

Spatiotemporal variation in total nitrogen and organic matter in sediments of the Jingjiang Reach, Yangtze River

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Abstract

Nitrogen (N) and organic matter (OM) in sediments are key indicators of river ecosystem health, and their distributions are strongly influenced by dam regulation, hydrological conditions, and channel morphology. In this study, surface sediments were collected from 21 sites during three sampling events (January 2022, November 2022, and May 2023) in the Jingjiang Reach of the Yangtze River, downstream of the Three Gorges Reservoir. Sediment total nitrogen (STN) and sediment organic matter (SOM) concentrations were measured and analyzed. STN and SOM exhibited distinct temporal differences and spatial distribution patterns, with mean concentrations highest in May 2023 and lowest in November 2022. Neither STN nor SOM exhibited a statistically significant longitudinal gradient in any sampling event. However, SOM, but not STN, was significantly enriched at sites downstream of mid-channel bars in January 2022 and November 2022, suggesting that flow and depositional conditions associated with mid-channel bars promote SOM retention. Correlation analysis revealed positive but statistically nonsignificant relationships between STN and SOM, and their coefficients of variation reached maxima in different sampling events, indicating that these two variables did not vary in a strongly synchronized manner. Organic pollution index assessment showed that four representative sites remained within the clean category, although one site exhibited relatively greater susceptibility to organic enrichment. These findings improve understanding of sediment nutrient and organic matter dynamics in large regulated rivers and provide a scientific basis for river ecosystem assessment and management.

1. Introduction

Rivers are integral components of regional and global biogeochemical cycles, serving as major pathways for the transport and transformation of nutrients and pollutants (Cole et al., 2007; S. Zhao et al., 2022). As dynamic components of the fluvial system, sediments act both as sinks and sources of contaminants, including nitrogen, phosphorus, and heavy metals, thereby exerting a critical influence on water quality and the ecological balance (Chon et al., 2012; Wu et al., 2019). Sediments not only archive historical pollution signals but also actively participate in internal nutrient cycling, making them essential indicators of river health.

River sediment dynamics are susceptible to human activities. Among these, dam construction represents one of the most influential factors, as it fundamentally alters river hydrodynamics and sediment transport processes, thereby reshaping pollutant distribution and nutrient retention in downstream reaches (J. Chen et al., 2019; X. Li et al., 2007; Maavara et al., 2017; Nie et al., 2021). The Three Gorges Reservoir (TGR), the largest hydraulic project in the world, has substantially increased suspended sediment retention and nutrient retention, resulting in lower downstream suspended sediment concentrations and altered sediment composition (Gao et al., 2016; Jiang et al., 2018; Ding et al., 2019).

The Jingjiang Reach, located 45–420 km downstream of the TGR, is a representative and ecologically sensitive section of the middle Yangtze River. The interception of sediments and nutrients by the TGR

has markedly changed the nitrogen (N) and organic matter (OM) concentrations in this reach, resulting in eutrophication risks, changes in nutrient cycling, and deterioration of water quality (Grabb et al., 2021; Y. Li et al., 2021; A. Wang et al., 2020).

Sediment nitrogen is an essential nutrient that influences the trophic status of aquatic ecosystems. It occurs in both organic and inorganic forms, such as ammonium ($\text{NH}_4^+\text{-N}$), nitrite ($\text{NO}_2^-\text{-N}$), and nitrate ($\text{NO}_3^-\text{-N}$) (He et al., 2025; Lin et al., 2019; X. Li et al., 2007). Its distribution is strongly influenced by environmental conditions and human interventions, including damming and land-use changes (Garzon-Garcia et al., 2017; Grabb et al., 2021; Nie et al., 2021). Under certain conditions, such as elevated temperature, low dissolved oxygen, pH fluctuations, or hydrodynamic disturbances, sediment nitrogen can be released into overlying water, increasing eutrophication and water quality risks (Ning et al., 2025; Su et al., 2024).

