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Morphometric Analysis of Canggu River Basin for Flood Management

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ABSTRACT : Flood management is vital for regions like the Canggu River Basin in Bali, Indonesia, where heavy rainfall frequently causes socio-economic disruptions. This study employs morphometric analysis—a quantitative evaluation of landform characteristics to enhance understanding of the basin's hydrological behavior and inform flood management strategies. Key morphometric parameters, such as drainage density, stream frequency, and bifurcation ratio, are analyzed to predict flood zones and identify contributing factors to flooding, including urbanization and climate change impacts. The research utilizes data collected from the Canggu River Basin, employing GIS tools to quantify morphometric parameters. Key metrics include the bifurcation ratio, stream order, stream length, stream frequency, drainage texture, form factor, circularity ratio, relief ratio, and overland flow length. Analytical methods calculate relationships between these parameters and their implications for flood dynamics, focusing on the structure of the stream network and its capacity for runoff collection. The result reveal a moderate bifurcation ratio (Rb = 1.91), indicating a stable stream network with potential flood risks due to simultaneous contributions from multiple tributaries. Shortened stream lengths in higher orders may delay flood responses, while high stream frequency and drainage texture suggest increased flash flood potential. The elongated basin shape contributes to prolonged flood durations, and gentle slopes reduce runoff speed, indicating a need for targeted flood management strategies. Recommendations include creating detention basins, modifying channels, implementing early warning systems, and enhancing water retention strategies to mitigate flood risks and improve resilience in the Canggu River Basin.

KEYWORDS: Morphometric, flood, river, management.

I. INTRODUCTION

Flood management is a critical concern for regions prone to heavy rainfall and river overflow [1], [2]. The Canggu River Basin, situated in a densely populated area of Bali, Indonesia, frequently experiences flooding, leading to significant socio-economic disruptions. Effective flood management strategies necessitate a comprehensive understanding of the river basin's characteristics. Morphometric analysis, which quantitatively evaluates the earth's surface and the shape of its landforms, is an essential tool in this regard [3], [4]. This research focuses on the morphometric analysis of the Canggu River Basin to inform and enhance flood management practices. Morphometric analysis provides valuable insights into the hydrological behavior and flood potential of a river basin. By examining various morphometric parameters—such as drainage density, stream frequency, bifurcation ratio, and watershed shape—researchers can predict flood zones and develop appropriate mitigation measures. Understanding these parameters helps identify the underlying factors contributing to flooding, including slope, land use, and soil type.

Several studies underscore the importance of morphometric analysis in flood management. Foundational work by Horton [5] and Strahler [6] established key principles for defining and calculating morphometric parameters. More recent studies have successfully applied these principles to river basins worldwide, demonstrating their utility in flood prediction and management. The Canggu River Basin faces heightened flood risks due to urbanization, deforestation, and climate change, particularly in its rapidly developing urban environment. The region's varied topography, characterized by differing elevations and steep slopes, complicates flood management efforts. However, a lack of comprehensive morphometric studies specific to this basin limits the effectiveness of current flood mitigation strategies. The Canggu River Basin flows into the Yeh Luwi estuary, where the overflowing Yeh Luwi River has caused significant erosion, sweeping away approximately 50 ares of Berawa Beach [7]. The severity of abrasion was particularly acute in 2023, driven by climate change and the shifting mouth of the Yeh Luwi estuary. To date, no effective management or regulation has addressed this situation, leading to ongoing sedimentation and minor abrasion exacerbated by the shifting estuary mouth. Flooding poses a critical challenge globally [8], [9], impacting socio-economic stability, environmental sustainability, and public safety.

Recent extreme weather events, compounded by climate change, have intensified flooding risks in many regions, including the Canggu River Basin. Here, rapid urbanization—driven by tourism, agriculture, and real estate development—has increased the area's vulnerability to flooding. The basin's diverse topography, encompassing hills, valleys, and coastal regions, influences its hydrological dynamics, necessitating a thorough understanding of how these geographical features interact with human activities. Morphometric analysis offers a robust framework for examining the complex dynamics of river basins. By quantitatively assessing parameters such as basin area, slope, stream length, drainage density, and land cover, researchers can glean insights into the hydrological processes that drive flood occurrences and severity. For instance, high drainage density may indicate an increased potential for flooding, while steep slopes can result in rapid runoff and heightened flood risks. This analytical approach allows for the identification of critical zones within the basin that may contribute to flood risk, facilitating targeted intervention strategies tailored to the unique characteristics of the Canggu River Basin.

