and land cover data. The DEM was used to analyze elevation, slope, and to delineate watershed boundaries. The topographic map was employed to verify the extracted stream network, while the land cover map was used to analyze the relationship between land cover conditions and morphometric characteristics.

b. Watershed Delineation and Stream Network Extraction

Watershed boundary delineation was carried out using the hydrology tools available in ArcGIS 10.8 to define the main watershed and its sub-watersheds in the Wai Batu Gantung Basin. The stream network was automatically extracted from DEM data using the Strahler (1964) method to determine stream order. The extracted stream network was then verified using the Indonesian Topographic Map (RBI) to ensure positional accuracy and flow continuity.

c. Morphometric Parameter Calculation

Morphometric analysis was conducted quantitatively based on the concepts of Horton (1945) and Strahler (1964). The parameters calculated include:

- **Bifurcation Ratio (Rb)**

  Calculated to represent the degree of branching and the influence of geological structures on drainage patterns.

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

Notation :

Rb = Bifurcation ratio, indicating the degree of branching of the river network.

Nu = Number of stream segments of a given order (u).

Nu+1 = Number of stream segments of the next higher order ($u + 1$)

- **Drainage density (Dd)**

  Indicates the relationship between the total length of streams (L) and the watershed area (A)

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

Notation :

Dd = Drainage density index (km/km²)

ΣL = Total length of streams (km)

A = Watershed area (km²)

- **Ratio Texture (Rt)**

  The texture ratio represents the comparison between the number of stream segments within a watershed or sub-watershed and its perimeter.

$$Rt = \frac{\Sigma N}{P} \text{ .... (3)}$$

Notation:

Rt = Texture ratio

ΣN = Total number of stream segments

P = Perimeter of the watershed or sub-watershed (km)

d. Land Cover Analysis

Land cover analysis was carried out using the *overlay* method between the land cover map and the sub-watershed boundaries obtained from the delineation process. Each land cover class such as shrub and settlement areas was calculated in hectares to determine the percentage of land cover dominance within each sub-watershed. The results of this analysis were used to assess the influence of land cover variation on the hydrological conditions of the study area.

e. Result and Disucussion

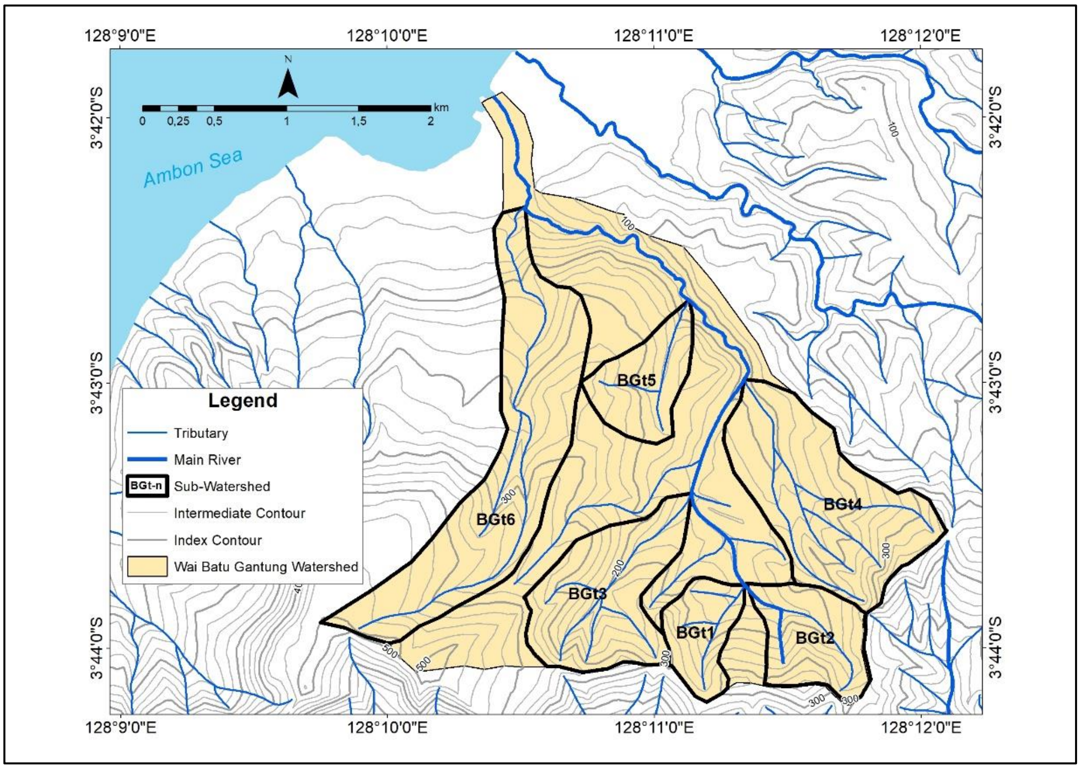
The interpretation stage was conducted by integrating the results of the morphometric and land cover analyses to assess flood potential within the Wai Batu Gantung Watershed. Morphometric indicators such as high drainage density and coarse texture ratio, when combined with a dominance of built-up land (settlement areas), were interpreted as regions with higher surface runoff and inundation potential.