Organic matter, another key sediment component, originates from both allochthonous sources, such as terrestrial plant debris, soil OM, and anthropogenic inputs, and autochthonous sources, such as algae, aquatic plants, and microbial biomass (Dan et al., 2019; C. Zhao et al., 2018). During transport and deposition, OM undergoes physical, chemical, and biological transformations, forming labile and stable fractions (M. Chen & Hur, 2015). Organic matter strongly influences river biogeochemistry: microbial decomposition releases nutrients, stimulating primary production and potentially promoting eutrophication under high OM input or low flow (X. Li et al., 2007; Y. Yang et al., 2017). Additionally, aerobic OM degradation consumes dissolved oxygen, and the subsequent nitrification of ammonium can exacerbate hypoxia or anoxia, causing fish mortality and benthic biodiversity loss (Carter et al., 2021).

The relationship between sediment total nitrogen (STN) and sediment organic matter (SOM) has been widely recognized. Numerous studies have reported a positive correlation between STN and SOM, including total carbon (Hong et al., 2019; Yao et al., 2022). This linkage is particularly evident in dam-affected river sections, where altered hydrodynamics and sedimentation processes promote the concurrent accumulation of SOM and STN, thereby shaping their biogeochemical cycling and influencing the risk of nutrient release. The co-distribution of STN and SOM reflects not only the input and transformation of both allochthonous and autochthonous materials but also highlights the critical role of SOM in regulating the storage, availability, and mobility of STN (Guan et al., 2022; Zhang et al., 2017).

In this study, surface sediments from 21 sites in the Jingjiang Reach were analyzed to characterize the spatiotemporal variation in STN and SOM under contrasting hydrological and reservoir-operation backgrounds. To further explore their spatial distribution patterns, this study examined whether STN and SOM exhibited longitudinal gradients along the reach and whether sites located downstream of mid-channel bars showed distinct enrichment characteristics relative to other sampling locations. In addition, the relationship between STN and SOM was examined, and the degree of organic pollution at four representative sites was evaluated.

2. Material and methods

2.1 Study area

The Jingjiang Reach, located between Zhicheng (ZC) and Chenglingji (CLJ) in the middle section of the Yangtze River, spans approximately 340 kilometers. This reach is characterized by meandering channels and is notably influenced by the operation of the TGR, resulting in significant alterations to its hydrodynamic and sediment transport regimes.

To comprehensively assess the spatiotemporal variation in STN and SOM in the Jingjiang Reach, 21 sites were selected for field sampling to represent the diverse hydrodynamic and geomorphological conditions along the Reach. The sites were distributed across upstream, midstream, and downstream sections, and their locations were chosen relative to the three major hydrological stations: Zhicheng, Shashi (SS), and Chenglingji, which are located approximately 90 km, 187 km, and 420 km downstream of the TGR, respectively. Among these stations, ZC marks the commencement of the Jingjiang Reach, whereas CLJ denotes its downstream terminus. The distance between adjacent sampling sites generally ranged from several to several tens of kilometers, allowing detailed spatial analysis while remaining relevant to the hydrological stations. Notably, the sampling sites were selected explicitly for targeted sediment sampling, so they may not always coincide precisely with the station locations. The geographic coordinates of all sampling sites are listed in Table 1, and their spatial distribution is shown in Fig. 1.

Table 1
Geographic coordinates of the field sampling sites

Sampling area	Sample site code	Latitude (°N)	Longitude (°E)
Jingzhou	JZ1	30.269	111.572
Jingzhou	JZ2	30.328	111.644
Jingzhou	JZ3	30.419	111.747
Jingzhou	JZ4	30.420	111.867
Jingzhou	JZ5	30.353	111.925
Jingzhou	JZ6	30.277	112.015
Jingzhou	JZ7	30.292	112.123
Jingzhou	JZ8	30.231	112.285
Shishou	SS1	30.067	112.247
Shishou	SS2	30.021	112.403
Shishou	SS3	29.868	112.392
Shishou	SS4	29.739	112.392
Shishou	SS5	29.780	112.451
Shishou	SS6	29.697	112.633
Jianli	JL1	29.736	112.712
Jianli	JL2	29.765	112.931
Jianli	JL3	29.624	112.908
Yueyang	YY1	29.468	112.955
Yueyang	YY2	29.526	113.048
Yueyang	YY3	29.440	113.093
Yueyang	YY4	29.460	113.155
Note: Geographic coordinates of the 21 sampling sites are provided in decimal degrees. Each site is assigned a unique code derived from the sampling area abbreviation (JZ for Jingzhou, SS for Shishou, JL for Jianli, YY for Yueyang), followed by a sequential number.			

