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Analysis Flow Velocity and Flow Type Characterization of Noelmina River (Case Study: KM 62.3 Timor Raya Road)

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Abstract

Background: River flow characteristics play a crucial role in controlling erosion processes, especially in river segments adjacent to infrastructure. The Noelmina River at Km 62.3 Timor Raya Road experiences repeated bank erosion that threatens road stability and nearby public facilities.
Objective: This study aims to analyze flow velocity, determine flow characteristics using the Froude and Reynolds numbers, and recommend appropriate riverbank protection structures to reduce erosion risk.
Methods: A quantitative field survey was conducted at three observation points (upstream, bend, and downstream). Flow velocity was measured using a current meter at different depth intervals. Hydraulic characteristics were analyzed using average velocity calculations, the Froude number for flow regime classification, and the Reynolds number for flow-type determination.
Results: The average flow velocities were 2.298 m/s (Point 1), 1.686 m/s (Point 2), and 1.062 m/s (Point 3), showing a decreasing trend along the river segment. All Froude numbers were below 1, indicating subcritical flow conditions. Reynolds number analysis showed transitional flow at Points 1 and 2, and laminar flow at Point 3. Higher velocities at the river bend indicate greater erosion potential.
Conclusion: The river exhibits subcritical flow with varying transitional and laminar characteristics. Recommended mitigation measures include gabions, interlocking concrete blocks, retaining walls, and weirs to reduce flow energy and prevent further bank erosion.

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INTRODUCTION

A river is an open channel with geometric dimensions, namely cross-section, longitudinal profile, and valley slope, that change over time depending on discharge, bed material, and banks (Basruddin, 2026; HEC-RAS, 2022; Putra et al., 2025). Every river has different characteristics and forms; this is caused by many factors, including topography, climate, and natural processes involved in their formation (Mananoma et al., 2025).

A river system is an organized and complex system in which all components interact with one another (Padang, 2024; Syaferi et al., 2019). Rivers generally exhibit a characteristic feature: changes in the morphology of their cross-sectional shape. These changes can result from both natural and human factors. The dynamic nature of rivers over time can cause damage to surrounding structures (HEC-RAS, 2022; Putra, 2014).

Indonesia is a country with numerous river basins (DAS) spread across all its islands (Ekawaty et al., 2018; Hadi, 2020; Khalis et al., 2025). According to the Ministry of Public Works Regulation No. 11A/PRT/M/2006, there are five classifications of river basins comprising 133 river basins in Indonesia. A river basin is a land area that forms a single unit with a river and its tributaries, functioning to collect, store, and naturally convey rainfall runoff to lakes or the sea; its land boundaries are defined by topographic features, while its marine boundaries extend to coastal waters still influenced by land-based activities. Therefore, optimal management of river basins is essential for community benefits across multiple aspects of life, such as irrigation and raw water supply (Atmajayani, 2022). One component of river basin management is the management of rivers or tributaries within that basin. River management is regulated under Government Regulation No. 38 of 2011 on rivers, which covers river conservation, river development, and river damage control (Bambang, 2026; Firdaus, 2021; Putra, 2016).

Scouring is a natural phenomenon caused by erosion from water flow on the bed and banks of alluvial channels; it is also the process of the riverbed being lowered below its natural surface elevation due to the interaction between flow and bed material (Negara et al., 2020; Pandra, 2023). Local scouring is a natural process occurring in rivers due to channel morphology or the presence of hydraulic structures obstructing flow. Therefore, scouring processes must be studied to determine appropriate control methods so that constructed structures can withstand potential damage (Tarigan, 2022).

Changes in river flow characteristics are phenomena influenced by hydrological conditions, topography, rainfall, land use, and human activities within the watershed (DAS). High rainfall intensity can significantly increase discharge, leading to changes in flow velocity and river energy distribution. These conditions may cause riverbed and bank erosion, sedimentation, and gradual morphological changes. Continuous morphological changes can threaten the stability of civil structures near rivers, such as highways, bridges, and residential areas. Therefore, river hydraulic analysis is crucial for understanding flow behavior as a basis for planning river damage control.

Flow velocity is one of the primary parameters in river hydraulics because it directly influences sediment transport capacity, erosion rates, and deposition patterns on the riverbed (Graf, 1998; Te Chow, 2009; Zhang et al., 2025). Understanding flow velocity distribution is essential for predicting morphological changes and designing effective river protection structures. According to Julien (2018), accurate velocity measurement using instruments such as current meters provides fundamental data for hydraulic modeling and erosion risk assessment (Chen et al., 2022). Higher flow velocity increases shear stress acting on the riverbed and banks, thereby increasing the risk of scouring. Conversely, low-velocity flow tends to promote sedimentation due to reduced transport capacity. Velocity distribution at different depths also shows distinct hydraulic behavior, making current meter measurements necessary for accurate flow characterization.

