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SENSITIVITY ANALYSIS OF GRAIN SIZE AND CHANNEL OPENING WIDTH ON SEDIMENT TRANSPORT IN BIFURCATED REACH

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ABSTRACT

Sediment transport dynamics in river bifurcations are highly sensitive to variations in channel geometry, especially to changes in channel width and sediment grain size. This study uses a physical model to study how sediment size affects flow and sediment movement for different channel opening width ratios. The tests were done in a sand bed channel at the Hydraulics and River Engineering Lab, WRE, BUET. This study examines the effect of sediment size on distribution patterns caused by bifurcation entrance variation. A total of 24 experimental runs were carried out with an upstream discharge of 0.04 m³/s. Sediment was supplied at rates of 44 kg/hr for bed load (d_{50} = 0.27 mm) and 60 kg/hr for suspended load (d_{50} = 0.22 mm). The experiments were conducted using three different opening width ratios: 0.43, 1.08, and 1.56. Measurements of bed load, suspended sediment load, and water depth were taken to assess their effects on sediment distribution in the downstream channel.

Sediment distribution is significantly affected by both the size of the sediment and the channel's opening width ratio. As the opening ratio increases, coarse sand (d_{50} = 0.27 mm) becomes less predominant in the bed load, while fine sand (d_{50} = 0.22 mm) becomes more predominant in the suspended load. Fine sand is more evenly spread through wider openings, whereas coarse sand remains more focused in narrower channels. Therefore, the discharge ratio is mainly controlled by the channel's opening width, rather than by the sediment size.

The findings of this study can provide valuable insight into how sediment size affects sediment distribution during flooding, potentially aiding in the development of more effective flood risk management strategies.

Keywords: *Sediment size, Bed load, Suspended load, Bifurcated channel, Channel width ratio, Dimensional analysis*

1. INTRODUCTION

Rivers naturally split into two or more channels downstream, called bifurcations or distributaries. Sediment size influences erosion and deposition, causing the main channel entrance to change over time. Factors affecting bifurcation include channel geometry, sediment properties, grain size, settling velocity, and bed load versus suspended load proportions (Ksiazek & Meijer, 2011). Bolla Pittaluga et al.'s model, extended by Miori et al., (2006), applies to channels with erodible banks, the evolution of channel bed and bank,(Bertoldi & Tubino, 2005) allowing channel width to adjust to flow conditions. The role of migrating alternate bars was studied in a Y-shaped channel with fixed banks and sandy, erodible beds. The nose angle is a key factor influencing these sediment divisions (Islam et al., 2006). To investigate this, a mobile bed model of channel bifurcation was developed at the Hydraulics and River Engineering Laboratory, BUET, in collaboration with Delft University of Technology (DUT), Netherlands. The experimental setup was originally designed by Dekker & van Voorthuizen, (1994). Physical model studies by Roosjen & Zwanenburg, (1995) provided further insights into bifurcation dynamics and helped formulate nodal point relations. More recently, Das et al., (2023) conducted experiments on channel bifurcation based on the Kangsabati River. Hossain et al., (2025) examined bed level changes in asymmetric bifurcated channels under varying discharge and tailwater depths, while Hossain et al., (2024) analyzed soil types to ensure underwater slope stability (Jany et al., 2025) during dredging. Edmonds & Slingerland, (2008) used the Delft3D model to study asymmetric, fine-grained cohesive bifurcations. Islam et al., (2004) conducted a physical model study on bifurcated channels to analyse scour patterns near the nose tip, examining two different nose angles. Obasi et al., (2012) found that increasing the offtake angle in concave bifurcations leads to higher suspended sediment concentration, supported by experiments and simulations. Malik & Matin, (2021) investigated flow and sediment distribution at river offtakes with varying angles, focusing on suspended sediment transport. Hossain, (2024) developed a mobile bed model using a median grain size (d_{50}) of 0.27 mm for bed load transport, while Rahman, (2024) studied suspended load with d_{50} of 0.22 mm. Sediment transport and bed morphology depend on particle properties like fall velocity (Cheng, 1997). Raju & Matin, (2013) created a settling velocity model validated against established formulas. Kleinhans et al., (2008) proposed a meander-influenced sediment division relation and examined the mechanisms, triggers, and modeling of bifurcations and avulsions (Kleinhans et al., 2013), including their stability conditions. Iwantoro et al., (2021) used a 1D model showing sediment size and slope impact transport in low-gradient rivers. However, the influence of sediment size on distribution patterns resulting from river entrance variation has not yet been thoroughly investigated. The combined effect of sediment discharge and flow discharge resulting from river entrance variation will be investigated, which may offer deeper insight into the influence of sediment size and its behavior. Understanding the influence of sediment size on sediment distribution during flood events may contribute to more effective flood risk management.