Sites located downstream of mid-channel bars were identified according to the planform morphology of the Jingjiang Reach and the relative positions of sampling sites shown in Fig. 1. The downstream group included JZ4, SS4, JL2, and YY1, whereas the remaining sites were assigned to the other site group.

2.2 Data collection

Field sampling was conducted in January 2022, November 2022, and May 2023. These sampling events were selected to represent contrasting hydrological and reservoir operation states. For the Jingjiang Reach, January 2022 and November 2022 corresponded to low flow or dry season periods, whereas May 2023 corresponded to the onset of the high flow and flood season transition.

In terms of Three Gorges Reservoir operation states, January 2022 corresponded to a high water to early drawdown state, November 2022 corresponded to the post-flood impoundment stage under the atypically low water conditions of 2022, and May 2023 corresponded to the pre-flood drawdown period of the reservoir (X. Liu et al., 2024).

Surface sediment samples were collected at each site.

Immediately after collection, all samples were sealed in clean polyethylene containers and transported to the laboratory under refrigeration. The sediment samples were stored at -20°C to prevent any alteration in their physicochemical properties before analysis.

2.3 Sample analysis methods

The total nitrogen in the sediment was determined via the modified Kjeldahl method (Bremner, 1960).

The sediment organic matter content was measured via the method for determining the soil organic matter content (Walkley & Black, 1934).

2.4 Evaluation of the degree of organic pollution in sediment

Given the lack of a globally standardized framework for evaluating nutrient pollution in river sediments, various assessment approaches have been developed and widely applied in environmental research. Representative examples include the geoaccumulation index method, which quantifies anthropogenic influence by comparing element ratios to natural background levels (Buccolieri et al., 2006); the Potential Ecological Risk Index (PERI), which incorporates toxicity response coefficients to quantify ecological threats (Hakanson, 1980); and Sediment Quality Guidelines (SQGs) formulated by agencies such as the United States Environmental Protection Agency (US EPA) and the Canadian Council of Ministers of the Environment (CCME), providing threshold values for contaminant concentrations in sediments (MacDonald et al., 2000).

As most existing indices either require localized background references or were developed primarily for heavy metal evaluation, the Organic Pollution Index (OPI) was applied to assess organic enrichment in sediments from four representative sites along the Jingjiang Reach. The OPI method is based on the concentrations of ON and SOM, providing a simple yet effective means of assessing sediment pollution caused by nutrient enrichment (D. Wang et al., 2021). This method has been widely used in Chinese river systems and is particularly appropriate in dam regulated environments where sediment composition has been altered. The formula is as follows:

$$TOC = SOM/1.724$$

1

$$ON = STN \times 95\%$$

2

$$OPI = TOC \times ON$$

3

In the formulas,

SOM is the organic matter content in the sediment (%);

TOC is the total organic carbon in the sediment (%);

STN is the nitrogen content in the sediment (%);

ON is the organic nitrogen content in the sediment (%);

OPI is the organic pollution index.

Before calculating OPI, STN and SOM values expressed in g/kg were converted to percentage. The evaluation criteria for the organic pollution index are shown in Table 2.