f. Research Flowchart

3. Result

a. Watershed Delineation

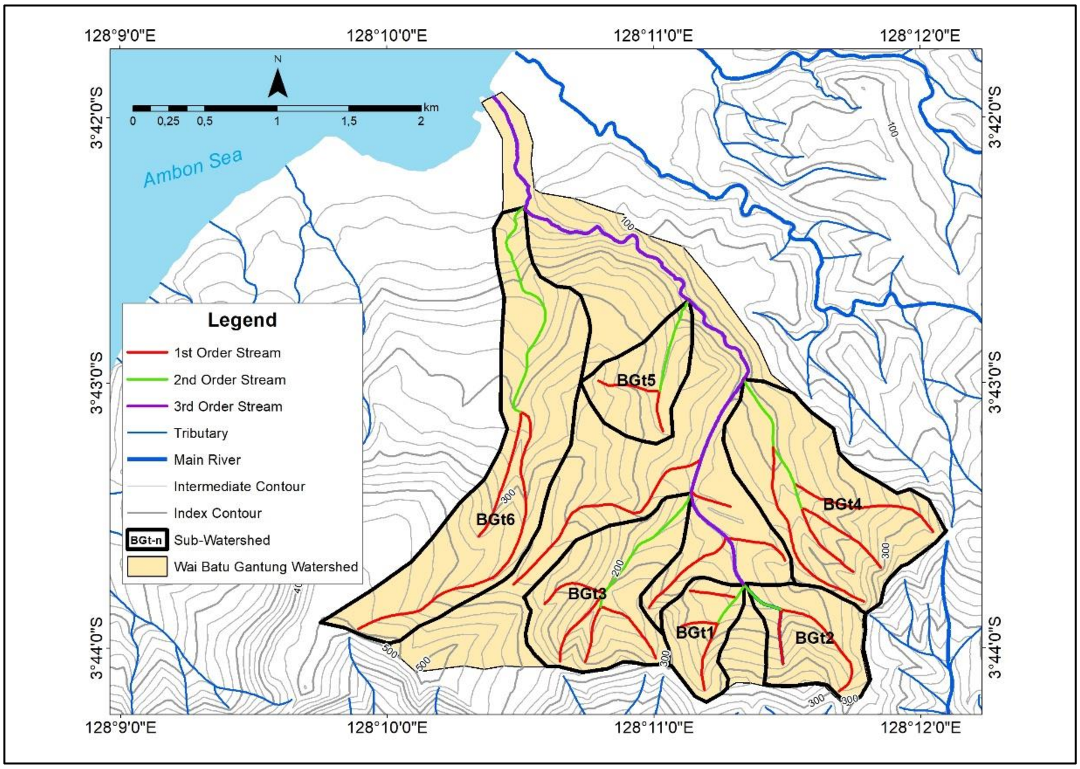
Based on the Digital Elevation Model (DEM) analysis using the watershed delineation method, the boundary of the Wai Batu Gantung Watershed was successfully defined covering an area of approximately 8.18 km² (Figure 1). Morphologically this watershed consists of several sub-watersheds (BGt1, BGt2, BGt3, BGt4, BGt5, BGt6) with flow patterns that are integrated toward the main river channel. The watershed is located in the downstream area of Ambon City which is densely populated, leading to high pressure on its hydrological functions. The delineation results also show that the main river flows directly into the coastal area, increasing the vulnerability of the downstream zone to local flood inundation.