In addition to flow velocity, flow characteristics can also be determined using the Froude number and Reynolds number approaches. The Froude number is used to identify subcritical, critical, or supercritical flow conditions based on the relationship between inertial and gravitational forces. Meanwhile, the Reynolds number describes whether the flow regime is laminar, transitional, or turbulent. Information on these two parameters is crucial in designing river control structures because each flow type has different potential for damage and erosion mechanisms. Analysis of flow characteristics serves as a foundation for determining effective and sustainable riverbank protection designs.

Several previous studies have shown that variations in flow velocity in specific river segments are closely related to cross-sectional shape, river meandering, and bed material conditions. A study by Junaidi (2014) found that flow velocity increases in narrowed cross-sections, triggering local scouring (Putri et al., 2024). Research by Kasianop (2025) also states that flow velocity variations affect riverbank stability and sedimentation potential. These findings highlight the importance of site-specific evaluation of hydraulic conditions to ensure appropriate river management strategies.

In the Noelmina River, road sections directly adjacent to the river flow make infrastructure highly vulnerable to damage caused by bank erosion, particularly during increased discharge in the rainy season. Direct interaction between river flow and surrounding road structures exerts continuous hydraulic pressure on the banks, accelerating soil erosion and potentially causing slope instability. Recurrent road foundation subsidence indicates a strong relationship between flow characteristics and infrastructure stability. Without adequate flow control, the risk of structural damage will continue to increase, especially in river segments with high velocity and significant erosion rates.

The novelty of this research lies in its integrated approach combining flow velocity measurement, Froude number analysis, and Reynolds number classification at multiple observation points along a river bend, specifically applied to the Noelmina River where critical infrastructure is directly threatened. Unlike previous studies that examined these parameters separately, this research integrates all three analyses to formulate site-specific riverbank protection recommendations. Therefore, this study is crucial not only to comprehensively understand hydraulic conditions but also to provide technical recommendations for river control. The results can be used to determine suitable protection structures such as gabions, interlocking concrete blocks, retaining walls, or weirs as energy dissipators. With appropriate implementation, erosion rates can be reduced, riverbank stability improved, and the sustainability of surrounding infrastructure maintained.

The Noelmina River is one of the largest river basins on the island of Timor, carrying water from the northern to the southern part of the island. The Noelmina River basin covers an area of 1,969.28 km^2, with a river length of 114.71 km and a radial basin pattern (Kasianop & Irawan, 2025).

At the 62.3 km mark, one of the Noelmina River's tributaries runs directly alongside the Trans Timor transportation route, which is the sole road connecting several regencies in West Timor, including Kupang City, Kupang Regency, South Central Timor Regency, North Central Timor Regency, Belu Regency, Malaka Regency, and the neighboring country of Timor-Leste.

At Km 62.3 of Timor Raya Road, slope erosion consistently occurs due to the impact of river flow during heavy rainfall upstream. This erosion affects the stability of road infrastructure located adjacent to the river, specifically at Km 62.3. This road section has experienced repeated foundation subsidence and repairs; however, subsidence continues, particularly during high-flow conditions. The location of the road on a river bend further exacerbates the damage. Additionally, an educational facility, State Elementary School 2 Bokong, is located nearby, with its rear building directly adjacent to the riverbank and increasingly threatened by ongoing erosion. This damage occurs annually during the rainy season.

The objective of this study is to analyze flow velocity, classify river flow types, and determine the most appropriate river control structures to mitigate bank erosion. Flow velocity analysis is used to determine the distribution of flow energy across river segments, serving as a key indicator of erosion potential. In addition, identifying flow types is necessary to understand hydraulic behavior (whether laminar, transitional, or turbulent) which influences riverbank stability. Based on these analyses, this study proposes technical recommendations for river control structures such as gabions, interlocking concrete blocks, retaining walls, and groynes, which function to dissipate flow energy and improve bank stability. Thus, the results are expected to support effective and sustainable river erosion mitigation planning and infrastructure protection.