Table 2
Evaluation criteria for the organic pollution index of sediments

Organic pollution index	Level	Level of contamination
$OPI < 0.05$	I	Clean
$0.05 \leq OPI < 0.20$	II	Slight pollution
$0.20 \leq OPI < 0.50$	III	Moderate pollution
$0.50 \leq OPI$	IV	Severe pollution
Note: This table presents the classification criteria for the sediment organic pollution index (OPI). The index values correspond to four contamination levels (I–IV), ranging from clean to severe pollution.		

2.5 Statistical analysis

Descriptive statistics, including minimum, maximum, mean, median, standard deviation, and coefficient of variation (CV), were calculated to summarize the distributions of STN and SOM during each sampling event. Pearson correlation analysis was applied to evaluate the relationships between STN and SOM within each sampling event.

To compare spatial enrichment patterns among sampling sites while reducing the influence of differences in the overall concentration levels among sampling events, STN and SOM values were standardized separately for each sampling event using Z-score normalization:

$$Z_i = (X_i - \mu) / \sigma$$

4

In the formulas,

X_i is the measured STN or SOM value at site i ;

μ is the mean concentration of STN or SOM across all sampling sites during the same sampling event;

σ is the corresponding standard deviation.

Positive Z-scores indicate relative enrichment compared with the event-specific mean, whereas negative Z-scores indicate relative depletion.

Spearman rank correlation analysis was used to examine whether the standardized STN and SOM values exhibited monotonic longitudinal trends with site longitudinal position along the Jingjiang Reach.

To assess the potential influence of mid-channel bars on sediment nutrient and organic matter accumulation, sampling sites located downstream of mid-channel bars were compared with the remaining sites using the Mann–Whitney U test based on their standardized STN and SOM values. Statistical significance was evaluated at $p < 0.05$.

3. Results

3.1 Variation in total nitrogen in the sediment

The STN values at the 21 sites along the Jingjiang Reach for the three sampling events are shown in Fig. 2. The statistical variation in the STN for the three sampling events is shown in Fig. 3.

For the samples collected in January 2022, the STN at each site ranged from 0.102 g/kg at JZ6 to 1.021 g/kg at SS2, with a mean concentration of 0.494 g/kg, a median concentration of 0.477 g/kg, and a CV of 0.516.

For the samples collected in November 2022, the STN content ranged from 0.107 g/kg at JZ6 to 1.151 g/kg at JZ4, with a mean concentration of 0.484 g/kg, a median concentration of 0.376 g/kg, and a CV of 0.668.

For the samples collected in May 2023, the STN content ranged from 0.113 g/kg at SS6 to 1.285 g/kg at JL3, with a mean concentration of 0.567 g/kg, a median concentration of 0.422 g/kg, and a CV of 0.724.

3.2 Variation in organic matter in the sediment

The SOM at 21 sites along the Jingjiang Reach for the three sampling events is shown in Fig. 4. The statistical variation in the SOM for the three sampling events is shown in Fig. 5.

For the samples collected in January 2022, the SOM content at each site ranged from 2.2 g/kg at JZ8 to 15.6 g/kg at JL2, with a mean concentration of 7.348 g/kg, a median concentration of 7.1 g/kg, and a CV of 0.542.

For the samples collected in November 2022, the SOM content ranged from 2.1 g/kg at JZ1 and YY3 to 18.2 g/kg at YY1, with a mean concentration of 7.038 g/kg, a median concentration of 4.8 g/kg, and a CV of 0.731.

For the samples collected in May 2023, the SOM content ranged from 2.6 g/kg at YY3 to 21.9 g/kg at SS2, with a mean concentration of 10.233 g/kg, a median concentration of 10.6 g/kg, and a CV of 0.550.

3.3 Correlation between STN and SOM

Pearson correlation analysis showed positive but statistically nonsignificant relationships between STN and SOM in January 2022, November 2022, and May 2023 ($p \geq 0.05$), as shown in Table 3.