2. METHODOLOGY

Experiments were conducted with a 0.04 m^3/s upstream discharge, 44 kg/hr (bed load condition) and 60 kg/hr (suspended load condition) sediment feed, based on pump and sand feeder capacity. Four tailwater levels were tested for each run, maintaining equal downstream water levels in the bifurcated channels. Discharge and water levels were measured at regular intervals using a Rehbock weir and point gauges. Flow velocity in the main and branch channels were measured using a current meter. During the experiment, the initial bed level is prepared according to the bed slope in the mobile bed channel. All measurements are taken with respect to a reference level. After each run, the tailgates are gradually lifted, and the pump and sand feeder are shut down in sequence. Once the water level stabilizes, bed-level readings are taken, and sediment from the sand traps is collected after siphoning out the water without any sediment loss, for a sediment size of d_{50} = 0.27 mm (as bed load movement). The collected sediment is dried for reuse in the next experiment. This process is used for bedload measurement (Hossain et al., 2025). Suspended sediment samples are collected from branch channels after stable bedforms develop, to assess sediment distribution between the downstream branches (Malik & Matin, 2021). Suspended sediment samples (500 ml) were collected using a modified cylindrical container and filtered through pre-weighed, oven-dried Whatman 40 ashless filter papers (Kibriya, 2024). The sediment-laden filter papers were then oven-dried at 105 °C for 24 hours (Obasi et al., 2012), and sediment concentration was determined based on the weight difference. The suspended sediment transport load was calculated (Rahman, 2024) using the multipoint method for a sediment size of d_{50} = 0.22 mm. All experimental data and observations are carefully recorded, including erosion and deposition patterns in key channel areas. Volumes of erosion/deposition (V_0, V_1, V_2), sediment transport (S_0, S_1, S_2), and sand trap contents (ST_1, ST_2) were calculated. Water depth, velocity, and discharge in both main and branch channels were also determined. The stepwise methodology is presented in Figure 1.

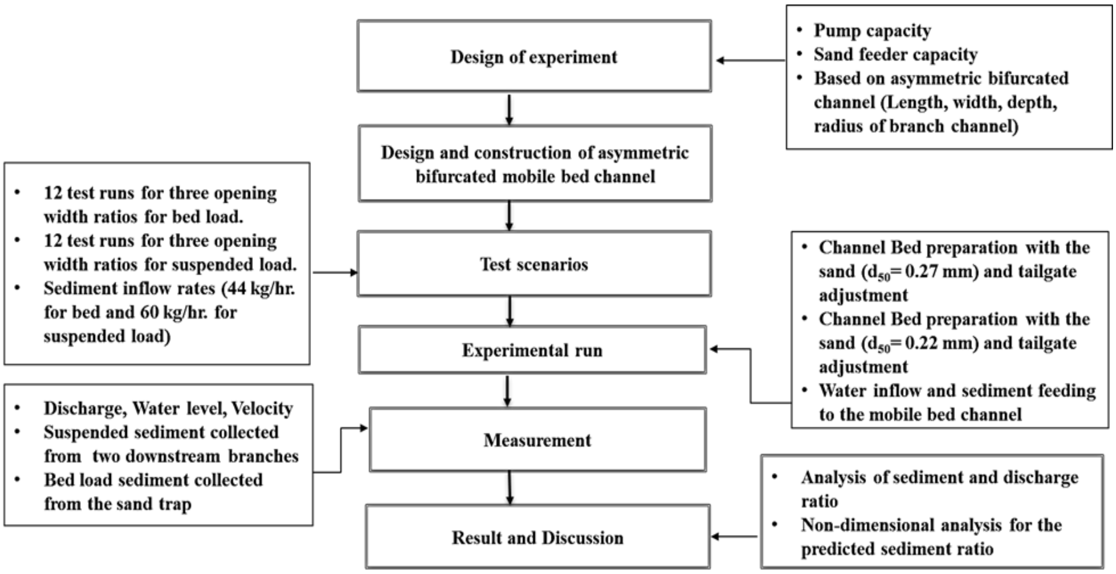


Figure 1: Stepwise methodology followed throughout the experiment.

