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Addressing sedimentation issues: Modelling the rating curve and river sediment transport using HEC-RAS 6.1 application

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Abstract: Fluvial sedimentation refers to the deposition of materials transported by water along the river, which can reduce the river's holding capacity. Over time, the process has become a serious global issue, significantly contributing to recurrent flooding. This study aims to develop a sediment rating curve and transport model to address the high sedimentation in the Krueng Langsa River, an issue requiring urgent action. The data set includes bedload measurements using a grab sampler, suspended load collected using a 1-dm^3 scale plastic bottle, hydrometric measurements using a currentmeter, as well as planned flood discharge, river geometry, and roughness. Sediment transport was modelled using the HEC-RAS 6.1 application. The results indicated sediment transport and movement ($\tau_0 > \tau_c$). Based on the sediment rating curve, the regression equations were: $Q_s = 0.0707Q_w^2 + 109.72Q_w$ (upstream), $Q_s = 0.0075Q_w^2 + 122.25Q_w$ (midstream), and $Q_s = 0.0043Q_w^2 + 103.97Qw$ (downstream), where Q_s is the sediment discharge and Q_w is the water discharge. The coefficient of determination (R^2) values were 0.9761 (upstream), 0.9782 (midstream), and 0.9796 (downstream), indicating an excellent correlation close to 1. The sediment transport model revealed changes in the riverbed due to sediment movement, with degradation of 0.365 m at the upstream review point (RS 346), aggradation of 1.655 m at the midstream point (RS 270), and aggradation of 0.218 m at the downstream point (RS 209). Extreme aggradation occurred at RS 364 (2.08 m), while extreme degradation occurred at RS 271 (0.482 m). The sediment rating curve and transport model provide valuable river improvement and management insights, offering a potential solution for mitigating recurrent flooding.

Keywords: aggradation, degradation, HEC-RAS, rating curve, sediment transport

INTRODUCTION

A river, whether natural or artificial, consists of a watercourse flowing from upstream to downstream, confined by banks on either side (Peraturan (2011). The size and shape of river channels can change due to the influence of sediment deposition, leading to geomorphic alterations (Dean *et al.*, 2024). Rivers are shaped not only by natural factors, such as climate, topography, hydrology, and soil, but also by human activities, which can significantly affect sediment accumulation (Hidayah *et al.*, 2023; Zhang *et al.*, 2023). Given their essential role in meeting human needs, it is crucial to maintain the stability of river cross-sections to prevent excessive sediment deposition (Azmeri *et al.*, 2017; Azmeri *et al.*, 2020a; Amri, Mase and Putra, 2023). Understanding river sediment balance is vital for assessing its effects on tributaries and floodplains (Vas and Tamás, 2023).

Sedimentation refers to the process by which materials transported by water or wind are deposited (Hambali and Apriayanti, 2016). Sediment consists of solid particles, including minerals, plant residues, and animal organic matter, which are relocated and deposited in new areas (Kamarudin *et al.*, 2017; Azmeri *et al.*, 2022b). Sediments accumulate through the sedimentation process, in which particles carried by the flow settle as bedload due to gravity, while suspended load particles remain in the water column (Azmeri, Legowo and Rezkina, 2020). Sediment transport plays a crucial role in shaping river ecosystems, affecting environmental conditions (Rodríguez-Padilla, Mariño-Tapia and Ruiz de Alegría-Arzaburu, 2024). This process occurs in various forms: suspension (sediment carried by the flow), traction (sediment rolling along the riverbed), saltation (sediment moved by short jumps), and solution (dissolved sediment) (Dehghan-Souraki *et al.*, 2024).

Sediment transport involves complex interactions between diverse factors over time and space, with water flow being the primary driver. Over time, the amount of transported sediment can alter river morphology and surrounding environment (Tassi *et al.*, 2023). This process leads to erosion (degradation) and deposition (aggradation) along the riverbed, affecting river morphology and potentially contributing to flooding (Basri *et al.*, 2020; Cahyani *et al.*, 2021). Sediment transport dynamics are closely linked to runoff formation and flood events, which vary spatially and temporally (Sherriff *et al.*, 2015).

