

# Sedimentation Modeling of the Surumana River Using HEC-RAS for Analysis of Riverbed Elevation Changes

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**Abstract:** The Surumana River, located in South Banawa Subdistrict, Donggala Regency, Central Sulawesi, is one of the rivers experiencing sedimentation problems, as evidenced by a series of recurring floods. This sedimentation process can cause changes in the riverbed elevation, which may potentially affect the river's flow capacity. This study aims to analyze changes in the Surumana River's riverbed elevation due to sedimentation based on HEC-RAS modeling results, as well as to evaluate its response to variations in design flood discharge at each cross-section. Modeling was performed using a one-dimensional (1D) hydraulic and sediment transport approach with HEC-RAS 6.6 software, on a river section approximately 2 km long (RS 106–RS 73) consisting of 34 cross-sections, using the Meyer-Peter Müller sediment transport function and an upstream equilibrium load boundary condition. Simulations were performed for three design flood discharge scenarios, namely 2-, 10-, and 50-year return periods ( $Q_2$ ,  $Q_{10}$ , and  $Q_{50}$ ). The results show that changes in riverbed elevation occurred at 33 of the 34 cross-sections, consisting of 16 cross-sections that experienced aggradation and 17 that experienced degradation, while one cross-section (RS 106) remained relatively unchanged. Elevation changes in the meandering river segments (RS 73–RS 89) were consistently greater than those in the straight segments (RS 90–RS 106), with a range of  $-0.193$  m to  $+0.183$  m under  $Q_2$  conditions. These elevation changes tend to increase as the design flood discharge rises, with the overall range reaching  $-0.279$  m to  $+0.241$  m under  $Q_{50}$  conditions, although this increase is not uniform across all cross-sections. The most significant elevation changes, which consistently increase with rising discharge, occur at the cross-sections around RS 74 through RS 77. Model validation using Mean Absolute Error (MAE) on the water-depth parameter yielded 0.19 m (11.35%), indicating good agreement with field measurements.

**Keywords:** Surumana River; HEC-RAS; sedimentation; riverbed elevation; sediment transport

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## I. INTRODUCTION

Rivers are natural channels within the hydrological system that convey water from higher to lower elevations, while also collecting surface runoff, transmitting discharge, and transporting sediment eroded from the catchment area (Nenny, 2024). Along its course, a river also experiences sediment deposition at particular reaches, a process commonly referred to as sedimentation.

River sedimentation is a natural phenomenon governed by the interaction between flow, sediment characteristics, and channel morphology, involving the stages of erosion, transport, and deposition. The accumulation of sediment on the riverbed can alter the riverbed elevation through aggradation or degradation, which has the potential to cause shoaling and a reduction in channel conveyance capacity (Syamsuddin et al., 2025).

Several previous studies have reported sedimentation problems in rivers across Indonesia. A study on the Tondano River found that significant riverbed elevation changes resulting from sediment aggradation reduced the channel's capacity to convey flood discharge (Zainuddin et al., 2023). Sediment modeling on the Welang River similarly showed aggradation and degradation over a five-year period that rendered the river unable to convey the design flood discharge (Iqbal et al., 2022). Meanwhile, a study on the lower Konawe River identified a spatial distribution of aggradation and degradation reflecting fairly complex river morphodynamics (Rustan et al., 2024). Research on the Palu River further showed that discharge and bed-material transport are directly proportional, with riverbed elevation changes ranging from  $-4.68$  cm to  $+2.93$  cm (Rusdin et al., 2014), while a more recent HEC-RAS-based study on the same river reported aggradation at 30 points and degradation at 14 points, with the model achieving a relatively small error (Tandju, 2025). Research

on the Kalukubula segment of the Palu River also showed that variations in flow discharge are a major driver of riverbed change, based on a HEC-RAS simulation (Warliawati et al., 2026). Sediment transport and erosion modeling approaches have been extensively reviewed (Andualem et al., 2023). On the Rokan River, morphological change was analyzed using geographic information systems and remote sensing (Kurniawan et al., 2017), while sediment transport around bridge piers on the Siak River was examined by Siregar Sormin et al. (2020). These findings confirm that sedimentation is an important factor governing river conveyance capacity; however, most previous studies have focused on general morphological change and have not quantitatively examined the relationship between design flood discharge and the dynamics of riverbed elevation change based on numerical modeling.