2.1 Experimental Setup

The dimensions of the bifurcated channel, including its length, width, radius, depth, sand bed thickness,

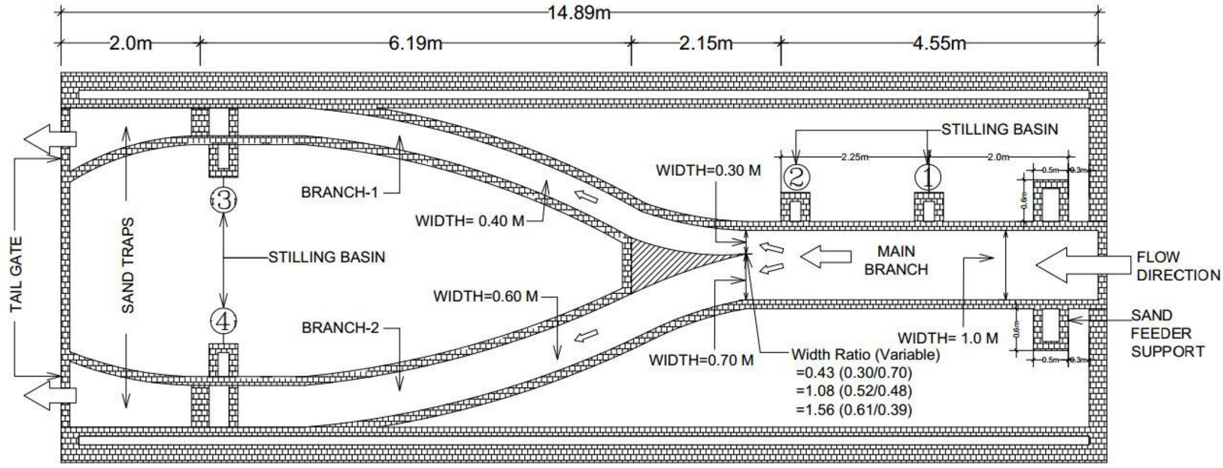


Figure 2: Experimental setup with varying channel opening width ratios.

sediment feed rate, bedforms, and sand trap capacity were designed based on the study by Dekker & van Voorthuizen, (1994). An asymmetric bifurcated channel system with fixed banks and a mobile sand bed (d_{50} = 0.27 mm) was constructed in the sand bed facility of the Hydraulics and River Engineering Laboratory, WRE, BUET, to carry out experimental investigations (Hossain, 2024). The experimental setup is illustrated in Figure 2. The width ratio is defined as the ratio of the opening widths of branch 1 and branch 2 at the bifurcation node. In this study, three opening width ratios were considered: width ratio: 1, where the widths of branch 1 and branch 2 are 0.3 m and 0.7 m, respectively; width ratio: 2, where the widths are 0.52 m and 0.48 m; and width ratio: 3, where the widths are 0.61 m and 0.39 m.

3. RESULTS AND DISCUSSIONS

A total of twenty-four experimental runs were conducted for three different channel width ratios, with an upstream discharge of 0.04 m³/s. The experiments were performed under varying water levels, while feeding sediment at a rate of 44 kg/hr for bed load (d_{50} = 0.27 mm) and 60 kg/hr for suspended load (d_{50} = 0.22 mm) into the flow based on Engelund & Hansen, (1967) transport formula and then a trial and error process like, Islam et al., (2006). The downstream water level was kept constant in the three-dimensional model of Kleinhans et al., (2008), and the present study followed the same approach to investigate the effect of different channel width ratios and to experimentally examine the sensitivity of sediment size variations in a bifurcated reach.