Despite existing flood management efforts, significant gaps remain in understanding the morphometric factors underlying flood risks in the Canggu River Basin. Current management practices often overlook these specific contributions, leading to a mismatch between flood risk reduction strategies and the basin's actual hydrological behavior. A benefit gap analysis reveals that while infrastructure such as retention basins and drainage systems exists, its effectiveness is undermined by a lack of comprehensive data on the basin's morphometry. Historical flooding incidents may not be adequately addressed if existing infrastructure does not account for changes in land use or increased precipitation patterns, resulting in inefficiencies and increased vulnerability during flood events. The primary aim of this research is to conduct an in-depth morphometric analysis of the Canggu River Basin to identify and quantify the key factors influencing flood dynamics. By employing advanced analytical techniques and GIS tools, this study will map and analyze various morphometric parameters, providing a detailed assessment of the basin's hydrological behavior. The study seeks to bridge existing knowledge gaps by delivering actionable insights into how specific morphometric characteristics impact flood risk and resilience. Furthermore, it aims to propose evidence-based recommendations for sustainable flood management practices that integrate local knowledge, traditional wisdom, and contemporary engineering approaches. By enhancing the resilience of the Canggu River Basin against flooding, this research aspires to contribute to the safety and sustainability of the region while fostering community engagement and participation in flood management initiatives.

II. RESEARCH METHODS

Research Location : This research was located in Canggu River Basin which is located in the Tibubeneng area, North Kuta District, Badung Regency, Bali. The location is close to Berawa Beach which is a tourist destination in the surrounding area as seen in Figure 1.

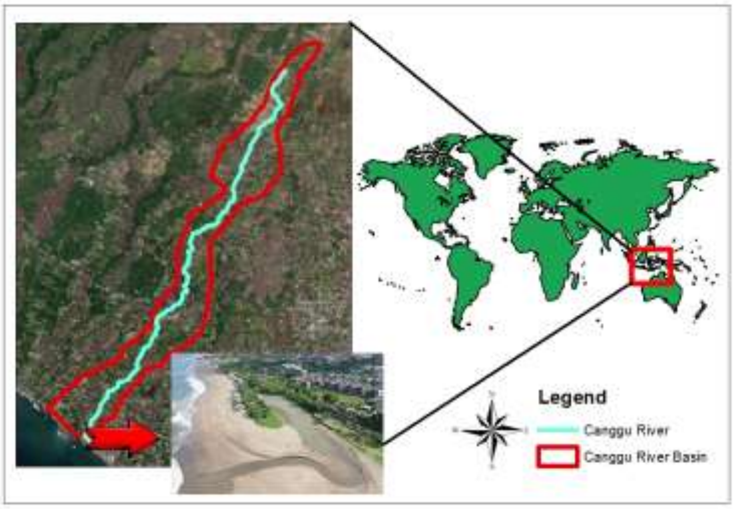

Figure 1 Research Location

Research Data : This study collected data on various morphometric parameters of a river system to understand their implications for flood management. Key metrics included the bifurcation ratio (Rb) indicating branching in the stream network. Data was also gathered on stream order and stream length (Lu), with lower-order streams progressively longer than higher-order ones, suggesting delayed runoff concentration. The stream length ratio (RL) showed a negative trend for third and fourth-order streams, meaning these streams are shorter than expected and may contribute to prolonged flooding post-peak discharge. Other important parameters included stream frequency (Fs) and drainage texture (Rt), measured at both indicating a finely textured drainage network that can quickly collect runoff, increasing the flash flood potential. The form factor (Rf) and circularity ratio (Rc) indicate an elongated basin shape, which delays peak discharge but may extend the duration of flood events. The relief ratio (0.020) and overland flow length (Lg) of were also recorded, providing insights into the slow runoff speed and potential for prolonged flooding.