Source: Author's GIS processing from RBI dataset (BIG, 2024)

Figure 1: Delineation Map of the Wai Batu Gantung Watershed

b. Stream Network



Source: Author's GIS processing from RBI dataset (BIG, 2024)

Figure 2: Stream order in Wai Batu Gantung Watershed

Based on the stream network extraction from the DEM using the Strahler method, the Wai Batu Gantung Watershed consists of three stream orders (Figure 2). First-order streams are represented by small tributaries that dominate the upstream area, second-order streams are formed by the confluence of two or more first-order streams, and third-order streams represent the main channels that flow toward the downstream area. The distribution of the stream network indicates that the Wai Batu Gantung Watershed comprises six sub-watersheds. The upstream sub-watersheds (BGt1 and BGt2) are dominated by first- and second-order streams, while the middle to downstream sub-watersheds (BGt3 – BGt6) show the presence of third-order streams as the main drainage channels.

This branching pattern suggests that the Wai Batu Gantung Watershed exhibits a relatively dense drainage network, which directly affects its bifurcation ratio (Rb) and drainage density (Dd) values. Such conditions indicate a relatively rapid hydrological response to rainfall, especially in the downstream areas that are densely populated.

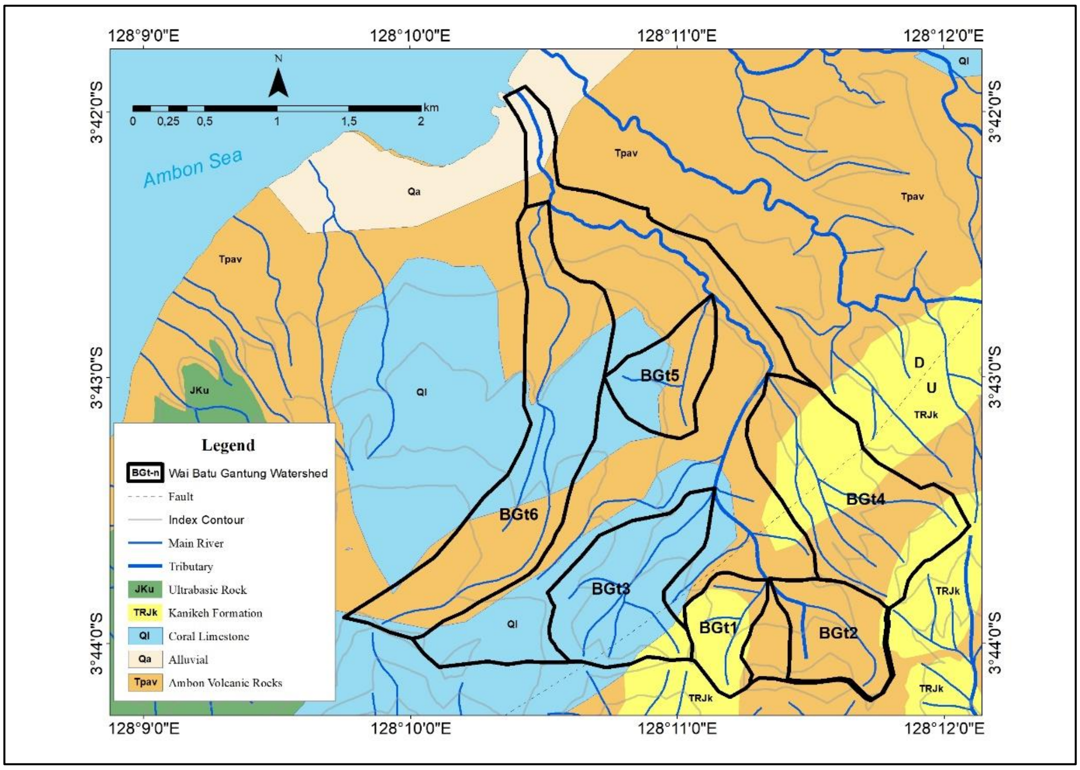
c. Morphometric Parameters

- **Bifurcation Ratio (Rb)**

Table 1: Bifurcation Ratio Values in the Wai Batu Gantung Watershed

Watershed	Sub-Watershed	Number of stream orders (u)		Number of stream segments (u+1)		Rb 1_2	Classifi-cation	Lithology
		1	2	1	2			
Wai Batu Gantung	BGt1	3	1	3	2	1.5	Deformed	Kanikeh Formation, Ambon Volcanic Rock
	BGt2	2	1	2	1	2.0	Deformed	Ambon Volcanic Rock
	BGt3	4	1	4	3	1.3	Deformed	Coral Limestone
	BGt4	4	1	4	3	1.3	Deformed	Kanikeh Formation, Ambon Volcanic Rock
	BGt5	2	1	2	1	2.0	Deformed	Ambon Vulvanic Rock, Coral Limestone
	BGt6	2	1	2	1	2.0	Deformed	Ambon Vulvanic Rock Coral Limestone