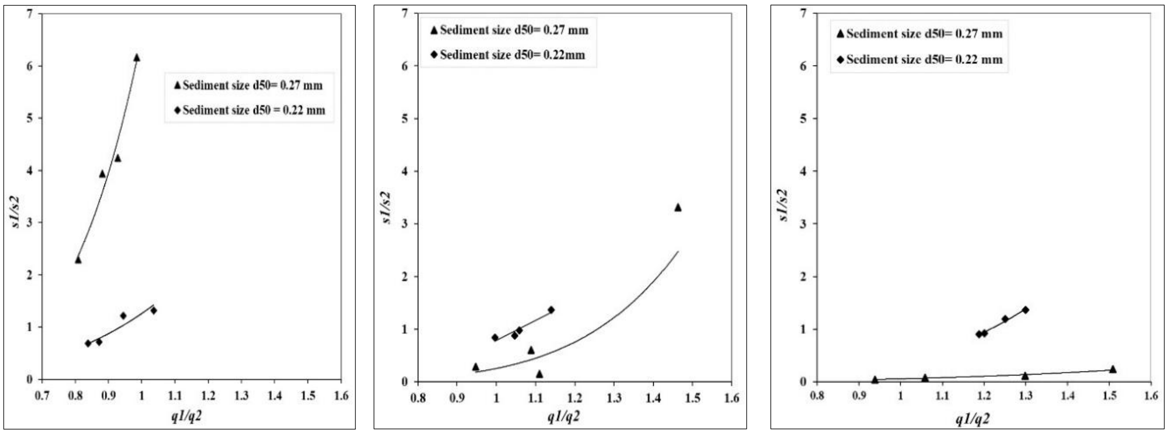
Table 1: Experimental data showing the discharge and sediment transport ratios per unit width.

Sediment Size d_{50} (mm)	Opening width ratio, W_r	Measuring Process	Discharge, Q (m^3/s)	Test Run	q_1/q_2	s_1/s_2
0.27	Opening width ratio:1 (0.43)	Measured as a bed load	0.04	1	0.8091	2.2919
				2	0.8811	3.9378
				3	0.9853	6.1647
				4	0.9275	4.2416
	Opening width ratio:2 (1.08)			1	1.0886	0.6077
				2	1.4635	3.3169
				3	0.9471	0.2906
				4	1.1097	0.1542
	Opening width ratio:3 (1.56)			1	0.9383	0.0484
				2	1.2982	0.1182
				3	1.5087	0.2467
				4	1.0585	0.0776
0.22	Opening width ratio:1 (0.43)	Measured as a suspended load		1	0.9442	1.2156
				2	0.8716	0.7203
				3	0.8390	0.6755
				4	1.0357	1.2849
	Opening width ratio:2 (1.08)			1	1.0583	1.0062
				2	1.1398	1.3411
				3	1.0471	0.8749
				4	0.9962	0.8447
	Opening width ratio:3 (1.56)			1	1.2511	1.2659
				2	1.2008	0.9227
				3	1.1877	0.9071
				4	1.2997	1.4138

The collected data were systematically analyzed and presented in various formats. Discharge measurements were taken at two rehbock weir located in the branch channels. Bed load sediment was collected and quantified using sand traps, while suspended sediment was obtained from sediment-laden water samples collected from downstream branch channels. Based on the measured discharge and sediment transport data, the downstream discharge ratio per unit width (q_1/q_2) and the sediment transport ratio per unit width (s_1/s_2) were calculated. These results are summarized in Table 1, which presents the discharge and sediment transport ratios for all experimental runs.