Sediments deposited on the riverbed interact with water flow at specific discharge levels, generating forces that cause sediment movement. Sediment can be transported in two main ways: mass transport and individual particle transport. Mass transport, such as debris flows, mudflows, landslides, and pyroclastic flows, is primarily driven by gravity. In contrast, individual particle transport, including bedload and suspended load, is influenced by fluid pressure. The resulting sediment transport impacts the natural hydrological cycle, reducing river discharge (Stajnko, Jecl and Perc, 2023). Critical conditions arise when sediment grains begin to move as hydrodynamic forces reach a threshold value, at which point flow parameters, such as velocity and shear stress also reach critical levels (Latif, Said and Amalia, 2019). Sediment transport occurs when the shear stress (τ_0) exceeds the critical shear stress (τ_c) (Christine, 2009).

The Krueng Langsa River flows through two areas: East Aceh Regency upstream and Langsa City downstream. As the main river within the Krueng Langsa watershed, it spans 64.31 km (Dinas Pengairan, 2022). The river's profile has significantly changed due to sedimentation, leading to recurring floods in parts of Langsa City during the rainy season (Rizky, Simanjutak and Urfan, 2022). This situation results from river morphology changes that have disrupted the river's storage capacity, rendering it increasingly unstable.

Sedimentation modelling is essential for understanding sediment movement and changes to the riverbed (Siqueira *et al.*, 2016). One effective method is computational sediment modelling (Cheng *et al.*, 2024). Sediment transport estimates were calculated using the HEC-RAS 6.1 application, which is well-suited for modelling sedimentation and shear stress constraints in complex hydrological contexts. The Krueng Langsa River serves as a case study for such modelling, as sedimentation is a major cause of increasing frequency of floods, which have become a recurring natural disaster, resulting in significant human and material losses (Graterol *et al.*, 2024). Therefore, it is the right step to develop a predictive model of sediment through rating curves to better manage flood risk. This research contributes to sustainable river management practices in the region, potentially leading to future recommendations based on research findings.

MATERIALS AND METHODS

STUDY AREA

This study was conducted in the Krueng Langsa River, which falls under the authority of the Aceh Provincial Government (Fig. 1). The Krueng Langsa watershed is located at the Langsa City at