A comparable problem occurs in the Surumana River, South Banawa Subdistrict, Donggala Regency, Central Sulawesi, which conveys sediment eroded from hillslopes within its catchment. Geological studies around the Surumana Dam area indicate that the river's alluvial deposits are dominated by medium-sized sand, gravel, and cobbles. In the downstream reach, sediment accumulation has raised the riverbed elevation and narrowed the flow cross-section, thereby reducing the river's capacity to convey discharge, particularly during heavy rainfall (Karson, 2021). This condition is corroborated by a flash flood on 24 June 2024, reported by the Regional Disaster Management Agency (BPBD) of Donggala Regency, which affected five villages, namely Mbuwu, Watatu, Tanampulu, Surumana, and Salumpaku, with 174 households affected in Surumana Village (Badan Penanggulangan Bencana Daerah Provinsi Sulawesi Tengah, 2024). Similar events were previously recorded in Sarjo Subdistrict, Pasangkayu Regency, West Sulawesi, in 2014 and 2019 due to the overflow of the Surumana River, which forms the border between West and Central Sulawesi. These recurring events indicate that the Surumana River has a considerable potential for downstream flash flooding, largely driven by reduced conveyance capacity associated with channel shoaling. However, no quantitative study has yet examined the impact of sedimentation on riverbed elevation change in this river, motivating the need for further investigation (Badan Penanggulangan Bencana Daerah Provinsi Sulawesi Tengah, 2024).

This study therefore analyzes riverbed elevation changes caused by sedimentation in the Surumana River using numerical modeling with the Hydrologic Engineering Center – River Analysis System (HEC-RAS), version 6.6, which is capable of simulating one-dimensional (1D) flow and riverbed elevation change due to sediment transport. Specifically, this study aims to: (1) analyze changes in the Surumana River's riverbed elevation due to sedimentation based on HEC-RAS modeling results, and (2) analyze the response of riverbed elevation change to variation in design flood discharge ( $Q_2$ ,  $Q_{10}$ , and  $Q_{50}$ ) at each cross-section. The findings are expected to provide a quantitative basis for river normalization planning and sediment-control measures in the Surumana River.

## II. MATERIALS AND METHODS

### 2.1 Study Area

The study was conducted on the Surumana River, South Banawa Subdistrict, Donggala Regency, Central Sulawesi. The Surumana catchment forms part of the Palu–Lariang River Basin, with a catchment area of approximately 304.08 km<sup>2</sup> and a river length of approximately 67.39 km, situated between 0°40'–1°00' S and 119°40'–120°00' E. The study reach covers approximately 2 km of the river, extending from cross-section RS 106 to RS 73 in the downstream direction and comprising 34 cross-sections (Figure 1).

