Proceedings of the 4th ITB Graduate School Conference
Innovation and Discovery for Sustainability
July 6, 2023

The Effect of Ameroro Reservoir on River Morphology Stability Using Regime Theory

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Abstract. The stability of river geometry is one of the considerations to determine whether a watershed is good or not. Ameroro River is a tributary of Konaweha River located in Konawe Regency, Southeast Sulawesi. The Ameroro River model uses river measurement data along 43.5% of the length of the main river and uses geological data as a model for sediment transport. In hydrological analysis using the Log-Normal distribution and daily discharge modeling with the Sacramento method calibrate by 9 years of observational data with a match rate of 52.9% and a calculation process was carried out with the help of the HECRAS program. The results of the modeling were checked and approached using 3 methods of regime theory, Blench, Lacey and Modified Regime as a reference for calculating river stability as seen from the cross-sectional width of the river. It was found that reservoir affect changes in riverbed elevation, water level elevation and degradation/aggradation compared to existing conditions. The existing condition has a stable river cross-section more than the condition of the reservoir but only 7.29% of the total river cross-section is reviewed. For overall of river, it was found that the reservoir affected the stability of the river is closer to the calculation results of 3 regime theory methods compared to existing conditions tested by NSE, RMSE and CORRELATION methods.

Keywords: *regime; reservoir; sediment; geology; HECRAS.*

1 Introduction

The stability of a river's geometry is one of the considerations in determining whether a watershed is good or not. The stability of a river's geometry becomes a problem if it is disturbed and not fully addressed directly, and over time it will turn watershed into a critical one with issues such as river siltation, bank river erosion, reduced river capacity, and expanded floodplains.

Ameroro River is a tributary of Konaweha River located in Konawe Regency, Southeast Sulawesi. The topography of Ameroro River ranges from the highest elevation of +289 m to the lowest elevation of +65 m with an average slope of ±4% and a length of the main channel of ±43.5 km. Floods and droughts in the downstream part of Konaweha River make the construction of Ameroro Reservoir one of the solutions to overcome them. The Ameroro Reservoir is located at coordinates 3°54'38.082" S, 122°0'34.432" E, which is approximately 8 km from the Konaweha River. The construction of the Reservoir across the river is one of the factors that affect the morphological changes of the river and its stability.

Figure 1 Site location of Ameroro Reservoir and Ameroro watershed

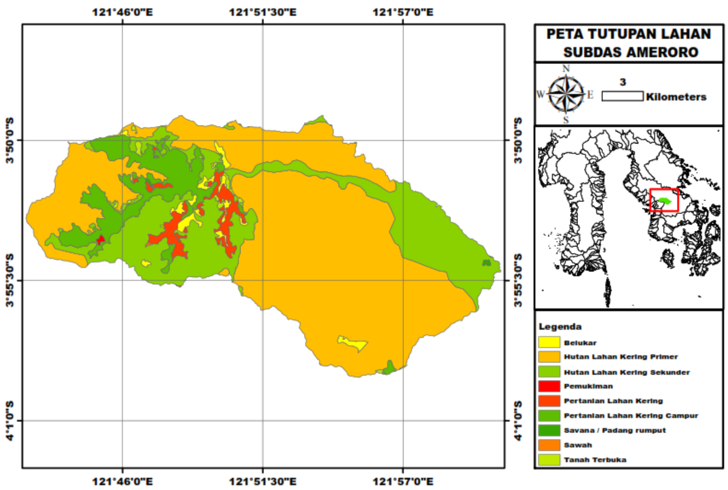

Figure 2 Land use of Ameroro watershed

One way to see river’s stability is using river regime theory where the stability conditions in question are the amount of degradation and aggradation in the river is equal to zero. Regime theory is used to predict the shape of rivers over long periods of time, Sigh, V. P [1].