METHOD

This research employed a quantitative descriptive approach with a field survey research design. The study was conducted along the Noelmina River channel at Km 62.3 of Timor Raya Road during the dry season (August 2025) to ensure stable flow conditions for measurement. The river segment was divided into three observation points: Point 1 (before the river bend), Point 2 (at the river bend), and Point 3 (after the river bend). At each of the three observation points, flow velocity measurements were conducted using a Current Meter (type: Price AA Current Meter) at three vertical depths: 0.2d, 0.6d, and 0.8d from the water surface. Each measurement was repeated three times to ensure data reliability, and the average value was recorded. The Current Meter was used to measure flow velocity at each measurement point. Measurements were taken at various depths to obtain the vertical distribution of flow velocity. Field data collection was conducted on August 12-14, 2025, during the dry season with stable base flow discharge conditions. The water temperature at the time of measurement was recorded at 30°C. River discharge conditions during measurement represented low to moderate flow, which is typical for the dry season in the Noelmina River basin. The data collection techniques used include: Flow Velocity Measurement with a Current Meter was used to measure water flow velocity at several points along the river segment.

Figure 1. *Layout of the Noelmina River and Measurement Points 1, 2, and 3*

Data Collection Method

The method for collecting flow velocity data used a current meter. The width of the water section to be measured by the current meter was first determined and then divided into three parts: the left side, the middle, and the right side. The water depth was measured, and the depth points where flow velocity would be measured were identified. Once the water depth was known, measurements were taken at various depths according to the Table 1.

Table 1. *Measurements at Different Depths*

River Depth (m)	Measurement Depth	Average Speed Calculation
0 - 0.6	0.6h	V = V0.6
0.6 – 3.0	0.2h and 0.8h	V = 0.5 (V0.2 + V0.8)
3.0 – 6.0	0.2h, 0.6h, and 0.8h	V = 0.25 (V0.2 + V0.6 + V0.8)
6.0	0.2h, 0.6h, 0.8h, and b	V = 0.1 (Vs + 3V0.2 + V0.6 + 3V0.8 + Vb)

Source: Survey Results

RESULTS AND DISCUSSION

Results

In this calculation analysis, the researcher divided the cross-section into three sections: Point 1 before the river bend, Point 2 at the river bend, and Point 3 after the river bend. One cross-section in each section was used as the reference for calculation data because it had the highest depth and velocity compared to with other cross-sections in each respective section. Mapping of the flow velocity distribution was performed on each segment of the river basin (see Table 2).

Table 2. *Results of Flow Velocity Measurements Using a Current Meter*

Observation Point	Point 1	Point 2	Point 3
0.2 h	0.8 m/s	0.5 m/s	0.3 m/s
0.6 h	0.6 m/s	0.6 m/s	0.3 m/s
0.8 h	0.4 m/s	0.4 m/s	0.2 m/s

Source: Survey Results

Analysis of flow velocity at Point 1
Velocity at Point 1 at a depth of 0.2h = < 0.6 Average velocity A = V × 0.6 × h
Average velocity = V × 0.6 × h = 0.096 m/s
Velocity at Point 1 at a depth of 0.6h = V = 0.5 (V0.2 + V0.8)
Average velocity = 0.5 (V0.2 + V0.8) = 3 m/s
Velocity of point 1 at depth 0.8h = V = 0.5 (V0.2 + V0.8)
Average velocity = 0.5 (V0.2 + V0.8) = 3.8 m/s

Analysis of flow velocity at Point 2
Velocity at point 1 at a depth of 0.2h = < 0.6 Average velocity A = V0.6 h
Average velocity = V × 0.6 × h = 0.06 m/s
Velocity at point 1 at a depth of 0.6h = V = 0.5 (V0.2 + V0.8)
Average velocity = 0.5 (V0.2 + V0.8) = 3 m/s
Velocity of point 1 at depth 0.8h = V = 0.5 (V0.2 + V0.8)
Average velocity = 0.5 (V0.2 + V0.8) = 2 m/s

Analysis of Flow Velocity at Point 3
Velocity at point 1 at a depth of 0.2h = < 0.6 Average velocity A = V0.6 h
Average V = V × 0.6 × h = 0.036 m/s
Velocity at point 1 at a depth of 0.6h = V = 0.5 (V0.2 + V0.8)
Average velocity = 0.5 (V0.2 + V0.8) = 3 m/s
Velocity of point 1 at depth 0.8h = V = 0.5 (V0.2 + V0.8)
Average V = 0.5 (V0.2 + V0.8) = 0.15 m/s

Calculation of Average Velocity at Point 1
Average velocity at Point 1
V = (V1 + V2 + V3)/3
= (0.096 + 3 + 3.8) / 3
= 6.896 / 3
= 2.298 m/s

Calculation of Average Velocity at Point 2
Average V at Point 2
V = (V1 + V2 + V3)/3
= (0.06 + 3 + 2) / 3
= 1.686 m/s

Calculation of Average Speed at Point 3
Average V at Point 3
V = (V1 + V2 + V3)/3
= (0.036 + 3 + 0.15) / 3
=1.062 m/s
From the analysis results, the fastest flow occurs at Point 1.