III. RESEARCH ANALYSIS METHODS

The research analyzed the collected morphometric data by calculating relationships between each parameter and its potential impact on flood management. For instance, the bifurcation ratio was determined by dividing the number of streams in one order by the number in the next higher order, helping to understand the branching structure's stability. Stream length ratios were computed by comparing the lengths of streams in successive orders, highlighting how the shortening of higher-order streams could delay flood responses. Stream frequency and drainage texture were assessed by measuring the density of streams within a specific area, which helped evaluate the network's capacity to collect runoff and the flash flood risks. Basin shape parameters like the form factor, circularity ratio, and elongation ratio were used to assess how water moves through the basin and its effect on flood timing and duration. Relief characteristics, such as the relief ratio and length of overland flow, were analyzed to estimate how terrain slopes influence the speed and volume of water flowing into the river system. Finally, the study linked these morphometric characteristics with flood management strategies by identifying critical areas for intervention, such as the need for upstream detention basins, channel modifications, and early warning systems to mitigate flood risks. Each analysis helped recommend suitable flood control measures tailored to the specific geomorphological features of the river basin.

IV. RESULT AND DISCUSSION

The morphometric characteristics of the river system have important implications for flood management strategies [10], [11], [12], [13]. The shape, relief, and drainage patterns significantly affect how floodwaters are generated, transported, and discharged within the basin.

Bifurcation Ratio (Rb) and Stream Network Structure : The average bifurcation ratio (Rb) of 1.91 is relatively low (Table 1), indicating a moderate degree of branching in the stream network [14], [15], [16]. A lower bifurcation ratio suggests a more stable geological structure and less structural control on drainage development. This indicates that the drainage system is moderately affected by tectonic activity and is less likely to experience abrupt changes in its pattern. The bifurcation ratio (Rb) of 1.91 indicates a moderately branched stream network. In terms of flood management, a lower bifurcation ratio suggests that the river has fewer, longer streams, which can delay the concentration of floodwaters, thus reducing the risk of flash floods. However, this moderate branching also means that during prolonged rainfall events, multiple tributaries can contribute to the main river simultaneously, potentially increasing flood volume over time. Flood management should focus on monitoring key tributaries, especially during extended rainfall periods, to predict peak discharges and mitigate downstream flooding. Early warning systems in higher-order streams can help manage flood risks as water accumulates.

Table 1. Bifurcation Ratio (Rb)

Stream order	Total no. of stream segments of order 'u' (Nu)	Bifurcation ratio (Rb)
1	143	
2	63	2.27
3	37	1.70
4	21	1.76
Average		1.91

Stream Length (Lu) and Stream Length Ratio (RL)

The progressive shortening of stream lengths (Lu) from lower to higher orders means that lower-order streams (first and second order) will collect runoff from localized areas and feed it into larger, higher-order streams. The negative stream length ratio (RL) for third and fourth-order streams indicates that these streams are shorter than expected [4], [17], which could cause the river to respond more slowly to rainfall, potentially leading to prolonged flooding after peak discharge. Flood management strategies should include channel modification and restoration projects to enhance the capacity of higher-order streams to hold floodwaters. Extending and deepening these channels might improve water retention and reduce the duration of flood peaks.

Stream Frequency (Fs) and Drainage Texture (Rt) : The high stream frequency (34.43 streams/km²) and drainage texture (790.84 streams/km) indicate a highly dissected and fine-textured drainage system, which can quickly collect runoff from rainfall. While this efficient collection reduces the time for runoff to reach the river, it also increases the risk of flash flooding, especially in steep areas where water can accumulate rapidly. To manage flash flood risks, flood management practices should emphasize upstream detention basins, storage ponds, and check dams to temporarily hold floodwaters. These structures can reduce peak flows by allowing water to slowly infiltrate or be released downstream in a controlled manner.

Form Factor (Rf), Circularity Ratio (Rc), and Elongation Ratio (Re) : The elongated basin shape, as reflected by a form factor of 0.18 and circularity ratio of 0.18, suggests that floodwaters take longer to reach the main channel, delaying the peak discharge during storm events. While this reduces the risk of sudden flash flooding, it increases the potential for longer-duration floods. Water might continue to drain into the main river over extended periods, maintaining high water levels even after the rainfall has ended. Flood management strategies should focus on maintaining and enhancing floodplain areas to store excess water during long flood events. Wetlands, retention ponds, and floodplain zoning can help store floodwaters temporarily and reduce downstream impacts.