So, this study aims to show the effects of the Ameroro Reservoir on the shape of the Ameroro River before and after the reservoir with an approach using regime theory. The effect of this change can be seen in the river cross-sections that have been measured by the BWS Sulawesi IV, Kendari, as the manager of Ameroro River and Ameroro Reservoir. The data used in this study can be seen in the following table:

Tabel 1 Material for research

Data	Notes	Source
Topographic Data	Topographic measurement of 74.76 km^2	measurement of the Ameroro Dam construction project in 2022
Cross-Section Data	96 cross-sections of the Ameroro River, 46 cross-sections of the Ameroro River tributaries	
Reservoir Detail	Detailed drawings of the reservoir planning calculations for the main dam	measurement of the Ameroro Dam construction project in 2019
Spillway Details	Detailed drawings of the spillway planning calculations for the spillway	planning for the Ameroro Dam construction project in 2019
Geological Data	Geological data of the dam and spillway area	
Hydrological Data	Rainfall data (Abuki, Tongauna, Ameroro, Lambuya), observation data of the Ameroro Dam discharge, and climate data (Unaaha)	BHLK & AWLR Ameroro
Land Cover Data	Distribution of land cover in Southeast Sulawesi	KLHK 2019
Digital Elevation Model	Distribution of land cover in Southeast Sulawesi	DEMNAS Indonesia

2 Methodology

2.1 River Stability

The stability of a river's geometry can be seen from its width, water depth, channel slope, hydraulic radius, and the slope of its banks, which show the pattern of the river's formation, Julien, Pierre. Y [2]. There are several methods for calculating the stability of a river's geometry, and this study uses the regime method.

2.1.1 Regime Theory

Regime theory calculates the stability of river geometry based on bankfull discharge data and sediment grain size distribution at each cross section. From these inputs, the stability of the river can be determined by examining the top width, bottom width, depth of flow, and channel slope, Sigh, V. P [1]. The calculation methods for the stability of river geometry using regime theory can use several methods with the following units;

w = width (m)

D = depth (m)

A = area (m^2)

S = slope

d = diameter of sediment (mm)

Q = discharge (m^3/s)

V = flow velocity (m/s)

R = hydraulic radius (m)

Tabel 2 Formula for calculation geometry with regime method

Method	Width	Depth	Slope	Supporting Equation
Lacey (1946)	$w = 2.67(Q^{0.5})$	$D^{\frac{1}{4}} = \frac{1}{1.346}\frac{V\,N_a}{R^{\frac{1}{2}}\,S^{\frac{1}{2}}}$	$S = \frac{f_L^{(\frac{5}{3})}}{1883\,(Q^{\frac{1}{6}})}$	$f_L = 1.6\,d^{\frac{1}{2}}$ $Na = 0.0225\,f_L$
Blench (1970)	$w = \left(\frac{F_B Q}{F_S}\right)^{\frac{1}{2}}$	$D = \left(\frac{F_S Q}{F_B^2}\right)^{\frac{1}{3}}$	$S = \frac{F_B^{5/6} F_S^{1/12} v^{1/4}}{3.63\left(1+\frac{C}{2330}\right) g Q^{\frac{1}{6}}}$ C = sediment concentration (mg/L) v = kinematic viscosity (m^2/s)	$F_B = 0.19\,d^{\frac{1}{2}}$ $F_S = 0.1$ (slightly cohesive bank) $F_S = 0.2$ (medium cohesive bank) $F_S = 0.3$ (slight cohesive bank)
Simon & Albertson (1963)	$w = C_5\,Q^{0.151} D$	$D = 1.73\,R$, for $(1 < R < 7)$ $D = 2.11 + 0.934R$ for $(7 < R < 12)$	$S^{\frac{1}{3}} = \frac{v}{C_4 R^{\frac{2}{3}}}$	$v = \frac{Q}{A}$ $A = C_3 Q^{0.873}$ $R = C_2 Q^{0.361}$

Tabel 3 Coefficient for calculating formula of Simon & Albertson Method

Coefficient	Sand bed and sand banks	Sand bed and cohesive banks	Cohesive bed and sand banks
C_1	3.3	2.51	2.12
C_2	0.37	0.43	0.51
C_3	1.22	1.08	1.08
C_4	13.9	16.1	16.0
C_5	6.5	4.3	3.0

Note: A soil is classed as cohesive if the plasticity index is >7

2.2 Hydrological Process

The stability of the river geometry is analyzed based on daily discharge data, which is modeled using the Sacramento method. The model calculation uses precipitation data and climate data from several measurement stations, with several input parameters to be calibrated. The modeling results are then tested for correlation using this criteria;

$$R = \frac{n\sum_{i=1}^{n} XY - \sum_{i=1}^{n} X \sum_{i=1}^{n} Y}{\sqrt{n\sum_{i=1}^{n} X^2 - \left(\sum_{i=1}^{n} X\right)^2}\sqrt{n\sum_{i=1}^{n} Y^2 - \left(\sum_{i=1}^{n} Y\right)^2}} \qquad (1)$$