The bifurcation ratio (Rb) values for each sub-watershed of the Wai Batu Gantung Watershed range from 1.3 to 2.0 (Table 1). According to the classification by Strahler (1964), bifurcation ratio (Rb) values lower than 3 indicate that the branching pattern of the river network is influenced by geological structures and the characteristics of the underlying rocks. These results suggest that all sub-watersheds within the Wai Batu Gantung Watershed fall into the deformed category, meaning that the development of the drainage network is still controlled by local geological conditions. The regional geological map of the watershed (Figure 3) shows that the Wai Batu Gantung Watershed is composed of several main lithological units: Ambon volcanic rocks (Tpav), coral limestone (Qa), and the Kanikeh Formation (Trjk). The eastern sub-watersheds (BGt1, BGt2, and BGt4) are generally composed of Ambon volcanic rocks and the Kanikeh Formation, while the western parts (BGt3, BGt5, and BGt6) are dominated by coral limestone and Ambon volcanic rocks. The relatively low bifurcation ratio (Rb) values observed in sub-watersheds BGt1, BGt3, and BGt4 are likely associated with the presence of fault structures crossing these areas (Figure 3). The fault zones cause the drainage pattern to follow the direction of rock fractures, which reduces the natural branching of the river system. In contrast, sub-watersheds BGt2, BGt5, and BGt6, which are located outside the fault influence, exhibit higher bifurcation ratio (Rb) values with a more complex drainage pattern.



Source: Author's GIS processing from RBI dataset (BIG, 2024)

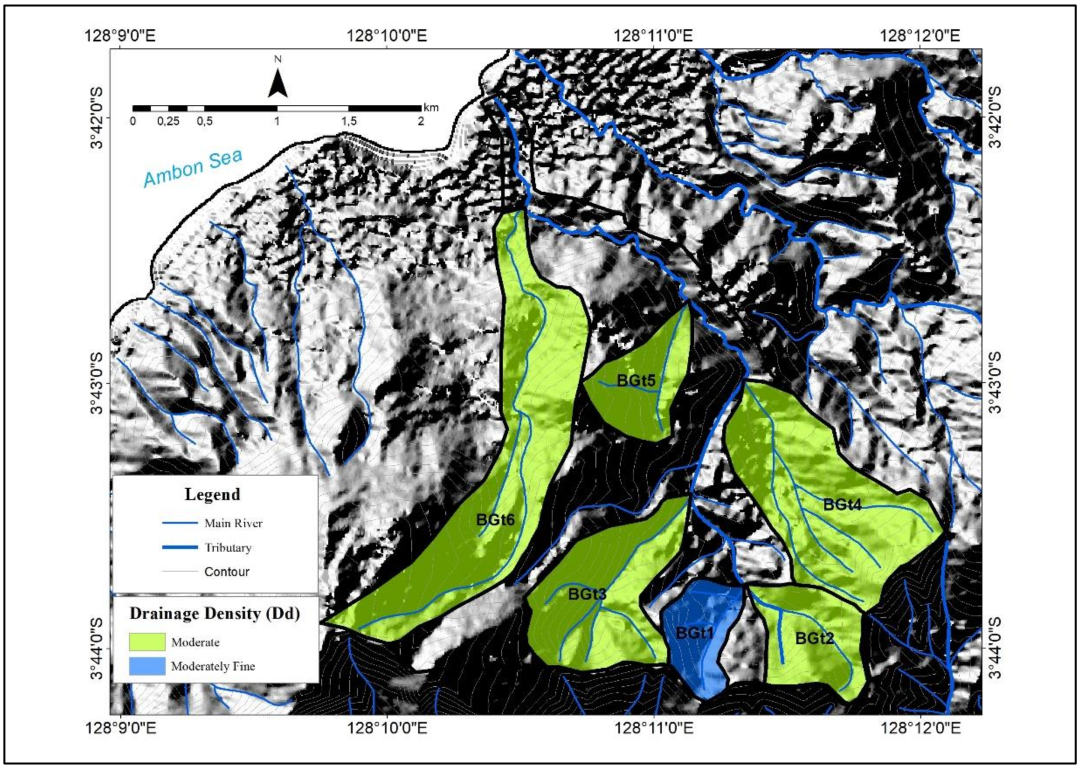
Figure 3. Regional Geological Map of the Wai Batu Gantung Watershed