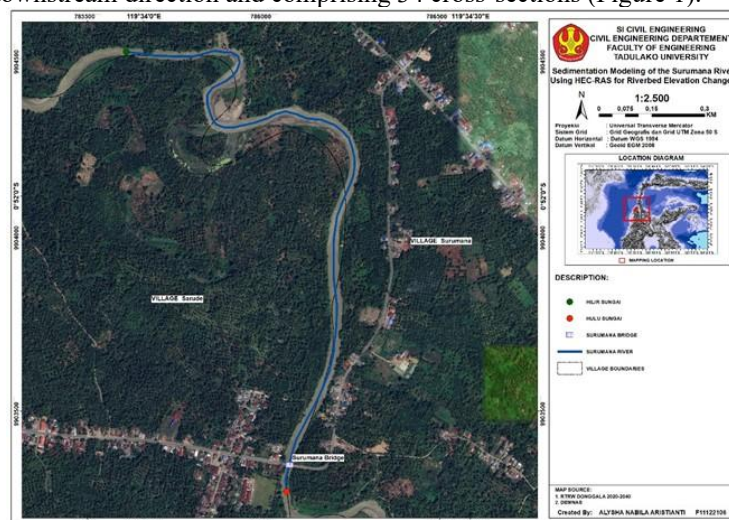


**Figure 1. Location map of the study reach on the Surumana River (RS 106–RS 73)**

## **2.2 Research Design and Data**

This study adopts a quantitative research design based on numerical modeling, simulating hydraulic and sediment-transport conditions with HEC-RAS 6.6 to determine riverbed elevation changes resulting from sedimentation. Two categories of data were used. Primary data, obtained directly from the field, comprised water-depth and flow-velocity measurements and the cross-sectional geometry at RS 105 (Surumana Bridge), together with bed-sediment samples collected using a sediment grab, followed by sieve analysis in the laboratory to determine the grain-size distribution. Secondary data comprised the river topographic map (Balai Wilayah Sungai Sulawesi III, 2023) and rainfall records obtained from the Sulawesi III River Basin Authority (Balai Wilayah Sungai Sulawesi III, 2024). Daily rainfall data spanning 20 years (2005–2024) from the Tanamea rain-gauge station, the nearest station to the study site, were used to represent catchment rainfall in the design-rainfall analysis. The use of a single rain-gauge station is acknowledged as a limitation, as the spatial variability of rainfall within the catchment could not be examined in further detail.

## **2.3 Hydrological Analysis**

Design rainfall was derived through frequency analysis of the maximum annual daily rainfall series (Triatmodjo, 2008; Soewarno, 1995). Prior to the frequency analysis, the data series was screened for outliers using an upper- and lower-limit test on the log-transformed values; all 20 years of data were found to fall within the admissible range and were retained for further analysis. Two probability distributions, the Gumbel and Log Pearson Type III distributions, were evaluated using the skewness ( $C_s$ ) and kurtosis ( $C_k$ ) criteria (Soewarno, 1995; Harto, 1993). The computed values ( $C_s = 1.250$ ;  $C_k = 6.706$ ) did not satisfy the Gumbel distribution criteria ( $C_s = 1.140$ ;  $C_k = 5.400$ ); consequently, the Log Pearson Type III distribution was adopted for the frequency analysis. The goodness-of-fit of the selected distribution was verified using the Smirnov–Kolmogorov test ( $\Delta_{\max} = 0.110 < \Delta_{\text{critical}} = 0.294$  at a 5% significance level) and the Chi-square test ( $\chi^2_{\text{computed}} = 4.600 < \chi^2_{\text{critical}} = 7.815$ ) (Limantara, 2010; Soewarno, 1995), both of which confirmed that the Log Pearson Type III distribution adequately represents the rainfall data. Design flood discharges for the 2-, 10-, and 50-year return periods were subsequently computed using the Nakayasu Synthetic Unit Hydrograph (SUH) method (Triatmodjo, 2008) and used as the discharge scenarios for the HEC-RAS simulations.

## **2.4 Sediment Data Processing**

Bed-sediment sampling and processing were conducted to obtain grain-size characteristics for use in the modeling. Samples were collected using a Van Veen sediment grab lowered from a bridge until it reached the riverbed, after which the jaws automatically closed and retained the sample. The collected samples were oven-dried, weighed, and subjected to sieve analysis using a sieve shaker with sieves arranged from the largest to the smallest opening. The mass retained on each sieve was used to calculate the percentage retained, cumulative percentage retained, and percentage passing, which were then used to determine grain-size distribution and median grain size ( $D_{50}$ ). Grain-size analysis to identify bed-sediment characteristics was also conducted by Mregawati et al. (2017), while Abeshu et al. (2022) used the median size of bed material as one of the characteristics of river sediment. Because sediment sampling could not be conducted at every cross-section, the obtained  $D_{50}$  value was uniformly applied to all modeled cross-sections as an approximation of bed-material characteristics along the study reach due to the limited spatial coverage of sediment data.