R = Correlation value of X and Y

X = Observe value

Y = Model value

n = Amount of data

Tabel 4 Correlation Criteria

Value R	Correlation Criteria
0 – 0.19	Very low
0.2 – 0.39	Low
0.4 – 0.59	Medium
0.6 – 0.79	Strong
0.8 – 1.00	Very Strong

Bank full capacity modeling in Indonesian rivers usually uses a recurrence interval discharge of 2 years, therefore, in the process of hydrological modeling for design discharges, several distribution methods and the ITB-1b unit hydrograph method are used because the hydrograph can describe small watersheds and does not require a lot of data to do calculations Natakusumah, et.al [3].

$$Q_p = \frac{R}{3.6t_p}\left(\frac{A_w}{A_{UH}}\right) \quad (2)$$

$$t_p = C_t\ 0.81225\ L^{0.6} \quad (3)$$

Q_p = Peak discharge (m^3/s)

t_p = Time to peak (hour)

A_w = Area of watershed (km^2)

A_{UH} = Area of unit hydrograph

R = Rainfall (mm)

2.3 Sediment Transport

The sediment transport process is a crucial factor that affects the stability of river geometry, such as degradation and aggradation. The HEC-RAS model with a quasi-unsteady approach is commonly used to simulate sediment transport processes. The sediment transport function used in the model is the Meyer Peter Muller (MPM) proposed by Vanoni (1975) and the ASCE Manual 54.

$$\left(\frac{k_r}{k'_r}\right)^{\frac{3}{2}}\gamma RS = 0.047(\gamma_s - \gamma)d_m + 0.25\left(\frac{\gamma}{g}\right)^{\frac{1}{3}}\left(\frac{\gamma_s-\gamma}{\gamma_s}\right)g_s^{\frac{2}{3}} \quad (4)$$

g_s = Sediment transport rate in weight/time/unit width

k_r = A roughness coefficient

k'_r = A roughness coefficient based on the grains

γ = Unit weight of water

γ_s = Unit weight of sediment

g = Acceleration of gravity

d_m = Median particle diameter

R = Hydraulic radius

S = Energy gradient

3 Result and Discussion

The process of modeling the flow of the Ameroro River with a watershed area of 368.81 km^2 obtained rainfall data from 4 measuring stations with the distribution area using the Thiessen Polygon method, where Abuki Station (201.13 km^2 as 20.12%), Tongauna Station (66.41 km^2 as 54.54%), Lambuya Station (74.2 km^2 as 18.01%) and Ameroro Station (27.07 km^2 as 7.34%).

The modeling of the Ameroro River flow used daily rainfall data, daily climate data, and daily discharge observation data. The daily discharge modeling was done using the Sacramento method Figure 4, which obtained a correlation coefficient value of 52.9%, categorized as moderate correlation, Sugiyono [6]. For modeling the 2-year return period of discharge, the best distribution was found to be the Log-Normal distribution.

Tabel 5 Distribution method

Method	Normal	Log-Normal	Gumbel	Log-Pearson III
Mean Absolute Error	2.990%	2.725%	3.437%	2.815%
NSE	0.934	0.949	0.947	0.946
Smirnov-Kolgomorov	Good	Good	Good	Good
Chi-Square	Good	Good	Good	Good