- **Drainage density (Dd)**

Table 2: Drainage Density (Dd) value in Wai Batu Gantung Watershed

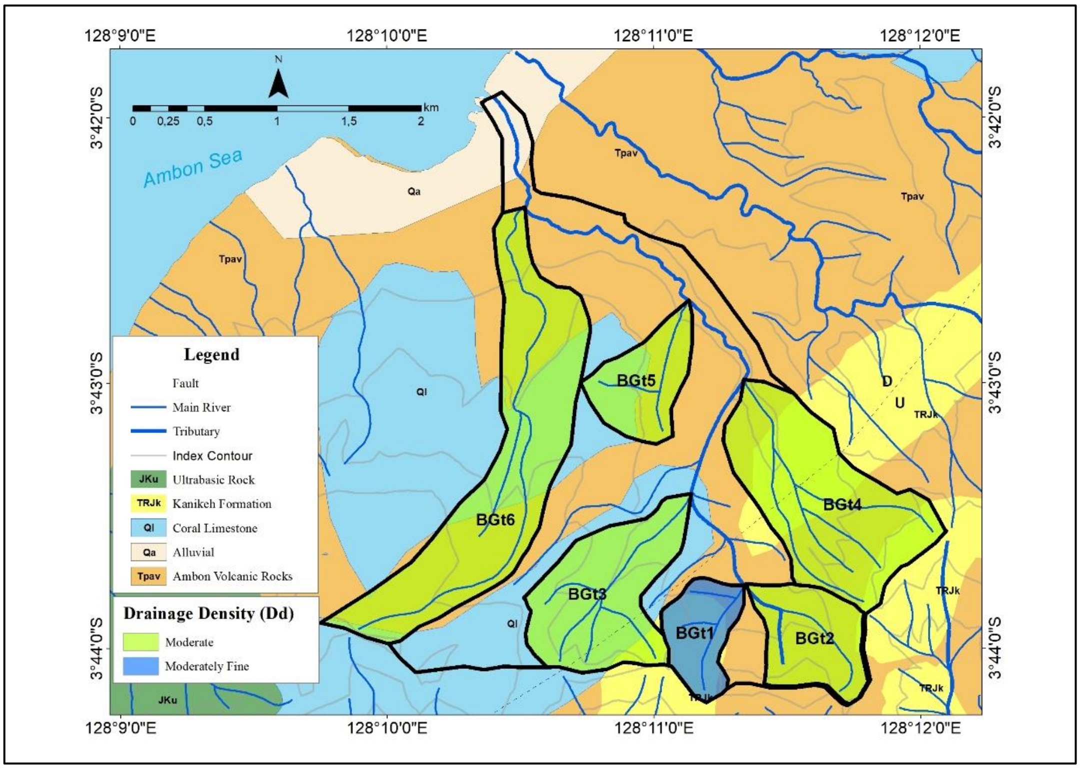
Watershed	Sub-Watershed	Total River Length	Watershed Area	Dd	Texture	Class	Lithology
Wai Batu Gantung	BGt1	1.4	0.32	4.4	Moderately Fine	4	Kanikeh Formation, Ambon Volcanic Rock
	BGt2	1.57	0.49	3.2	Moderate	3	Ambon Volcanic Rock
	BGt3	3.05	0.86	3.5	Moderate	3	Coral Limestone
	BGt4	4.73	1.23	3.8	Moderate	3	Kanikeh Formation, Ambon Volcanic Rock
	BGt5	1.4	0.42	3.3	Moderate	3	Ambon Vulvanic Rock, Coral Limestone
	BGt6	4.86	1.59	3.1	Moderate	3	Ambon Vulvanic Rock Coral Limestone