3.1 Sediment and Discharge Ratio in Different Sediment Size

The present study demonstrates that the sediment and discharge ratios in bifurcated channels are strongly influenced by the bifurcation opening width ratio. As shown in Figure 3, the sediment ratio increases with an increase in the opening ratio for fine sand (d_{50} = 0.22 mm), but decreases with an increase in the opening ratio for coarse sand (d_{50} = 0.27 mm). The discharge ratio increases with an increase in the opening ratio for both fine sand and coarse sand. As the opening ratio increases, coarse sand (d_{50} = 0.27 mm) becomes less predominant in the bed load, while fine sand (d_{50} = 0.22 mm) becomes more predominant in the suspended load. The sediment ratio increases with particle size, suggesting that coarser sediments tend to accumulate more in the Old Kasai, which has a larger bifurcation opening width ratio. In contrast, the right branch of the New Kasai has a smaller opening width ratio and receives less sediment (Das et al., 2023). In the context of bed load transport,(Ksiazek & Meijer, 2011) identified the existence of a corresponding critical width ratio (bifurcation nose angle), beyond which the diverted branch attains its maximum sediment conveyance capacity. The sediment transport ratio is higher at lower width ratios (Islam et al., 2006), and the present study follows the same phenomenon using the same sediment size (d_{50} = 0.27 mm) for bed load transport. Conversely, at lower opening width ratios, more sediment is transported due to higher flow velocities (Hossain et al., 2025). Under fixed bed and suspended load conditions, the proportion of water and sediment diverted from the main channel to the off-take was found to rise with increasing off-take angle (Obasi et al., 2012 ; Malik & Matin, 2021), which is consistent with the present study. Also, the discharge ratio increased with increasing opening width ratio for both fine and coarse sands. In contrast, experiments with graded sediments showed larger streamline and sorting pattern angles (35°–60°), which exhibited a slight positive correlation with the bifurcation width ratio (Bertoldi & Tubino, 2005).



Opening width ratio:1 (0.43)   Opening width ratio:2 (1.08)   Opening width ratio: 3 (1.56)

Figure 3: Sediment and discharge ratio for different opening width ratios

The study shows that discharge ratio is mainly controlled by bifurcation opening width, while sediment distribution is influenced by both sediment size and opening width ratios. These observations are consistent with previous findings that sediment grain size directly affect the quantity of sediment transport (Iwantoro et al., 2021) and also, sediment size influence slope stability (Hossain et al., 2024). The affects of flow and sediment dynamics, as widening enhances discharge asymmetry (Miori et al.,

2006) and interactions with sediment mass balance can prolong avulsion (Kleinhans et al., 2013). Overall, bifurcation width strongly governs flow partitioning and selective sediment transport, highlighting the coupling between channel morphology and sediment dynamics.

4. PREDICTED SEDIMENT RATIOS BY DIMENSIONAL ANALYSIS

The proposed relationship is developed through dimensional analysis using the Rayleigh method, ensuring dimensional consistency and offering a solid foundation for empirical calibration. Drawing from both theoretical reasoning and observed field behavior, the key physical variables influencing the sediment discharge ratio (S_1/S_2) at a bifurcation were identified. Here, S_1 and S_2 represent the sediment discharges in branches 1 and 2, respectively (volumetric rate, L^3T^{-1}).

W_r, the channel opening width ratio (dimensionless); h, the flow depth; and median grain size d_{50}.While the conventional Rayleigh method typically involves selecting “repeating variables” corresponding to the fundamental dimensions (Mass, Length, Time) to form dimensionless groups, this study adopts a conceptual approach that directly identifies the governing dimensionless ratios derived from the physical characteristics of the bifurcation system.

Based on the identified variables and insights from previous research, the following dimensionless groups (Pi terms) were formulated:

$\pi_1 = S_1 / S_2$ (Sediment discharge ratio)
$\pi_2 = W_r$ (Opening width ratio)
$\pi_3 = h_0/ d_{50}$ (Depth and median grain size ratio in main channel)

According to the principles of dimensional analysis, a functional relationship between a dependent dimensionless group and a set of independent dimensionless groups can be expressed as a power law. Thus, the relationship was postulated in the form:

$$\pi_1 = a\,\pi_2^b \pi_3^c \tag{1}$$

Dimensional analysis establishes a functional relationship among the non-dimensional parameters involved. It provides a systematic approach to organizing the variables in a physical relationship by combining dimensional quantities into non-dimensional groups. The proposed dimensional equation is

$$\frac{s_1}{s_2} = a * {W_r}^b * \left(\frac{h_0}{d_{50}}\right)^c \tag{2}$$

The dimensionless parameter (h_0/d_{50}) is used to express the ratio of water depth in the main river (h_0) to the median grain size (d_{50}), (s_1/s_2) denotes the sediment transport ratio per unit width, and W_r is the width ratio. The exponents a, b and c correspond to the respective powers of the dimensionless terms. Based on the analysis conducted using Python Programmed, the coefficients R^2, RMSE, and MAE have been determined and are presented in Table 2. By incorporating the coefficients, the equations were developed for sediment transport ratio per unit width in equation 3.