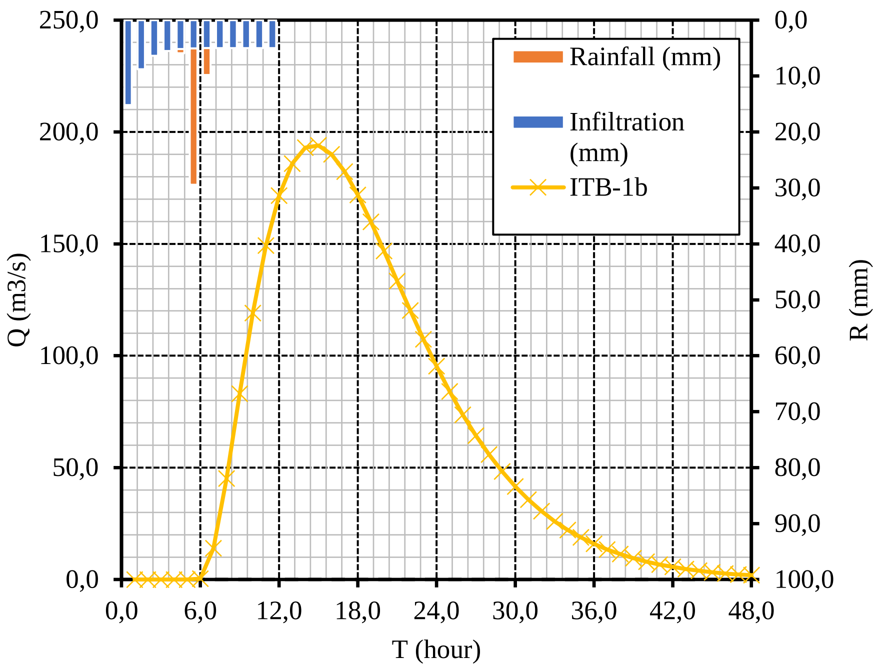

Figure 3 Hydrograph ITB-1b for 2 years return period.

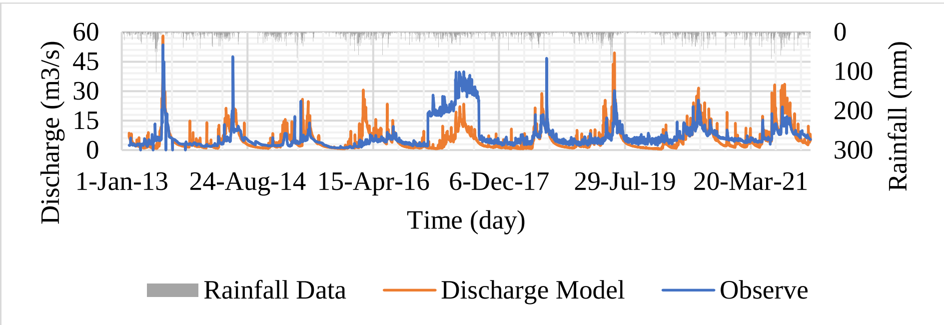

Figure 4 Sacramento model

Based on the obtained data, the modeling in HECRAS uses measurements of river cross-sections along a 19.74 km reach or equivalent to 43.5% of the main stream length of Ameroro River, Figure 1. The measurement at the upstream section of the river is located at an elevation of +130.73 m, while the downstream section is located at an elevation of +66.3 m.