The drainage density (Dd) analysis was carried out based on the extracted river network derived from DEMNAS data, which is a medium-resolution remote sensing product capable of depicting the Earth's surface in detail. The analysis results show that the drainage density (Dd) values range from 3.1 to 4.4 (Table 2). Sub-watershed BGt1 recorded the highest value of 4.4 with a “moderately fine” classification, while the lowest value was found in BGt6 with 3.1, classified as “moderate.” The spatial distribution map of Dd (Figure 3) shows that sub-watersheds with higher values are located in the eastern part of the basin, and those in the western part tend to have lower values. When correlated with lithology (Figure 4), areas dominated by coral limestone (Qa) and the Kanikeh Formation (Trjk) tend to exhibit higher drainage density (Dd) values compared to sub-watersheds dominated by Ambon volcanic rocks (Tpav). Thus, variations in drainage density (Dd) values within the Wai Batu Gantung Watershed are influenced by lithological conditions and topographic positions, both of which jointly determine the density of the drainage network in each sub-watershed.



Source: Author's GIS processing using RBI and DEMNAS dataset (BIG, 2024)

Figure 3: Drainage Density (Dd) Distribution Map using DEMNAS



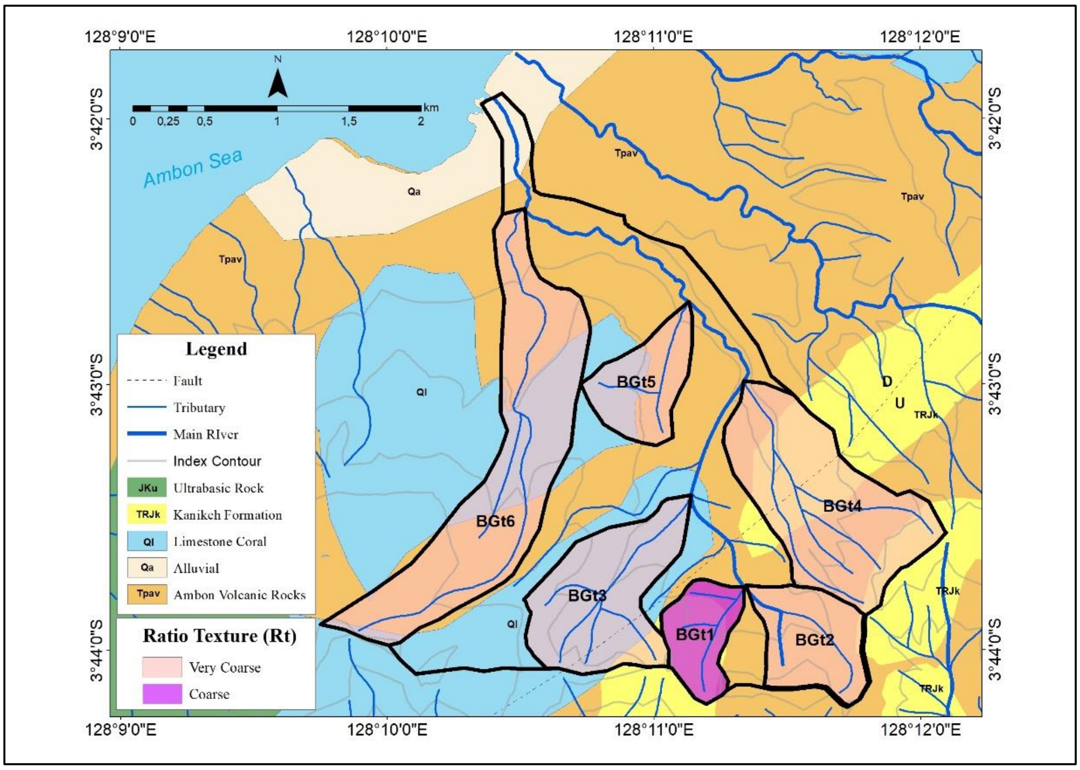
Source: Author's GIS processing from RBI dataset (BIG, 2024)

Figure 4. Drainage Density (Dd) Distribution Map with Regional Geology

- **Texture Ratio (Rt)**

Table 3: Texture Ratio (Rt) Values in the Wai Batu Gantung

Waterhsed	**Sub-Watershed**	**Number of stream segments (u+1)**		**Total**	**Perimeter**	**Rt**	**Classification**
		1	**2**				
Wai Batu Gantung	BGt1	3	2	5	2.41	2.07	Coarse
	BGt2	2	1	3	2.97	1.01	Very Coarse
	BGt3	4	3	7	4.22	1.66	Very Coarse
	BGt4	4	3	7	4.86	1.44	Very Coarse
	BGt5	2	1	3	2.78	1.08	Very Coarse
	BGt6	2	1	3	7.96	0.38	Very Coarse