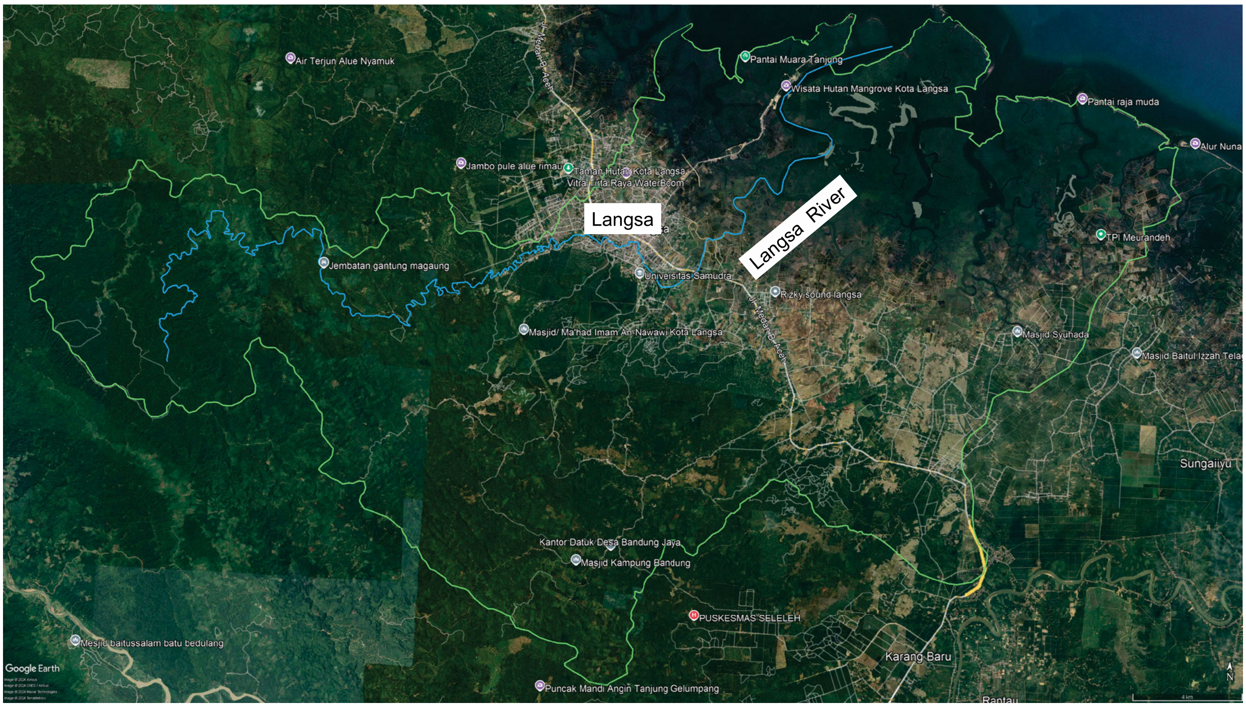

Fig. 1. The study area – the Krueng Langsa River; source: own study

4°27'0.17"N–97°46'26.32"E (upstream) to 4°30'32.44"N–98°8'51.27"E (downstream). The Krueng Langsa watershed covers a total catchment area of 499.40 km^2, with a river length of 64.31 km and a river slope of 0.0014. The river flow pattern within the Krueng Langsa watershed is dendritic, with tributary rivers of Langsa resembling tree branches that eventually merge into the main river. The climate in this region is classified as tropical. The rainfall in the Krueng Langsa watershed is categorised as heavy to very heavy, with monthly rainfall exceeding 100 mm·day^{-1}. The ratio between the average monthly dry period and the average wet month over a 10-year consecutive rainfall record is 1%. According to the Schmidt–Ferguson climate classification, the climate of the Langsa watershed is classified as type A (very wet), particularly in the central and upstream areas. The soil in the Krueng Langsa watershed is categorised into three types: entisol, inceptisol, and ultisol. Inceptisol soil is the dominant type in this watershed, covering approximately 70.17% of the total area. In the upstream of the river, the land along the river is predominantly used for plantations and shrubland. The midstream section of the river is mainly dominated by residential and developed areas. Meanwhile, the downstream section is dominated by mangrove forests. Langsa City is one of the cities that frequently experiences flooding events. In 2022, a total of 2,261 households and 6,782 people were affected by flooding. The recurring annual pattern of flooding in the Langsa City underscores the urgency and necessity of this research.

DATA COLLECTION AND METHODS

The research data comprises the following parameters, which were used to generate the rating curve and sediment transport analysis.

1. Annual maximum daily rainfall data: collected from the Dinas Pengairan AcehDepartment's ARR Langsa rain station, covering a period of 13 years (2009–2021).
2. Hydrometric data: obtained through field measurements at three locations along the Krueng Langsa River.
3. The upstream site at Geudubang Aceh Village (4°27'3.756"N, 97°55'3.175"E),
4. The midstream site at Pondok Keumuning Village (4°27'43.573"N, 97°56'4.923"E),
5. The downstream site at Teungoh Village (4°28'3.009"N, 97°58'19.411"E).
6. Bedload and suspended load data: collected from field sampling at the same locations as the hydrometric data. Sediment sampling was conducted to obtain bed load samples using a grab sampler and suspended sediment samples using a 1-dm^3 scale plastic bottle. The selection of three sampling locations along the river (upstream, midstream, and downstream) represents a straight section of the river, which is a requirement for sediment sampling, and also covers the entire watershed area for the upstream, midstream, and downstream parts of the river.
7. River geometry data: provided by Dinas Pengairan Aceh (2015) and used to describe the river's longitudinal and cross-sectional profiles in the HEC-RAS model.
8. River roughness data: derived from Brunner (2021) to determine the Manning's coefficient for model calibration.