Determining Flow Characteristics and Types
To determine the type of flow at each point, the Froude number and Reynolds number can be used. The Froude number can be calculated using the equation:
Determining the Flow Type at Point 1
Length 50 m
Width 65.9 m
Area 3295 m^2
Flow Rate Q = V × A
Flow velocity 0.2 h = 0.8 m/s
Q = 0.8 × 3295
= 2,636 m^3/s

Froude number : $\frac{V}{\sqrt{(gy)}} = \frac{0.8}{\sqrt{(9.8 \; x \; 65.9)}}$ = 0.0314
Temperature (T) : 30°C
Velocity (V) : 0.8 m/s (the highest value is used)
Characteristic Length : 50 m

Kinematic viscosity depends on the temperature of a fluid. Kinematic viscosity can be calculated using the formula
$\nu = (1.14 - 0.031(T° - 15) + 0.00068\ (T° - 15)^2)^{10^{-6}}$
$\nu = (1.14 - 0.031(30° - 15) + 0.00068\ (30° - 15)^2)\ ^{\times 10^{-6}}$
$\nu = (12.45 + 0.153)\ ^{\times}\ 10^{-6}$
$\nu = 12.603 \times 10^{-6} m^2/s$
Reynolds number (Re) : $\frac{V.L}{\nu}$

: $\frac{0.8 \; x \; 50}{12.603.10-6}$
: $\frac{40}{0.012603}$
: 3173.847

Determination of Flow Type at Point 2
Length 50 m
Width 32.25 m
Area 1,762.5 m^2
Flow Rate Q = V × A
Review 0.6 h = 0.6 m/s
Q = 0.6 × 3295
= 1056 m^3/s
Froude number : $\frac{V}{\sqrt{(gy)}} = \frac{0.6}{\sqrt{(9.8 \; x \; 32.25)}}$ = 0.0337

Temperature (T) : 30°C
Velocity (V) : 0.6 m/s (taken as the maximum)
Characteristic Length : 50 m

The kinematic viscosity depends on the temperature of a fluid. Kinematic viscosity can be calculated using the formula
$\nu = (1.14 - 0.031(T° - 15) + 0.00068\ (T° - 15)^2)^{10^{-6}}$
$\nu = (1.14 - 0.031(30° - 15) + 0.00068\ (30° - 15)^2)\ ^{\times 10^{-6}}$
$\nu = (12.45 + 0.153)\ ^{\times}\ 10^{-6}$
$\nu = 12.603 \times 10^{-6} m^2/s$
Reynolds number (Re) : $\frac{V.L}{\nu}$
: $\frac{0.6 \; x \; 50}{12.603.10-6}$
: $\frac{30}{0.012603}$
: 2,380.386

Determination of Flow Type at Point 3
Length 50 m
Width 45.9 m
Area 2295 m^2
Flow Rate Q = V x A
Slope 0.6 h = 0.3 m/s
Q = 0.3 × 2295
= 688.5 m^3/s

Froude number : $\frac{V}{\sqrt{(gy)}} = \frac{0.3}{\sqrt{(9.8 \times 45.9)}} = 0.0141$
Temperature (T) : 30°C
Velocity (V) : 0.8 m/s (taken as the maximum)
Characteristic Length : 50 m

The kinematic viscosity depends on the temperature of a fluid. Kinematic viscosity can be calculated using the formula
$\nu = (1.14 - 0.031(T° - 15) + 0.00068\,(T° - 15)^2)10^{-6}$
$\nu = (1.14 - 0.031(30° - 15) + 0.00068\,(30° - 15)^2) \times 10^{-6}$
$\nu = (12.45 + 0.153) \times 10^{-6}$
$\nu = 12.603 \times 10^{-6} m^2/s$
Reynolds number (Re) : $\frac{V.L}{\nu}$
: $\frac{0.3 \times 50}{12.603.10-6}$
: $\frac{15}{0.012603}$
: 1190.193