Source: Author's GIS processing from RBI dataset (BIG, 2024)

Figure 5: Spatial Distribution Map of Texture Ratio (Rt) with Regional Geology

The texture ratio (Rt) values for each sub-watershed of the Wai Batu Gantung watershed range between 0.38 and 2.07 (Table 3). Based on the classification, most sub-watersheds fall into the very coarse category except BGt1 which is classified as coarse. The highest texture ratio (Rt) values are found in BGt1 and BGt3, while the lowest value occurs in BGt6. The spatial distribution map of the texture ratio (Figure 5) shows that texture ratio (Rt) variation in the Wai

Batu Gantung watershed does not follow an upstream downstream pattern but is instead influenced by the lithological characteristics and morphometric form of each sub-watershed. Higher texture ratio (Rt) values such as those in BGt1 and BGt3 occur in areas composed of Ambon volcanic rocks and coral limestone. In contrast, the lower texture ratio (Rt) value in BGt6 is associated with more compact coral limestone and a larger watershed perimeter. These differences indicate that the texture ratio (Rt) not only reflects the drainage density (Dd) network but also reveals the relationship between lithology, geological structure, and watershed shape. A high texture ratio (Rt) value represents a denser drainage pattern, whereas a low texture ratio (Rt) value indicates a sparser network with greater infiltration potential.

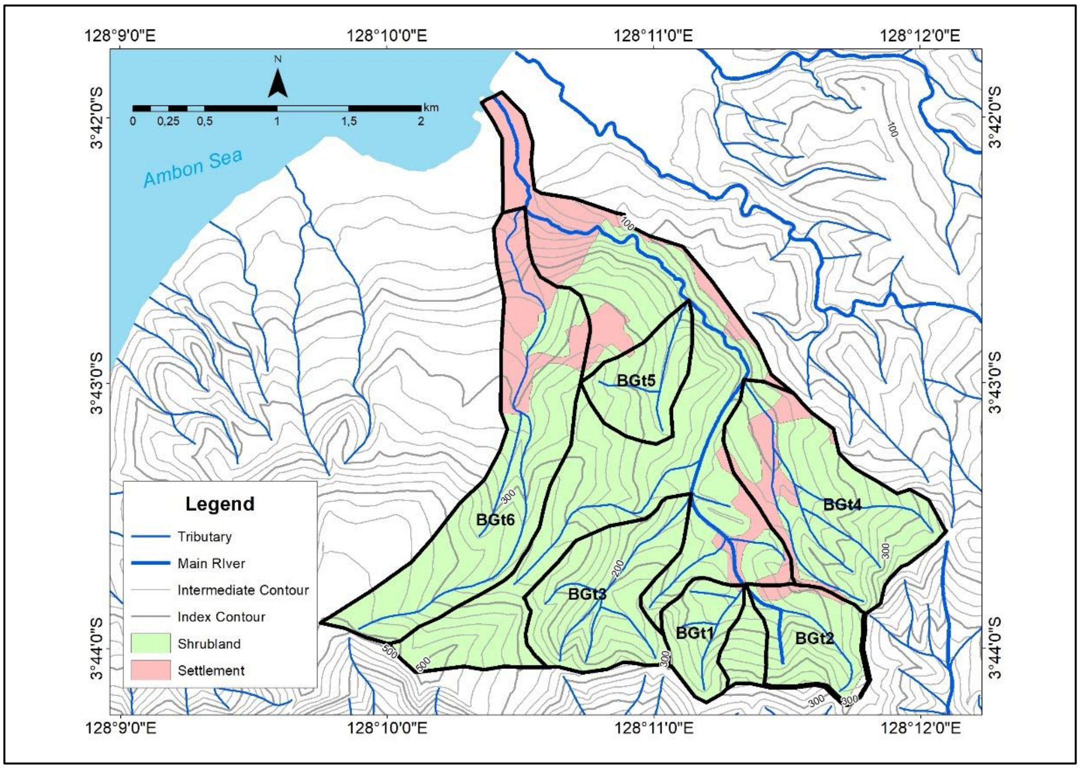
d. Land Cover Analysis

Table 4: Area and Percentage of Land Cover in the Wai Batu Gantung Watershed

Watershed	Sub-Watershed	Area (km)*	Shrulbland (Ha)	Settlement (Ha)	Shrulbland %	Settlement %	Total %
Wai Batu Gantung	**BGt1**	0.32	32.09	0.22	99.33	0.67	100
	BGt2	0.49	45.53	3.72	92.44	7.56	100
	BGt3	0.86	85.76	0.00	100.00	0.00	100
	BGt4	123	100.55	22.93	81.43	18.57	100
	BGt5	0,42	41.55	0.23	99.45	0.55	100
	BGt6	1.59	120.04	39.37	75.30	24.70	100
	**	3.26	253.38	72.87	77.66	22.34	100