EMPIRICAL SEDIMENT TRANSPORT ANALYSIS

The sediment transport analysis was conducted in two stages. First, the sediment transport calculations for field measurements were performed using empirical formulas. Second, sediment transport estimates for discharge return periods were calculated using the HEC-RAS application (Siqueira *et al.*, 2016). In sediment transport studies involving HEC-RAS, the key information includes river geometry, sediment characteristics, and hydrological parameters, specifically river flow (Farajzadeh *et al.*, 2014). The Engelund-Hansen method, suitable for the parameters and characteristics of the field survey data, was applied to calculate sediment transport using empirical formulas. This method employs a dimensionless relationship of shear forces and coefficients derived from laboratory studies (Farajzadeh *et al.*, 2014). The Engelund–Hansen equation for sediment transport is given as follows.

$$q_s = 0.05\gamma_s v^2\sqrt{\frac{d_{50}}{g(\frac{\gamma_s}{\gamma_w}-1)}}\left[\frac{\tau_0}{(\gamma_s-\gamma_w)d_{50}}\right]^{3/2} \tag{1}$$

where: q_s = total sediment (Mg·day^{-1}), γ_s = density of soil (g·m^{-3}), γ_w = density of water (g·m^{-3}), d_{50} = diameter median (mm), τ_0 = shear stress (N·s^{-2}), v = velocity (m·s^{-1}), g = gravitational acceleration (kg·s^{-1}).

Suspended sediment transport ($Q_{\text{suspended}}$, Mg·day^{-1}) was calculated based on the following direct measurements of water discharge (Q_w) and sediment concentration (C_s) (Stajnko, Jecl and Perc, 2023).

$$Q_{\text{suspended}} = 0.0864 Q_w \cdot C_s \tag{2}$$

where: Q_w = water discharge (m^3·s^{-1}), C_s = sediment concentration (mg·dm^{-3}).

Sediment characteristics data were obtained from bed load and suspended load sediment sampling at three points upstream (left, centre, and right of the river) and at one point downstream (right of the river) using a grab sampler (Basri *et al.*, 2020). Several dynamic factors that influence sediment deposition and explain sedimentation conditions in the surrounding environment include the distribution and inhomogeneity of sediment gradation. These factors encompass grain size, sediment type, classification into sediment parameters, and sediment distribution (Hambali and Apriyanti, 2016). The inhomogeneity of sediment gradation and dispersion indicates sediment flow movement in an area (Anggraini, Yanuhar and Risjani, 2020; Rachman *et al.*, 2021). Tests on bottom sediments included mass density analysis in determining sediment-specific gravity and grain size analysis to assess sediment gradation. These tests were conducted at the Soil Mechanics Laboratory of the USK Faculty of Engineering, while sediment concentration testing was undertaken at the Environmental Quality Testing Laboratory of the USK Faculty of Engineering.

Before calculating sediment transport, confirming the onset of sediment grain movement is essential to calculate the flow shear stress (τ_0) and the critical shear stress (τ_c). If τ_0 exceeds τ_c, sediment transport will occur (Christine, 2009) (Eq. 3).

$$\tau_0 = \gamma_w DS \tag{3}$$

where: γ_w = density of water (g·m^{-3}), D = channel depth (m), S = slope.

SEDIMENT TRANSPORT MODELLING

Modelling is employed to solve complex equations and analyse changes in river geometry (Vas and Tamás, 2023). It is crucial to implement an appropriate model to produce accurate simulations of sediment transport in rivers. The HEC-RAS 6.1 application is based on a model that effectively simulates sediment transport (Das and Vadivel, 2022). The HEC-RAS simulates permanent and non-permanent one-dimensional sediment transport, incorporating a component to calculate sediment transport in open channels (Zainuddin *et al.*, 2023; Novelyne, Nurhayati and Gunarto, 2024). The modelling process is conducted using sediment data, comprising initial conditions, transport parameters, boundary conditions, bed gradations, and quasi-unsteady flow data to input discharge information (Shiami, Lasminto and Wardoyo, 2017). The Meyer–Peter Müller function is based on the principle of sediment movement due to energy from the slope, with the bed load formula developed from sand and gravel flume experiments under plane bed conditions (Hermawan and Afianto, 2021). This formula relates sediment transport capacity to the difference between the bed and the critical shear stresses required to move the particles (Stajnko, Jecl and Perc, 2023). In this study, the energy slope and shear stress serve as critical indicators of sediment movement, making the Meyer–Peter Müller method highly suitable for the modelling applied.