## **2.5 HEC-RAS Numerical Modeling**

The one-dimensional river geometry was constructed in HEC-RAS based on surveyed cross-sections and riverbed elevations (U.S. Army Corps of Engineers, 2024). Hydraulic parameters included the Manning roughness coefficient ( $n$ ) (Chow, 1959), design flood discharge obtained in Section 2.3, and boundary conditions, with the flow hydrograph specified at the upstream boundary and normal depth specified at the downstream boundary. Sediment transport was simulated using the HEC-RAS sediment transport module (U.S. Army Corps of Engineers, 2024), with input parameters consisting of grain-size distribution, the Meyer-Peter Müller (MPM) sediment transport function (Meyer-Peter and Müller, 1948), initial sediment gradation conditions, and an upstream equilibrium-load boundary condition. HEC-RAS has been used for sediment transport analysis in several Indonesian rivers, including the Welang River (Iqbal et al., 2022), the Opak River (Nandi Wardhana, 2015), and the Palu River (Warliawati et al., 2026; Warliawati and Rusdin, 2025), and Rustan et al. (2024) applied it to model aggradation and degradation along the downstream Konawe River. The MPM function was selected because it is suitable for estimating the transport capacity of bed material that controls changes in riverbed elevation, consistent with the sediment characteristics and hydraulic conditions represented in the model. Three quasi-unsteady flow simulation scenarios were conducted over four days, each representing design flood discharges with 2-, 10-, and 50-year return periods ( $Q_2$ ,  $Q_{10}$ , and  $Q_{50}$ ), with outputs consisting of aggradation patterns, degradation patterns, and riverbed elevation changes at each cross-section.

## 2.6 Model Evaluation

Model performance was evaluated using the Mean Absolute Error (MAE) between the simulated and field-measured water depth (Hodson, 2022):

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i|$$

where  $y_i$  denotes the water depth measured in the field and  $\hat{y}_i$  denotes the simulated water depth at observation point  $i$ , while  $n$  represents the number of observation points. For validation, the actual discharge measured in the field on June 30, 2026, rather than the design discharge, was used as model input at cross-section RS 105 (Surumana Bridge), so that the simulated hydraulic conditions corresponded to those observed during the field survey and enabled an objective comparison between simulated and measured water depths. The use of MAE as a model-error measure is consistent with Chicco et al. (2021), who discussed MAE as one of the error metrics for comparing model results with observational data.

## III. RESULTS AND DISCUSSION

### 3.1 Design Rainfall and Flood Discharge

The frequency analysis using the Log Pearson Type III distribution produced design rainfall values that increase with return period, as summarized in Table 1. The design rainfall increased from 97.81 mm for the 2-year return period to 219.13 mm for the 50-year return period, indicating that longer return periods are associated with progressively larger design rainfall and, consequently, larger design flood discharges used as input to the HEC-RAS simulations.

**Table 1. Design rainfall by return period, Log Pearson Type III distribution**

| Return Period (years) | Exceedance Probability (%) | Design Rainfall, XTr (mm) |
|-----------------------|----------------------------|---------------------------|
| 2                     | 50                         | 97.81                     |
| 10                    | 10                         | 165.81                    |
| 50                    | 2                          | 219.13                    |

### 3.2 Riverbed Elevation Change from Sediment Transport Simulation

The sediment-transport simulations show that riverbed elevation changed at 33 of the 34 cross-sections along the study reach, comprising 16 cross-sections that experienced aggradation (positive  $\Delta h$ , indicating sediment deposition) and 17 that experienced degradation (negative  $\Delta h$ , indicating bed scouring), while cross-section RS 106 remained essentially unchanged across all three scenarios (Table 2, Figure 2).