Table 3
Pearson correlations between STN and SOM within each sampling event

Sampling event	Pearson correlation coefficient, <i>r</i>	<i>p</i> -value	Significance
January 2022	0.314	0.17	Not significant
November 2022	0.321	0.16	Not significant
May 2023	0.363	0.11	Not significant
Note: This table presents the Pearson correlation coefficients and corresponding <i>p</i> -values between STN and SOM within each sampling event. Cross-event correlations were not included because they were not relevant to the present analysis. Statistical significance was evaluated at $p < 0.05$.			

3.4 Organic pollution assessment

The OPI values of sediments at four representative sites during the three sampling events are shown in Table 4. All samples were classified as “clean” according to the adopted assessment criteria. The highest OPI value was observed at JZ1 in May 2023 (0.0409), whereas the lowest value was found at JZ8 in January 2022 (0.0012).

Table 4
Organic pollution indices of sediments at four representative sites

Sampling site	Sampling time		
	Jan 2022	Nov 2022	May 2023
JZ1	0.0059	0.0070	0.0409
JZ3	0.0229	0.0060	0.0209
JZ8	0.0012	0.0034	0.0023
YY3	0.0143	0.0048	0.0022
Note: This table presents the organic pollution index (OPI) values for sediments at four representative sites (JZ1, JZ3, JZ8, YY3) across three sampling events (Jan 2022, Nov 2022, May 2023).			

3.5 Standardized spatial patterns of STN and SOM across sampling events

To further characterize the relative enrichment and depletion patterns of STN and SOM across the Jingjiang Reach, the values of both indicators were standardized separately within each sampling event using Z-score normalization. The standardized values for the 21 sampling sites are presented in Table 5.

Table 5
Z-score-standardized STN and SOM values at each site during the three sampling events

Sampling site	Relative position to the mid-channel bar	Jan 2022		Nov 2022		May 2023	
		STN	SOM	STN	SOM	STN	SOM
JZ1	tributary side	-0.659	-1.017	0.391	-0.960	0.069	0.403
JZ2		1.362	-1.117	1.827	-0.843	1.367	0.883
JZ3		0.153	0.114	-0.789	-0.435	-0.509	0.065
JZ4	downstream side	0.907	0.892	2.059	1.062	0.086	0.474
JZ5	mainstream side	-0.071	-0.414	-0.394	0.517	-0.353	-1.233
JZ6		-1.491	-0.891	-1.166	-0.804	1.517	-0.646
JZ7		-1.150	-0.615	-1.033	-0.785	1.386	-0.771
JZ8		-1.538	-1.293	-0.839	-0.804	-1.037	-1.286
SS1		0.565	0.139	0.740	-0.241	0.051	-0.664
SS2		2.068	0.792	0.712	1.703	-0.518	2.075
SS3	downstream side	0.153	0.315	-0.335	1.139	-1.020	0.563
SS4		-0.067	1.093	1.141	-0.066	0.069	0.652
SS5		-0.396	-1.218	-1.043	-0.804	-0.913	0.848
SS6		0.695	1.671	1.283	0.867	-1.105	-0.966
JL1		-0.553	-1.168	-0.715	-0.571	0.858	0.101
JL2	downstream side	-1.323	2.073	-1.061	1.509	-1.018	-0.646
JL3	downstream side	-0.687	0.516	-0.573	-0.435	1.749	1.879
YY1		1.542	1.093	0.666	2.169	1.552	0.919
YY2		-0.491	-0.062	-0.817	-0.571	-0.796	-0.753
YY3	mainstream side	0.322	-0.715	-0.224	-0.960	-1.008	-1.357
YY4		0.659	-0.188	0.171	-0.688	-0.426	-0.539
Note: STN and SOM values were standardized separately within each sampling event using Z-score normalization. Positive values indicate concentrations higher than the event-specific mean, whereas negative values indicate concentrations lower than the event-specific mean. Sites located downstream of mid-channel bars included JZ4, SS4, JL2, and YY1; the remaining sites were classified as other sites for subsequent group comparisons.							

The Spearman rank correlations between site longitudinal position and the Z-score-standardized STN and SOM values are presented in Table 6.