RESULTS AND DISCUSSION

GRAIN GRADATION AND SEDIMENT CONCENTRATION

Bed sediment grain gradation is necessary for HEC-RAS modelling, both for the upstream and downstream sections of the river (Junaidi and Wigati, 2011). Grain size and gradation variations are crucial for understanding river geometry and optimising sediment transport design and effectiveness (Meijer *et al.*, 2002). Grain gradation input adjustments involve aligning field conditions with the grain size options available in the HEC-RAS program (Cahyani *et al.*, 2021). The grain gradation test performed ranged from passing sieve No. 10 (2 mm) to sieve No. 200. The results for the Krueng Langsa River showed a wide range of sediment grain sizes. Upstream, the predominant sediment grain sizes fall between fine sand and coarse sand, ranging from 0.074 to 2 mm. In the midstream section, the predominant sizes are coarse sand to gravel, ranging from 0.074 mm to 4.5 mm. Downstream, the predominant grain size is fine sand, ranging from 0.074 mm to 0.40 mm.

The mass density tests revealed that the upstream section has an average density of 2,579 g·cm^{-3}, the midstream – 2,560 g·cm^{-3}, and the downstream – 2,368 g·cm^{-3}. The G_s values for the upstream and midstream sections correspond to gravel/sand soil types, while the downstream section falls within the clay soil category (Hardiyatmo, 2012).

The testing of suspended sediment samples (suspended load) using the total suspended solids (TSS) parameter revealed that the concentration of floating sediment ranged from 9 mg·dm^{-3} to 32 mg·dm^{-3}. If the floating sediment concentration falls within the 0–100 mg·dm^{-3} range, these results indicate a relatively low sediment concentration. Consequently, the impact on the flow's potential to carry sediment is minimised, resulting in lower sediment transport.

SHEAR STRESS

The beginning of sediment grain transport motion is influenced by the flow shear stress (τ_0) that occurs in the flow cross section and the critical shear stress (τ_c). The initiation of grain movement influences sediment transport along the riverbed. Sediment particles begin to move when τ_0 exceeds τ_c (Hermawan and Afiato, 2021). If τ_0 does not exceed τ_c, the bed material remains stationary. In the case of the Krueng Langsa River, τ_0 in each river section surpasses τ_c, leading to sediment particle movement.

MODEL CALIBRATION

HEC-RAS was used to determine the river's capacity by considering its hydraulic characteristics. Calibration is required to achieve a valid sediment transport model by adjusting hydraulic coefficients to reflect field conditions. One important parameter is Manning's roughness coefficient (n) (Joshi *et al.*, 2019). The Manning's coefficient was adjusted by running a steady flow simulation using observed discharge data and Manning's coefficient. Manning's coefficient value is crucial, as it reflects characteristics such as vegetation density, river shape, and curvature (Jobe, Kalra and Ibendahl, 2018). The initial Manning's coefficient is deemed appropriate if the maximum river depth from the steady flow simulation matches or closely approximates the observed maximum depth. The Manning's coefficient must be recalibrated if the difference between the simulated and observed maximum depths is greater than 10%. However, in very complex river systems, finding the ideal Manning's coefficient can be challenging (Zainuddin *et al.*, 2023).

The optimal Manning's coefficient for the upstream section (left, centre, and right of the river) were 0.013, 0.015, and 0.013, respectively. In the midstream section, the values were 0.096, 0.099, and 0.094. Based on upstream discharge measurements of 1.33 m^3·s^{-1}, the simulated depth during Manning's calibration was 0.59 m. In the midstream section, with a discharge of 2.09 m^3·s^{-1}, the water depth was 1.10 m. These results showed a difference between the simulated and observed river flow depths of 3.38% for the upstream and 4.54% for the midstream.