**Table 2. Riverbed elevation change ( $\Delta h$ ) at each cross-section for the  $Q_2$ ,  $Q_{10}$ , and  $Q_{50}$  scenarios**

| RS  | Reach geometry | $\Delta h$ $Q_2$ (m) | $\Delta h$ $Q_{10}$ (m) | $\Delta h$ $Q_{50}$ (m) |
|-----|----------------|----------------------|-------------------------|-------------------------|
| 106 | Straight       | 0.000                | 0.000                   | 0.000                   |
| 105 | Straight       | 0.093                | 0.083                   | 0.073                   |
| 104 | Straight       | -0.042               | -0.017                  | -0.005                  |
| 103 | Straight       | 0.001                | -0.063                  | 0.057                   |
| 102 | Straight       | 0.010                | 0.048                   | 0.085                   |
| 101 | Straight       | 0.046                | 0.074                   | 0.101                   |
| 100 | Straight       | 0.022                | 0.036                   | 0.054                   |
| 99  | Straight       | -0.012               | -0.012                  | -0.012                  |
| 98  | Straight       | 0.006                | 0.006                   | 0.006                   |
| 97  | Straight       | -0.003               | -0.005                  | -0.006                  |
| 96  | Straight       | 0.006                | 0.009                   | 0.004                   |
| 95  | Straight       | -0.006               | -0.005                  | -0.005                  |
| 94  | Straight       | 0.032                | 0.042                   | 0.047                   |

| RS | Reach geometry | $\Delta h$ Q <sub>2</sub> (m) | $\Delta h$ Q <sub>10</sub> (m) | $\Delta h$ Q <sub>50</sub> (m) |
|----|----------------|-------------------------------|--------------------------------|--------------------------------|
| 93 | Straight       | -0.011                        | -0.010                         | -0.007                         |
| 92 | Straight       | -0.014                        | -0.014                         | -0.010                         |
| 91 | Straight       | 0.035                         | 0.031                          | 0.032                          |
| 90 | Straight       | -0.043                        | -0.049                         | -0.050                         |
| 89 | Meander        | 0.014                         | 0.014                          | -0.005                         |
| 88 | Meander        | -0.166                        | 0.060                          | 0.002                          |
| 87 | Meander        | -0.055                        | -0.122                         | -0.055                         |
| 86 | Meander        | -0.033                        | -0.056                         | -0.069                         |
| 85 | Meander        | 0.103                         | 0.129                          | 0.150                          |
| 84 | Meander        | -0.049                        | -0.068                         | -0.037                         |
| 83 | Meander        | 0.030                         | 0.048                          | 0.030                          |
| 82 | Meander        | -0.037                        | -0.062                         | -0.050                         |
| 81 | Meander        | -0.037                        | -0.024                         | -0.052                         |
| 80 | Meander        | 0.012                         | 0.008                          | 0.010                          |
| 79 | Meander        | 0.016                         | 0.036                          | 0.047                          |
| 78 | Meander        | -0.136                        | -0.148                         | -0.166                         |
| 77 | Meander        | 0.183                         | 0.184                          | 0.200                          |
| 76 | Meander        | -0.186                        | -0.196                         | -0.274                         |
| 75 | Meander        | 0.181                         | 0.192                          | 0.241                          |
| 74 | Meander        | -0.193                        | -0.246                         | -0.279                         |
| 73 | Meander        | -0.055                        | -0.019                         | -0.277                         |