Table 2: Empirical equation for sediment distribution with different sediment sizes

Proposed equation	Coefficients			R^2	RMSE	MAE
	a	b	c			
$\frac{s_1}{s_2} = a * {W_r}^b * \left(\frac{h_0}{d_{50}}\right)^c$	$1*10^5$	-1.15304	1.90115	0.564	0.989	0.840

$$\frac{s_1}{s_2} = 10^5 * \left(\frac{1}{W_r}\right)^{1.15304} * \left(\frac{h_0}{d_{50}}\right)^{1.90115} \tag{3}$$

5. COMPARISON OF EXPERIMENTAL AND PREDICTED VALUE

The R^2 value for this model was found to be 0.564 (approximately 0.56). Figure 4, illustrates the comparison between the experimentally observed sediment distribution ratios per unit width and the values calculated by Equation (3). The plot reveals a moderate correlation, indicating that the proposed equation explains approximately 56% of the variability in the sediment distribution ratio.

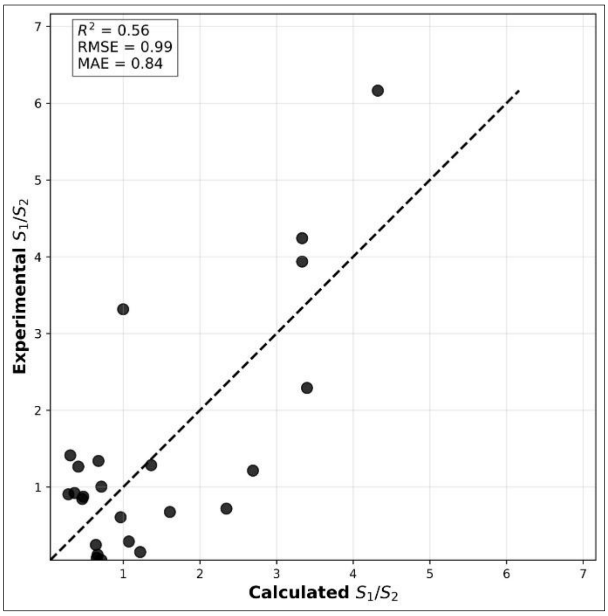


Figure 4: Experimental vs. calculated sediment distribution ratio per unit width with different sediment size

The proposed dimensional relationship demonstrates a reasonable predictive capability for estimating sediment distribution ratios at river bifurcations. Although the correlation indicates moderate accuracy, the model provides a valuable framework for understanding the influence of geometric and sediment characteristics on sediment transport behaviour.

6. CONCLUSIONS

This study experimentally investigates the effects of sediment grain size and channel opening width ratio on sediment transport behavior within a bifurcated reach. The results indicate that both flow and sediment partitioning are significantly controlled by these parameters.

The discharge ratio increases consistently with widening, whereas sediment division is jointly influenced by grain size and geometric asymmetry. Fine sediment (d_{50} = 0.22 mm) tends to remain in suspension and becomes more pronounced with increasing width ratio, while coarse sediment (d_{50} = 0.27 mm) predominantly contributes to bed load transport at narrower openings. These outcomes are consistent with earlier studies and reinforce the significance of bifurcation geometry in shaping flow sediment interactions and morphological evolution. The discharge ratio consistently rises with increasing opening width ratio for both sediment sizes, indicating that flow division is primarily controlled by channel geometry rather than grain size.

Dimensional analysis using the Rayleigh method established a predictive relationship between the sediment discharge ratio per unit width (s_1/s_2), opening width ratio (W_r), and the ratio of flow depth to median grain size (h_0/d_{50}). The derived equation demonstrated a moderate correlation ($R^2 = 0.56$) between the predicted and experimental sediment ratios, suggesting its suitability for empirical calibration. It is recommended that further refinement be carried out through additional experimental runs with more sediment size and validation against field observations.

Overall, the findings emphasize that bifurcation width exerts dominant control over discharge asymmetry, while sediment grain size modulates transport mode and spatial distribution. These insights contribute to a better understanding of sediment behaviour in bifurcated channels and provide a basis for optimizing sediment management and flood control strategies in river engineering applications.

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DECLARATION OF USE OF AI

The authors used ChatGPT and Grammarly exclusively for language editing, including grammar and sentence clarity. No AI tools were used for data analysis, interpretation, or scientific decision-making.

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