The downstream section of the Krueng Langsa River forms a delta that directly connects to the Strait of Malacca. This area is characterised by calmer and slower currents. The river mouth creates a delta influenced by tidal fluctuations, which dampen the fluvial dynamics and result in unique patterns of progradation and geomorphology. Variations in riverbed roughness create contrasting effects in this section (Sassi *et al.*, 2012; Davies and Woodroffe, 2020). Determining suitable conditions for the river's geomorphology presents a significant challenge during the calibration process. The most appropriate Manning's coefficient, estimated at 0.013 based on observed flow rates, was found to be consistent with values measured in the middle section (0.096, 0.099, and 0.094, respectively). At a discharge rate of 0.76 m^3·s^{-1}, the recorded water depth was 0.79 m. The deviation downstream can be omitted due to the relatively fine grains forming wetted areas (such as fine sand and silt loam), resulting in a low roughness value and minimal effect from changes in the flow stage (Zainuddin *et al.*, 2023). Moreover, Kim *et al.* (2009) and Sassi *et al.* (2011) emphasised that differences in water surface configurations are a distinct characteristic of downstream river sections influenced by tidal fluctuations.

SEDIMENT SIMULATION

Sediment transport calculation using the empirical formula

The bed load sediment transport was calculated using the Engelund–Hansen formula, based on the diameter data and parameters obtained. Table 1 presents a summary of observed sediment transport for upstream, midstream, and downstream points.

The presence of corners and boundaries in an open channel results in the flow velocity vectors having components not only in the longitudinal and lateral directions, but also in the direction perpendicular to the flow. The flow rate depends on the velocity and the cross-section area. In the middle part of river cross section, the velocity is the highest due to the smallest frictional forces. In this research, the discharge of both water and sediment significantly increases in the middle stream section because the water depth is the highest, and the flow cross-sectional width is smaller compared to the upstream and downstream sections. This results in the middle section having significantly higher flow velocity and discharge.

Calculation of estimated sediment transport using HEC-RAS

Sedimentation modelling using HEC-RAS was conducted to develop a sediment transport model and analyse changes in river elevation. The Meyer–Peter Müller sediment transport function was applied, and a bed load formula was derived from sand and gravel flume experiments under plane bed conditions (Brunner, 2021). This formula is suitable for the sediment samples from the Krueng Langsa River, which are predominantly sand and gravel, and it aligns with the river's varied channel bottom conditions. Sediment transport modelling was performed through quasi-unsteady flow simulations, incorporating sediment input data (grain size distribution) and discharge hydrographs for different return periods. Simulations were conducted for 2, 5, 10, 25, 50, and 100 years to estimate sediment transport in the upstream, midstream, and downstream sections of the Krueng Langsa River (Tab. 2). This data was used to generate the sediment rating curve for the river (Fig. 2).

The relationship between the flow and sediment discharge is presented by the following regression equations: $Q_s = 0.0707Q_w^2 + 109.72Q_w$ (upstream), $Q_s = 0.0075Q_w^2 + 122.25Q_w$ (midstream), and $Q_s = 0.0043Q_w^2 + 103.97Q_w$ (downstream). The coefficients of determination (R^2) for these equations were 0.9761 (upstream), 0.9782 (midstream), and 0.9799 (downstream), indicating a strong correlation between Q_w and Q_s. This suggests that as water discharge increases, sediment discharge also increases (Wibisono, 2018; Wiryamanta *et al.*, 2021).

Sediment transport modelling

Sediment transport was modelled using a 2-year return period discharge to assess changes in the riverbed of the Krueng Langsa River (Fig. 3). The 2-year return period discharge was chosen because the river was in a normal discharge state during the

Table 1. Summary of the water discharge and sediment discharge of the Krueng Langsa River based on field measurements (observation)

River cross section	Water discharge and sediment discharge					
	upstream		midstream		downstream	
	Q_w ($m^3 \cdot s^{-1}$)	Q_s ($Mg \cdot day^{-1}$)	Q_w ($m^3 \cdot s^{-1}$)	Q_s ($Mg \cdot day^{-1}$)	Q_w ($m^3 \cdot s^{-1}$)	Q_s ($Mg \cdot day^{-1}$)
Left	0.391	0.710	0.088	0.204	0.405	0.385
Middle	0.238	0.535	1.518	3.673	0.123	0.096
Right	0.699	1.934	0.482	1.166	0.228	0.276
Total	**1.328**	**3.178**	**2.087**	**5.043**	**0.756**	**0.757**

Explanations: Q_w = water discharge, Q_s = sediment discharge.
Source: own study.