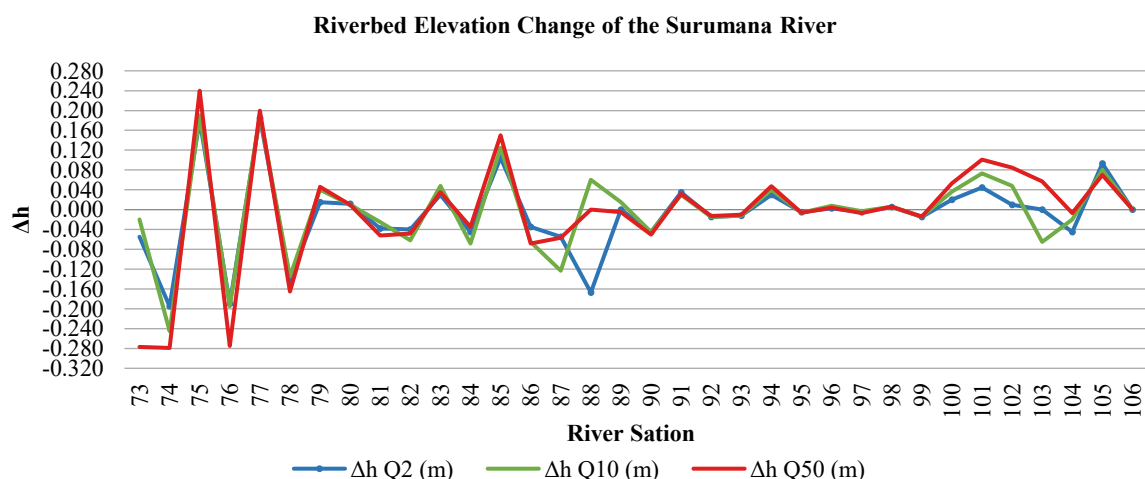


**Figure 2. Riverbed elevation change profile along the Surumana River for the Q<sub>2</sub>, Q<sub>10</sub>, and Q<sub>50</sub> scenarios**

The results show clear morphological differences between the two geometric conditions within the study reach. In the relatively straight segment (RS 90–RS 106), elevation changes were relatively small and fluctuated around zero, ranging from  $-0.043$  m to  $+0.093$  m under the Q<sub>2</sub> scenario. In contrast, the meandering segment (RS 73–RS 89) showed consistently greater and more variable elevation changes, ranging from  $-0.193$  m to  $+0.183$  m under the same scenario, reflecting stronger interactions between flow and morphology that are

generally associated with meandering channel reaches (Schumm, 1977; Rosgen, 2003). These results can be compared with the study by Rustan et al. (2024), which showed patterns of aggradation and degradation on the bed of the downstream Konawe River, as well as the study by Rusdin et al. (2014) on the Palu River, which also showed riverbed elevation changes due to sediment transport.

Increasing the design flood discharge from  $Q_2$  to  $Q_{50}$  generally increased the magnitude of riverbed elevation changes at most cross-sections, although the response was not uniform along the reach. At RS 74, degradation increased from  $-0.193$  m ( $Q_2$ ) to  $-0.246$  m ( $Q_{10}$ ) and  $-0.279$  m ( $Q_{50}$ ), whereas at RS 75, aggradation increased from  $+0.181$  m to  $+0.192$  m and  $+0.241$  m for the same sequence of scenarios; a similar trend was also observed at RS 76 and RS 77. These cross-sections, located within the meandering segment, consistently showed the largest elevation changes and the greatest sensitivity to discharge along the study reach. However, this pattern did not occur at all locations: at RS 88, the response changed from degradation ( $-0.166$  m) under  $Q_2$  to aggradation ( $+0.060$  m and  $+0.002$  m) under  $Q_{10}$  and  $Q_{50}$ , respectively, indicating that the local response of riverbed elevation to discharge is also influenced by cross-sectional geometry and site-specific hydraulic conditions, rather than discharge magnitude alone. A link between discharge and bed-material transport has also been documented on the Palu River by Rusdin et al. (2014) and Warliawati et al. (2026). Likewise, simulations by Warliawati and Rusdin (2025) showed that scour around the Palu I Bridge piers deepened as discharge rose, from  $0.92$  m under minimum discharge to  $1.91$  m under maximum discharge.

Because the simulations used a one-dimensional hydraulic and sediment transport approach, the model represents elevation changes only in the longitudinal direction and cannot describe the lateral distribution of erosion and deposition between the inner and outer sides of bends in the meandering segment. Therefore, the elevation changes obtained in the meandering segment should be interpreted as a tendency of riverbed-elevation response in the longitudinal direction, rather than as a spatial representation of erosion–deposition patterns across the entire river cross-section. Similar numerical modeling approaches have also been used in studies by Iqbal et al. (2022) and Rustan et al. (2024) to examine sediment transport dynamics and riverbed changes.