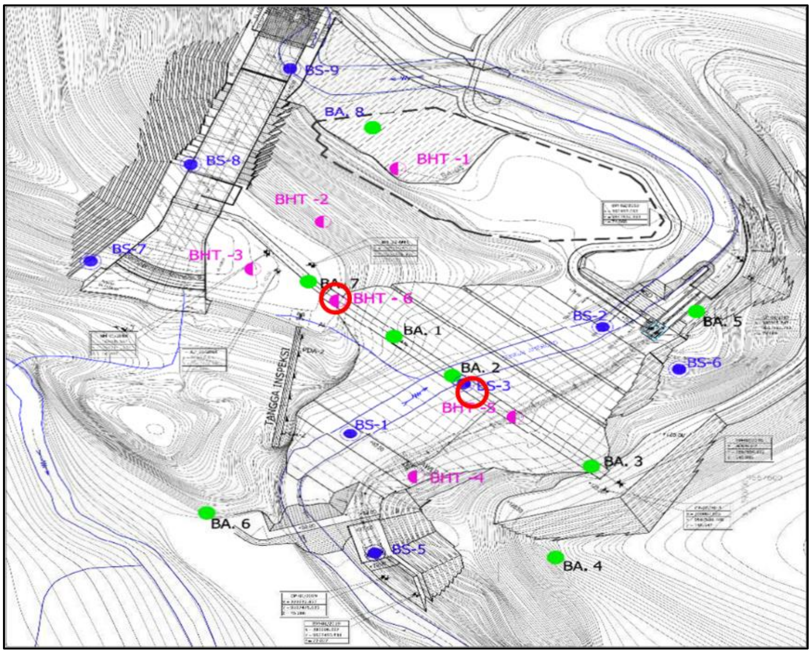

Figure 5 Coordinate points of geological data collection

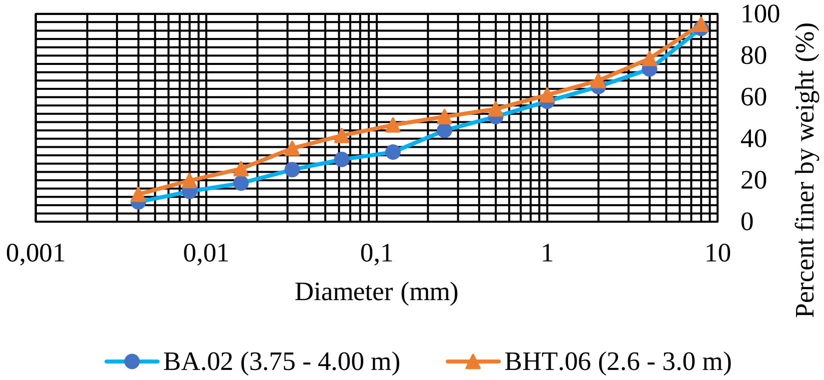

Figure 6 Sediment grain size

Using the quasi-unsteady flow model of HECRAS, sediment data was input based on geological data obtained from core drilling in the reservoir body, Figure 5. Sediment data was adjusted to the riverbed elevation in the upstream and downstream areas and interpolated along the river course. The model was run with daily discharge data for 9 years, and the following graph was obtained.

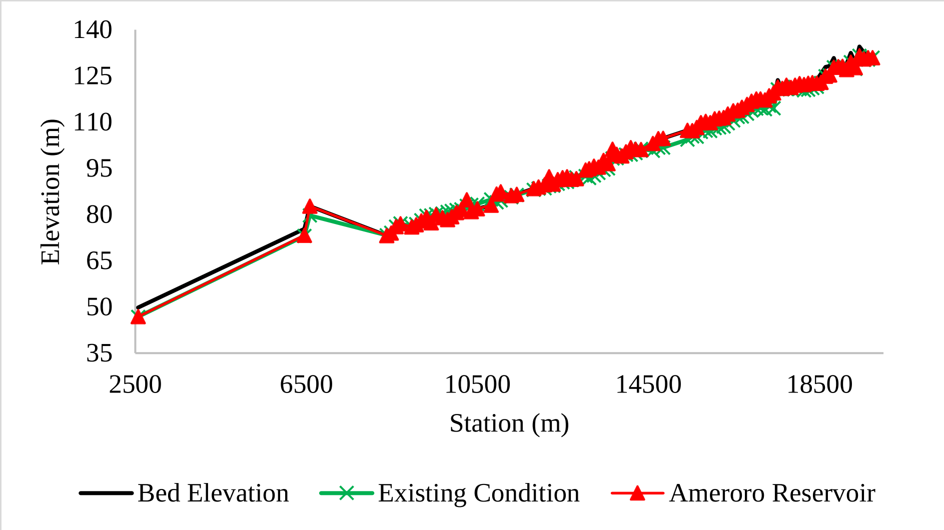

Figure 7 Comparation for bed elevation changes

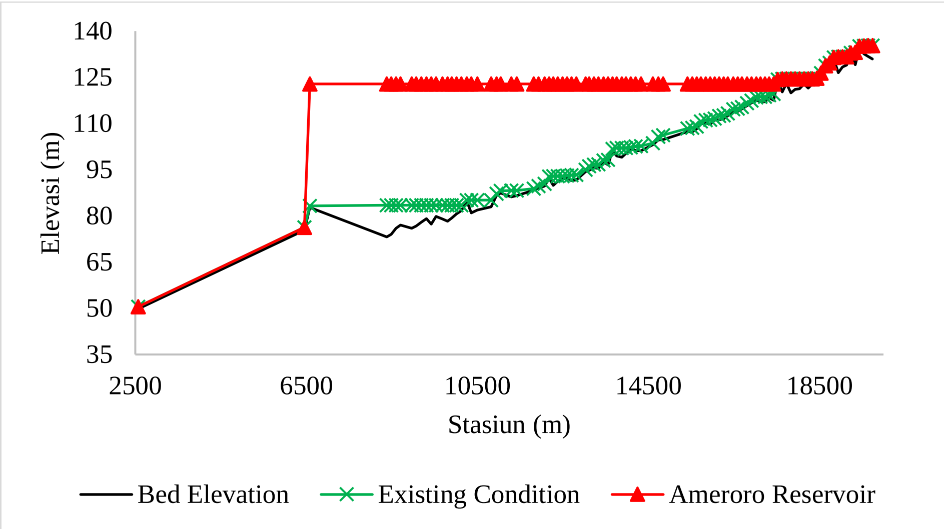

Figure 8 comparation for water surface elevation

Tabel 6 Amount of cross section that calculated stable.