Table 2. Sediment discharge at the upstream, midstream, and downstream of the Krueng Langsa River

Description	Sediment discharge at					
	upstream		midstream		downstream	
	Q_w ($m^3 \cdot s^{-1}$)	Q_s ($Mg \cdot day^{-1}$)	Q_w ($m^3 \cdot s^{-1}$)	Q_s ($Mg \cdot day^{-1}$)	Q_w ($m^3 \cdot s^{-1}$)	Q_s ($Mg \cdot day^{-1}$)
2-year return period	135.260	18,129	160.660	23,365	228.960	30,043
5-year return period	231.150	33,251	274.548	37,354	391.262	40,832
10 year return period	285.701	37,259	339.341	42,850	483.599	49,737
25 year return period	345.790	41,416	410.712	46,548	585.311	57,103
50 year return period	385.106	52,523	457.408	57,763	651.859	68,396
100 year return period	420.473	63,409	499.416	68,092	711.724	80,920

Explanations as in Tab. 1.
Source: own study.

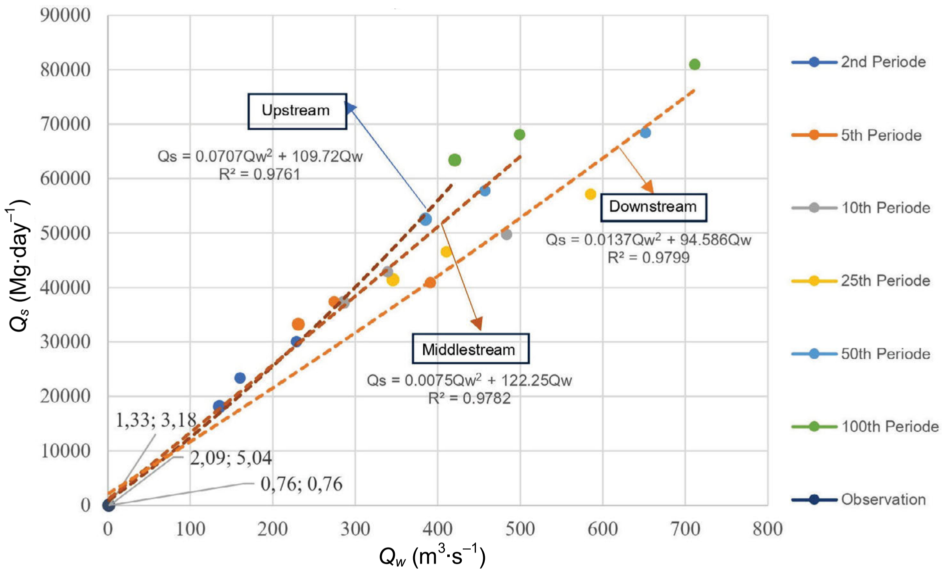

Fig. 2. Rating curve of relationship between water discharge (Q_w) and sediment discharge (Q_s) upstream, midstream, and downstream of the Krueng Langsa River; source: own study