### 3.3 Model Validation

Model validation was performed by comparing simulated and field-measured water depth at cross-section RS 105 (Surumana Bridge), using the actual discharge measured during the field survey ( $12.353$  m<sup>3</sup>/s, obtained from the product of the measured wetted cross-sectional area and mean flow velocity) as the model input. The resulting Mean Absolute Error, summarized in Table 3, was  $0.19$  m, corresponding to a relative error of  $11.35\%$ , which falls within the "good" model performance category (Maricar, 2019) and indicates a satisfactory level of agreement between the simulated and observed hydraulic conditions at the validation cross-section.

**Table 3. Mean Absolute Error (MAE) between simulated and field-measured water depth**

| Cross-section            | MAE (m) | Relative error (%) |
|--------------------------|---------|--------------------|
| RS 105 (Surumana Bridge) | 0.19    | 11.35              |

It should be noted that this validation was limited to one cross-section and the water-depth parameter; therefore, it does not directly validate the simulated riverbed elevation changes at the other cross-sections. Accordingly, the elevation-change results presented in Section 3.2 for the other cross-sections should be interpreted as tendencies of aggradation and degradation generated based on the sediment parameters and boundary conditions used in the model, rather than as values independently verified through field measurements. This limitation is important because the studies by Rustan et al. (2024) and Iqbal et al. (2022) also used HEC-RAS modeling as an approach to represent changes in sediment transport and riverbed elevation, meaning that model results remain dependent on the input data and represented conditions. A comparable limitation was noted on the Palu River, where simulated bed changes were smaller than those measured in the field, although the two agreed reasonably well under average discharge (Warliawati et al., 2026).

## IV. CONCLUSION

Riverbed elevation change in the Surumana River due to sedimentation occurred at 33 of the 34 modeled cross-sections, comprising 16 cross-sections with aggradation and 17 with degradation, while RS 106 remained essentially unchanged. The distribution of elevation change was non-uniform along the reach: the relatively straight segment (RS 90–106) showed smaller changes ( $-0.043$  to  $+0.093$  m), whereas the meandering segment (RS 73–89) showed larger and more fluctuating changes ( $-0.193$  to  $+0.183$  m), indicating that riverbed response to sedimentation is more variable in meandering reaches than in straight ones.

The response of riverbed elevation change to variation in design flood discharge shows that discharge magnitude influences the extent of riverbed elevation change. Increasing the discharge from  $Q_2$  to  $Q_{10}$  and  $Q_{50}$  tended to increase the magnitude of elevation change at most cross-sections, with the largest changes generally

occurring under  $Q_{50}$ ; for example, degradation at RS 74 increased from  $-0.193$  m ( $Q_2$ ) to  $-0.279$  m ( $Q_{50}$ ), while aggradation at RS 75 increased from  $+0.181$  m to  $+0.241$  m. This response was not entirely uniform, as illustrated by RS 88, which shifted from degradation ( $-0.166$  m) under  $Q_2$  to aggradation ( $+0.002$  to  $+0.060$  m) under  $Q_{10}$  and  $Q_{50}$ . Overall, the increase in design flood discharge tended to enlarge the range of riverbed elevation change, with  $Q_{50}$  producing the widest range ( $-0.279$  to  $+0.241$  m), indicating that larger design floods increase the potential for riverbed elevation change through erosion and sedimentation processes, although the magnitude of change at any given location remains governed by its specific cross-sectional geometry and hydraulic characteristics.

For future research, it is recommended that more up-to-date river geometry data, or a comprehensive cross-sectional survey prior to modeling, be used, since the present study relied on a 2023 topographic map assumed unchanged up to the study period; that additional verification cross-sections be surveyed, since only one cross-section (RS 105) was used to verify the HEC-RAS simulation; and that a two-dimensional (2D) HEC-RAS model or an alternative morphological modeling approach be considered to resolve the lateral distribution of erosion and deposition across meander bends, which the present one-dimensional approach could not capture in detail. The findings of this study may serve as preliminary information for the management of the Surumana River, particularly for identifying reaches prone to deposition or scour, especially within meandering segments, to support river maintenance, normalization, and sediment-control planning.

### Conflict of interest

There is no conflict to disclose.

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