Table 6

Spearman rank correlations between site longitudinal position and Z-score-standardized STN and SOM values

Sampling event	Variable	Spearman's ρ	p -value
Jan 2022	STN	0.060	0.797
Jan 2022	SOM	0.270	0.236
Nov 2022	STN	-0.131	0.571
Nov 2022	SOM	0.174	0.451
May 2023	STN	-0.203	0.377
May 2023	SOM	-0.048	0.836
Note: Site longitudinal position was represented by the ordered sequence of the 21 sampling sites along the Jingjiang Reach from Zhicheng to Chenglingji. STN and SOM values were standardized separately within each sampling event using Z-score normalization. Spearman's ρ was used to evaluate monotonic longitudinal trends. Statistical significance was assessed at $p < 0.05$.			

None of the correlations reached statistical significance during the three sampling events, and the directions of the correlation coefficients were not consistent among events. These results indicate that neither STN nor SOM exhibited a statistically significant longitudinal gradient in any sampling event.

The Mann-Whitney U test results comparing sites downstream of mid-channel bars with the remaining sites are presented in Table 7.

Table 7

Mann-Whitney U test results comparing Z-score-standardized STN and SOM between sites downstream of mid-channel bars and other sites

Sampling event	Variable	Mean Z-score at sites located downstream of mid-channel bars	Mean Z-score at other sites	U statistic	p -value
Jan 2022	STN	0.265	-0.062	42.0	0.502
Jan 2022	SOM	1.288	-0.303	65.0	0.006
Nov 2022	STN	0.701	-0.165	46.0	0.303
Nov 2022	SOM	1.169	-0.275	61.0	0.017
May 2023	STN	0.172	-0.040	42.5	0.474
May 2023	SOM	0.350	-0.082	47.5	0.244
Note: sites located downstream of mid-channel bars included JZ4, SS4, JL2, and YY1; the remaining 17 sampling sites were classified as other sites. STN and SOM values were standardized separately within each sampling event using Z-score normalization. The Mann-Whitney U test was used to compare the standardized values between the two site groups. Statistical significance was assessed at $p < 0.05$. Significant p -values are shown in bold.					

SOM Z-scores at sites located downstream of mid-channel bars were significantly higher than those at other sites in January 2022 and November 2022, whereas no significant difference was detected in May 2023. In contrast, STN Z-scores did not differ significantly between the two site groups during any of the three sampling events.

4. Discussion

4.1 Controls on the STN-SOM relationship

As shown in Table 3, STN and SOM exhibited positive but statistically nonsignificant correlations during the three sampling events. The lack of statistical significance between SOM and STN likely reflects the complex interplay among multiple environmental factors that govern sediment composition. Although SOM can affect STN through microbial decomposition and nitrogen retention, their relationship is influenced by hydrodynamic sorting, variation in sediment particle size, anthropogenic nutrient inputs, and patterns of land use across the watershed. Moreover, asynchronous inputs from different sources, such as agricultural runoff with high nitrogen and organic detritus from vegetation, may further weaken the direct association between the two.

Taken together, despite a general tendency for SOM and STN to vary together, their correlation was not statistically significant in this study. This finding might suggest that the variation in STN and SOM is controlled by a combination of physical and biogeochemical processes, highlighting the need for integrated monitoring and management strategies that address multiple factors affecting sediment quality in large river systems.

4.2 Effects of mid-channel bars on the variation in STN and SOM

As shown in Table 6, neither STN nor SOM exhibited a statistically significant longitudinal gradient along the Jingjiang Reach. The results in Table 7 further showed that SOM Z-scores at sites located downstream of mid-channel bars were significantly higher than those at the remaining sites in January 2022 and November 2022, whereas no significant difference was detected in May 2023. These results indicate that the downstream influence of mid-channel bars was more clearly reflected in the spatial accumulation of SOM than in that of STN.