Note: Area (km^2) was converted to hectares (ha) for percentage calculation purposes. Non Sub – Watershed area refers to regions within the Wai Batu Gantung watershed but not included within the boundaries of the six designated sub-Watershed (BGt1-BGt6)

Based on land cover analysis, the Wai Batu Gantung Watershed is generally dominated by shrulbland, both within and outside the six main sub-watersheds. The highest percentage of shrubland cover was found in BGt3 (100%), while the highest residential land cover was observed in BGt6 (24.59%) andBGt 4 (18.57%). Areas outside the designated sub-watersheds also exhibited significant residential pressure (22,34%), indicating that land use activities are not limited to the sub-watersheds but are also dispersed across other areas. This condition may affect the overall hydrological stability of the watershed, thus emphasizing the need for watershed management strategies that prioritizes the protection of remaining natural areas and regulate development in zones experiencing land use intensification.



Source: Author's GIS processing from RBI dataset (BIG, 2024) and land cover shp from Indonesia Geospasial 2019

Figure 6. Land Cover Map of the Wai Batu Gantung Watershed

e. Discussion

GIS based analysis reveals thath morphometric characteristic and land cover play a significant role in determining the flood potential of the Wai Batu Gantung watershed. The bifurcation ratio (Rb) ranges from 1.3 to 2.0 indicating that the drainage network is still influenced by local geological and lithological structures, particularly the Ambon volcanic rocks and the Kanikeh Formation. This suggests that the flow patterns are controlled by fractures and faults, resulting in stream orientations that generally follow existing geological structures. The drainage density (Dd) ranges from 3.1 to 4.4 km/km² which is classified as high according to Strahler (1964) and Nag & Chakraborty (2003). These values indicate a dense drainage system with a rapid hydrological response to rainfall. Sub-watersheds in the eastern part exhibit the highest drainage density (Dd) values suggesting faster surface runoff formation and an increased risk of inundation particularly in areas with moderate to steep slopes. The texture ratio (Rt) ranging from 0.38 to 2.07 falls into the "very coarse" category (Smith, 1950), reinforcing the indication of a dense drainage system. Low Rt values reflect a tendency for rapid surface flow and limited infiltration capacity thereby increasing the likelihood of runoff and erosion. The combination of high drainage density and coarse texture ratio indicates that the Wai Batu Gantung watershed responds quickly to high-intensity rainfall events. Land cover interpretation shows that the upstream region is still predominantly covered by shrubland while the middle to downstream segments especially BGt4 and BGt6 are increasingly dominated by residential development. Such land cover changes reduce the soils capacity to absorb water and accelerate surface runoff. Based on these morphometric parameters and land use conditions, the Wai Batu Gantung watershed can be categorized as having a moderate to high flood potential. This assessment is supported by Dd values exceeding 3 km/km² and Rt values below 2 which empirically indicate a rapid hydrological response to precipitation (Strahler, 1964; Smith, 1950). GIS has proven to be a valuable tool in analyzing the spatial relationships among these parameters allowing for both quantitative and visual identification of flood prone areas.

f. Conlussion

Analysis using GIS applications demonstrates that morphometric characteristics and land cover in the Wai Batu Gantung watershed significantly influence its flood potential. The combination of high drainage density (Dd), coarse texture ratio (Rt), and bifurcation ratio (Rb) reflecting geological structural control indicates a rapid hydrological response to rainfall. While much of the upstream area remains covered by natural vegetation such as shrubland, the middle to downstream regions have begun to experience an increase in residential development. This combination of dense drainage and land cover change places the Wai Batu Gantung watershed in the moderate to high flood potential category. The GIS based approach has proven effective in integrating morphometric and spatial data, enabling a quantitative assessment of flood-prone areas. These findings provide a foundation for conservation planning, controlling downstream development, and strengthening disaster mitigation policies based on watershed morphometry.
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