Relief Characteristics and Overland Flow (Lg) : The low relief ratio (0.020) and gentle slopes reduce the speed at which water travels overland, causing slower but sustained runoff. While this may lower the intensity of floods, it can lead to longer-lasting flood events, especially in flatter regions of the basin. The length of overland flow (0.37 km) also means that water has a relatively short distance to travel before entering the stream network, which contributes to quicker runoff but slower recession of floodwaters. In flood management, maintaining or creating buffer zones along streams and flood-prone areas can help slow down the movement of floodwaters. Vegetation and permeable surfaces in these zones can enhance infiltration and reduce the volume of surface runoff, helping mitigate prolonged flooding events.

Predicted Drought Conditions: The morphometric characteristics, particularly the high drainage density and elongated basin shape, suggest that the system may also be vulnerable to drought. While floodwaters may recede slowly, water retention within the basin is not efficient, leading to dry conditions once the floodwater drains. This cyclic behavior of rapid flooding followed by slow drought conditions requires a careful balance in flood management. Flood management should therefore integrate water retention strategies that are effective not only for flood control but also for water conservation during dry periods. Constructing rainwater harvesting systems, increasing groundwater recharge through permeable surfaces, and using aquifer storage and recovery techniques can ensure that floodwaters are used to recharge groundwater supplies for use during droughts.

Young Geomorphic Stage and River Behavior : The geomorphological immaturity, indicated by the negative stream length ratio (RL) and classification as a young geomorphic system, means that the river's response to rainfall can be rapid and erratic. The quick rise in water levels during floods followed by slow drainage makes flood management more challenging, as the system is not yet in equilibrium. Over time, natural processes may lead to the stabilization of the stream network, but until then, flood behavior may be unpredictable. Flood management should be adaptive, with a focus on building flexible infrastructure that can handle both extreme floods and prolonged dry periods. Regular monitoring of the river's geomorphological changes, combined with adaptive management approaches, will be crucial in mitigating flood risks in the future.

Recommendations for Flood Management : To effectively manage floods, several strategies should be considered. Flood storage through the creation of detention basins, retention ponds, and wetlands is essential [3][18]. These structures slow down floodwaters and store excess water during flood events, helping to reduce peak flows and prevent downstream flooding. Channel modification is another important measure; widening or deepening the channels of higher-order streams can increase their capacity to hold floodwaters, minimizing the risk of prolonged flooding and improving overall drainage efficiency. Floodplain zoning is critical for restricting development in flood-prone areas, allowing natural floodwater storage in open spaces, which can significantly mitigate flood risks. Vegetative buffer zones along streams can further aid in flood control by reducing runoff velocity, enhancing infiltration, and minimizing the volume of surface water entering the river system. These buffers also contribute to the ecological health of the area. The implementation of early warning systems is crucial for effective flood management. By developing real-time flood monitoring and prediction systems, authorities can better prepare for and respond to flood events, especially during periods of extended rainfall. Finally, integrated water management strategies that address both flood control and water conservation are essential. This includes measures like aquifer recharge, which help mitigate flood impacts while ensuring sustainable water availability during dry periods, offering a balanced approach to water resource management.

V. CONCLUSION

This study show the critical role of morphometric analysis in understanding the hydrological behavior of the Canggu River Basin and its implications for flood management. The findings indicate that the basin's morphometric characteristics such as a moderate bifurcation ratio, shortened stream lengths in higher orders, high stream frequency, and an elongated basin shape significantly influence flood dynamics. These features contribute to both the rapid onset of flooding during heavy rainfall and the prolonged duration of flood events, emphasizing the need for tailored management strategies. Effective flood management must address the unique geomorphological traits of the Canggu River Basin. Recommended strategies include the establishment of detention basins and retention ponds to slow floodwaters, channel modifications to enhance drainage capacity, and the implementation of early warning systems for timely responses to flood risks. Additionally, integrating water conservation measures, such as aquifer recharge and vegetative buffer zones, can promote sustainable water management while mitigating the impacts of both flooding and drought. Ultimately, this research underscores the necessity of a comprehensive approach to flood management that incorporates local knowledge, traditional wisdom, and modern engineering practices. By enhancing the resilience of the Canggu River Basin against flooding, we can better safeguard the socio-economic stability and environmental sustainability of the region, fostering community engagement in flood management initiatives.

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