The SOM enrichment at sites located downstream of mid-channel bars can be interpreted in relation to the hydraulic and sedimentary effects of mid-channel bars. Previous studies of the Jingjiang Reach have shown that mid-channel bars are commonly associated with spatial differentiation in composition of bed materials and local changes in flow and sediment transport conditions; in some cases, upstream sections dominated by gravel, vegetated middle sections, and downstream sections dominated by sand have been observed (Yang et al., 2023). Experimental evidence further indicates that vegetated mid-channel bars can substantially modify local flow and turbulence structures in bifurcated channels, including longitudinal velocity, Reynolds stress, turbulence intensity, momentum transfer, and

development of shear layers (Nandi et al., 2024). Such changes may weaken local flow energy downstream of the bars and favor the retention of particles rich in organic matter. In addition, finer sediments generally have larger specific surface areas and stronger adsorption capacity for substances associated with organic matter than coarser sediments (Y. Liu et al., 2024). Therefore, the relatively high SOM concentrations at sites located downstream of mid-channel bars may reflect the combined effects of flow adjustment, particle retention, and favorable local depositional conditions.

Sites located downstream of mid-channel bars showed statistically detectable SOM enrichment but did not display a corresponding and consistent STN enrichment pattern. This may suggest that nitrogen accumulation in the sediments was not governed solely by the same local depositional mechanism that favored SOM retention. Compared with SOM, STN may be more strongly affected by multiple concurrent processes, including external nitrogen inputs, transformation among nitrogen forms, and hydrodynamic redistribution of particulate and dissolved nitrogen. This spatial contrast is consistent with the weak STN–SOM association discussed in Section 4.1.

4.3 Effects of hydrological conditions and TGR operation on temporal variation in STN and SOM

As shown in Fig. 3 and Fig. 5, the mean concentrations of both STN and SOM were highest in May 2023 and lowest in November 2022. The CV values reported in Sections 3.1 and 3.2 further show that STN exhibited its greatest spatial dispersion in May 2023, whereas SOM showed its greatest spatial dispersion in November 2022. The asynchronous CV maxima of STN and SOM provide additional evidence that the two indicators did not vary in a strongly synchronous manner, which is consistent with the statistically nonsignificant correlations discussed in Section 4.1.

The higher mean concentrations of STN and SOM in May 2023 may be associated with the relatively stronger hydrological conditions during this sampling event. Compared with January 2022 and November 2022, the higher water level and discharge in May 2023 facilitated the transport of substances from watersheds to rivers as well as their redistribution within river channels. Increased runoff can enhance the mobilization and transport of nitrogen from agricultural drainage, urban effluents, and soil erosion. Meanwhile, stronger hydrodynamic exchange and material transport driven by floods can promote the redistribution of dissolved substances and the deposition of particles bearing nutrients in favorable depositional zones (Gu et al., 2025; Yu et al., 2020; Huang et al., 2022; H. Liu et al., 2025). These processes may have contributed to the higher mean concentrations of STN and SOM in May 2023.

The higher mean concentrations of STN and SOM in May 2023 may also have been influenced by the drawdown-period operation of the TGR. The TGR remained in the pre-flood drawdown period during the first half of 2023, although the decline in forebay water level was weaker than that observed in typical years (X. Liu et al., 2024). Previous studies have shown that drawdown-period operation can promote sediment movement in the backwater area of TGR. Meanwhile, reservoir drawdown is widely recognized as a general mechanism that enhances the remobilization and downstream transport of deposited

sediments (Hu & Fang, 2022; Kondolf et al., 2014). Therefore, the TGR drawdown regime may have facilitated the downstream transport of fine sediment carrying organic and nitrogenous materials.

Conversely, the lower mean concentrations of STN and SOM in November 2022 may have been related in part to the post-flood impoundment operation of the TGR. The TGR initiated post-flood impoundment on 10 September 2022 from a relatively low forebay water level of 147.94 m, after which the reservoir level increased gradually and fluctuated around 159 m during November to December 2022 (X. Liu et al., 2024). Studies on sediment regulation in the TGR have shown that rising reservoir water levels reduce sediment discharge ratios and enhance sediment retention within the reservoir system. Reduced downstream transport of fine suspended sediment and its associated organic and nitrogenous constituents may therefore have contributed to the lower mean concentrations of STN and SOM in November 2022 (Guo et al., 2023; Tang et al., 2021).