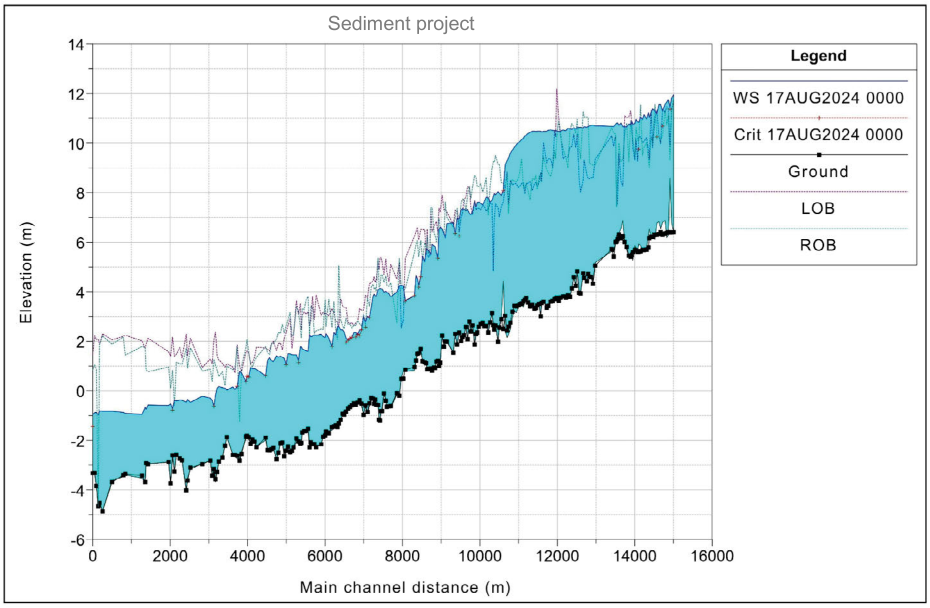

Fig. 3. Riverbed changes due to aggradation and degradation; source: own study

survey (Hariyadi, Istiarto and Raharjo, 2023). This modelling allowed for calculating sediment deposition, riverbed changes, and erosion analysis (Joshi *et al.*, 2019).

The study observed changes in the riverbed due to sediment movement. The modelling results revealed that the upstream and midstream reaches of the Krueng Langsa River experienced runoff, particularly affecting the Pondok Keumuning area (upstream) – Figure 3. This corresponds to the flood event in the area on 4 November 2022 (Iradah, 2022). The downstream of the river showed silty clay deposits consisting of fine grains (Dinas Pengairan Aceh, 2022), which aligned with the grain size distribution results for the lower reaches of the Krueng Langsa River, where fine sand grains dominate. The river profile due to degradation for the upstream review point (RS 346). The riverbed has been degraded as high as 0.365 m. The river profile due to aggradation for the midstream (RS 270) and downstream (RS 209). The riverbed has been aggradated as high as 1.655 m and 0.218 m.

The modelling results also reveal extreme aggradation at RS 364, with a height of 2.08 m, and extreme degradation at RS 271, with a depth of 0.482 m. The profiles also show aggradation and degradation occurring along certain parts of the river embankment, resulting from runoff in these locations. Runoff carries sediment to the river embankment, leading to aggradation, where runoff occurs at the channel bottom and embankment, and degradation under opposite conditions.

The Krueng Langsa River predominantly experiences sediment aggradation. The amount of sediment transported correlates with the high shear stress (τ_0). The magnitude of this shear stress indicates that the river can move more sediment at the midstream and downstream (Mohd Nasir and Abustan, 2022). Sediment transport processes continue, as evidenced by the variations in grain size across the research locations (Noor, Hidayah and Thalib, 2022). In the Krueng Langsa River, sediment particle sizes classified as fine sand were recorded at 0.80 mm upstream, 0.73 mm in the midstream, and 0.24 mm downstream section. The river's high sediment concentration, ranging from 9 to 32 mg·dm^{-3}, determines its substantial sediment transport capacity (Noor, Hidayah and Thalib, 2022). This sediment load contributes to aggradation, reducing the river's storage capacity and increasing the risk of flooding during periods of high discharge (Azmeri, Legowo and Rezkina, 2020).

CONCLUSIONS

The primary motivation for this study was to develop a sediment rating curve and estimate sediment transport, a task made challenging by the complexity of sediment transport processes, especially in natural rivers. The study established a relationship between flow discharge (Q_w) and sediment discharge (Q_s) through the following regression equations: $Q_s = 0.0707Q_w^2 + 109.72Q_w$ (upstream), $Q_s = 0.0075Q_w^2 + 122.25Q_w$ (midstream), and $Q_s = 0.0043Q_w^2 + 103.97Q_w$ (downstream). The rating curve results demonstrate a strong relationship between flow and sediment discharge. The sediment profile from upstream to downstream shows that sediment accumulation has increased over time, causing siltation. Civil engineering methods, such as river normalisation, are recommended to address the issue of sediment deposition in the midstream and downstream sections of the Krueng Langsa River. This is particularly important in areas experiencing extreme aggradation, such as at RS 364 (2.08 m), and at RS 271 (0.482 m).

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at https://www.jwld.pl/files/Supplementary_material_65_Azmeri.pdf.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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