Method	Existing Condition	Present of Ameroro Reservoir
Blench	4 Cross section (upstream) 3 Cross section (middle stream)	1 Cross section (upstream)
Lacey	1 Cross section (middle streqam)	1 Cross section (downstream)
Regime Modification	1 Cross section (upstream) 3 Cross Section (middle stream)	2 Cross section (upstream)

Note: Cross section stable when mean absolute error <5%

Tabel 7 Comparison result with regime theory on width at the existing condition

Segment	Width (m)	Width using Regime Theory (m)		
		Blench	Lacey	Regime Modification
Upstream (St. 19741 - St. 16488)	46.76 - 107.57	15.58 - 312.44	4.25 - 74.22	8.13 - 99.36
Middle Stream (St. 16359 - St. 8383)	37.91 - 457.73	4.41 - 266.53	3.89 - 120.53	7.48 - 120.53
Downstream (St. 6583 - St. 2565)	35.36 - 90.40	129.52 - 950.96	29.98 - 160.79	55.91 - 309.18

Tabel 8 Comparison result with regime theory on width at the reservoir condition

Segment	Width (m)	Width using Regime Theory (m)		
		Blench	Lacey	Regime Modification
Upstream (St. 19741 - St. 16488)	41.68 - 101.15	6.33 - 227.22	3.40 - 63.87	6.61 - 118.51
Middle Stream (St. 16359 - St. 8383)	76.90 - 620.25	28.56 - 78.78	23.13 - 23.19	43.03 - 43.14
Downstream (St. 6583 - St. 2565)	13.36 - 199.07	80.32 - 315.58	23.13 - 116.85	48.36 - 362.61

Based on 3 river segments and 96 cross sections, it can be seen in Table 6 that existing conditions have more stable cross sections (1.04 % - 7.29%) than reservoir conditions (1.04% - 2.08%). A comparison of river width ranges can be seen in Table 7 and Table 8 that the existing condition of the river and the presence of dams show that both conditions are overall unstable based on regime theory.

Tabel 9 Comparation of regime calculation for 2 conditions of geometry

Method	Existing Condition			Present of Ameroro Reservoir		
	NSE	RMSE	COR	NSE	RMSE	COR
Blench	(0.64)	146.50	(0.28)	0.35	194.95	0.02
Lacey	(1.24)	100.74	(0.25)	(0.54)	223.94	(0.13)
Regime Modification	(1.16)	98.83	(0.26)	(0.37)	210.83	(0.05)

By checking the results thoroughly of the river using the NSE, RMSE and CORRELATION methods in Table 9, it was found that the condition of the reservoir was closer to stable compared to the existing condition.

4 Conclusion

The Ameroro River model on the existing condition and the condition of the functioning of the Ameroro Reservoir shows that there are changes in river morphology in riverbed elevation, water level elevation and degradation aggradation. Using 3 types of regime theory seen from the cross-sectional width of the river, it was found that the existing condition had more stable river cross-section compared to the reservoir condition but less than 10% of the cross-section reviewed. In the overall of river, the effect of reservoir on the stability of the river is closer to the results of regime theory calculations than existing conditions based on NSE, RMSE and CORRELATION tests. So based on the results of the study, it was found that the existence of the Ameroro Reservoir will affect the stability of the Ameroro River compared to the existing conditions, where the stability of the river becomes closer to the calculation of the regime theory.

The river stability approach using regime theory is strongly influenced by sediment gradation that happens in rivers. The sediment transport model in this study uses data from soil drilling results that are adjusted for use based on drilling elevation with riverbed elevation. This approach can be the subject of future research by calibrating the results of sediment modeling by taking sediment samples directly on the river bed.

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