Discussion

From the analysis of the average river flow velocity at the three observation points, different velocity values were obtained. The average velocity at Point 1 is 2.298 m/s, at Point 2 is 1.686 m/s, and at Point 3 is 1.062 m/s. The highest flow velocity occurs at Point 1. This condition may be caused by a steeper riverbed slope, a narrower flow cross-sectional area, or relatively low flow resistance, allowing water to move faster. High-velocity flow possesses greater energy and can induce erosion of the riverbed and banks. At Point 2, the flow velocity decreases to 1.686 m/s, indicating a change in hydraulic conditions, particularly a wider cross-sectional area. Meanwhile, the lowest flow velocity occurs at Point 3, at 1.062 m/s. This condition indicates lower flow energy compared to the other points, likely due to a flatter and wider river section. These velocity distribution patterns are consistent with findings by Putra (2014) on the Musi River, where velocity increases in narrower cross-sections and decreases in wider segments (Tarigan, 2022). However, the velocity magnitudes in the Noelmina River are notably lower than those reported by Tarigan (2022) on the Tuntungan River, which may be attributed to differences in riverbed slope and channel roughness. The decreasing velocity trend from Point 1 to Point 3 also aligns with the hydraulic principle described by Te Chow (2009), where flow energy dissipates as the channel widens and the slope decreases (Zhang et al., 2025).

The Froude numbers at all observation points are less than 1 (Fr < 1), indicating subcritical flow conditions. This suggests that the flow moves relatively calmly, with lower velocity and relatively greater flow depth. At Point 1, the Froude number is 0.0314; at Point 2, the highest value is 0.0337; while the lowest value occurs at Point 3, at 0.0141.

Point 1 has a Reynolds number of 3,173.847, which falls within the transitional range (2,000 < Re < 4,000), indicating a flow condition between laminar and turbulent regimes, where flow behavior tends to be unstable. In open-channel flow, Reynolds number thresholds are often adapted from pipe flow classifications, where values below 500 are typically considered laminar and values above 12,500 fully turbulent (Te Chow, 2009; Zhang et al., 2025), although actual transition ranges depend on hydraulic radius and channel geometry. This condition is influenced by the relatively higher flow velocity at this point. At Point 2, the Reynolds number of 2,380.386 also falls within the transitional range but with lower intensity compared to Point 1, suggesting a gradual shift toward more stable flow conditions. Meanwhile, at Point 3, the Reynolds number is 1,190.193 (< 2,000), indicating laminar-like flow behavior, which reflects relatively calm conditions and a higher potential for sediment deposition due to lower flow energy.

Based on the results of the analysis above, the maximum flow velocity is 2.298 m/s, which has the potential to cause bank erosion. However, the flow characteristics are classified as subcritical (Fr < 1), and the overall flow regime is predominantly transitional.

CONCLUSION

Based on the results of the analysis conducted, the following conclusions can be drawn. First, the average flow velocity at Point 1 is 2.298 m/s, at Point 2 is 1.686 m/s, and at Point 3 is 1.062 m/s, indicating a progressive decrease in flow velocity from upstream (before the river bend) to downstream (after the bend). This variation is attributed to changes in riverbed slope, channel width, and flow resistance along the studied river segment, as well as geometric changes that influence energy dissipation.

Second, the Froude number analysis at all observation points yielded values of less than 1 ($Fr < 1$), confirming that the flow is subcritical across all three locations. The Reynolds number analysis indicates transitional flow conditions at Point 1 ($Re = 3{,}173.847$) and Point 2 ($Re = 2{,}380.386$), while Point 3 exhibits laminar flow conditions ($Re = 1{,}190.193$). These hydraulic characteristics suggest a gradual reduction in turbulence intensity along the flow path, consistent with decreasing velocity and energy.

Third, based on these flow characteristics, the recommended riverbank protection measures include slope reinforcement using gabions or interlocking concrete blocks at Points 1 and 2, where transitional flow increases erosion potential; stone masonry retaining walls at Point 3, where flow is relatively calmer; and the installation of weirs to dissipate flow energy and reduce localized scour along vulnerable riverbanks. These interventions are intended to improve bank stability and reduce erosion risk under existing hydraulic conditions.

This study is limited to dry-season flow conditions at a single river segment; therefore, further research should incorporate wet-season measurements, multiple cross-sections, and numerical modeling to more comprehensively assess long-term erosion dynamics in the Noelmina River system.

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AUTHOR CONTRIBUTION STATEMENT

All authors contributed equally to this research, including the conceptualization of the study, field survey design, data collection using current meter measurements, hydraulic analysis using Froude and Reynolds numbers, interpretation of results, and manuscript preparation. Each author participated in reviewing and refining the final manuscript. All authors have read and approved the final version of the article and are fully responsible for the integrity of the research findings.

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