4.4 Environmental implications of the organic pollution assessment

As shown in Table 4, although all sediment samples from the four representative sites were classified as “clean” during the three sampling events, the relatively high OPI at JZ1 suggests a greater potential for STN and SOM accumulation, which may be associated with localized hydrodynamic conditions, patterns of land use, or anthropogenic influences. Continuous monitoring is recommended for such sites to prevent potential organic pollution in the future, particularly given that excessive SOM accumulation can induce oxygen depletion and adversely affect aquatic ecosystems (Hogsett & Goel, 2013).

4.5 Limitations of the study

This study has several limitations. First, the three sampling events represented contrasting hydrological and reservoir-operation states, but they did not cover continuous seasonal cycles or multiple years. Therefore, the temporal patterns identified here should be interpreted as event-based differences rather than long-term trends. Second, although the 21 sampling sites covered the main section of the Jingjiang Reach, the sampling interval was not sufficient to resolve fine-scale flow and deposition gradients around individual mid-channel bars. The influence of mid-channel bars on SOM enrichment was therefore inferred mainly from site position and standardized spatial comparisons. Third, the organic pollution assessment was conducted at only four representative sites, so the results should not be regarded as a full reach pollution assessment. Finally, this study measured only STN and SOM, but did not distinguish different nitrogen species or directly examine sediment-water exchange. These limitations should be addressed in future work using denser sampling and more detailed hydrological and sedimentological observations.

5. Conclusions

This study characterized the spatiotemporal variation in STN and SOM in surface sediments of the Jingjiang Reach under contrasting hydrological and reservoir operation states. Neither STN nor SOM

exhibited a statistically significant longitudinal gradient in any sampling event. However, sites located downstream of mid-channel bars showed significantly higher SOM Z-scores than other sites in January 2022 and November 2022, whereas STN did not exhibit a corresponding significant enrichment response. This suggests that mid-channel bars may more strongly influence SOM accumulation, likely by modifying local flow and depositional conditions that favor the retention of particles rich in organic matter.

The mean concentrations of STN and SOM were highest in May 2023 and lowest in November 2022. Their CV maxima occurred in different sampling events, which, together with the positive but statistically nonsignificant STN–SOM correlations, indicates that the two indicators were related but not strongly synchronized in their spatial and temporal responses. The organic pollution assessment classified all four representative sites as clean. Nevertheless, JZ1 showed the highest OPI, indicating comparatively greater susceptibility to organic enrichment. This identifies JZ1 as a priority site for continued monitoring of potential organic pollution.

These findings highlight the combined relevance of hydrological conditions, TGR operation, and local channel morphology to sediment nutrient and organic matter dynamics in the Jingjiang Reach. They also provide a useful basis for sediment quality assessment and targeted monitoring in large regulated river systems.

Declarations

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Author Contributions

All authors contributed to the conception and design of the study. Runpei Liu was mainly responsible for data collection, data analysis, and preparation of the initial manuscript draft. Xiaobing Meng contributed primarily to data analysis, figure preparation, result interpretation, conclusion formulation, and manuscript drafting and revision. Yuhong Zeng provided funding support, supplied experimental facilities, supervised the research progress, and critically revised the manuscript. All authors read and approved the final manuscript.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Data Availability Statement

The data used in this study were collected by the authors and are available from the corresponding author upon reasonable request.

Abbreviations

N, nitrogen; OM, organic matter; TN, total nitrogen; TGR, Three Gorges Reservoir; SOM, sediment organic matter; STN, sediment total nitrogen; OPI, organic pollution index; SS, Shashi; CLJ, Chenglingji; JL, Jianli; JZ, Jingzhou; YY, Yueyang; ZC, Zhicheng.

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Figures

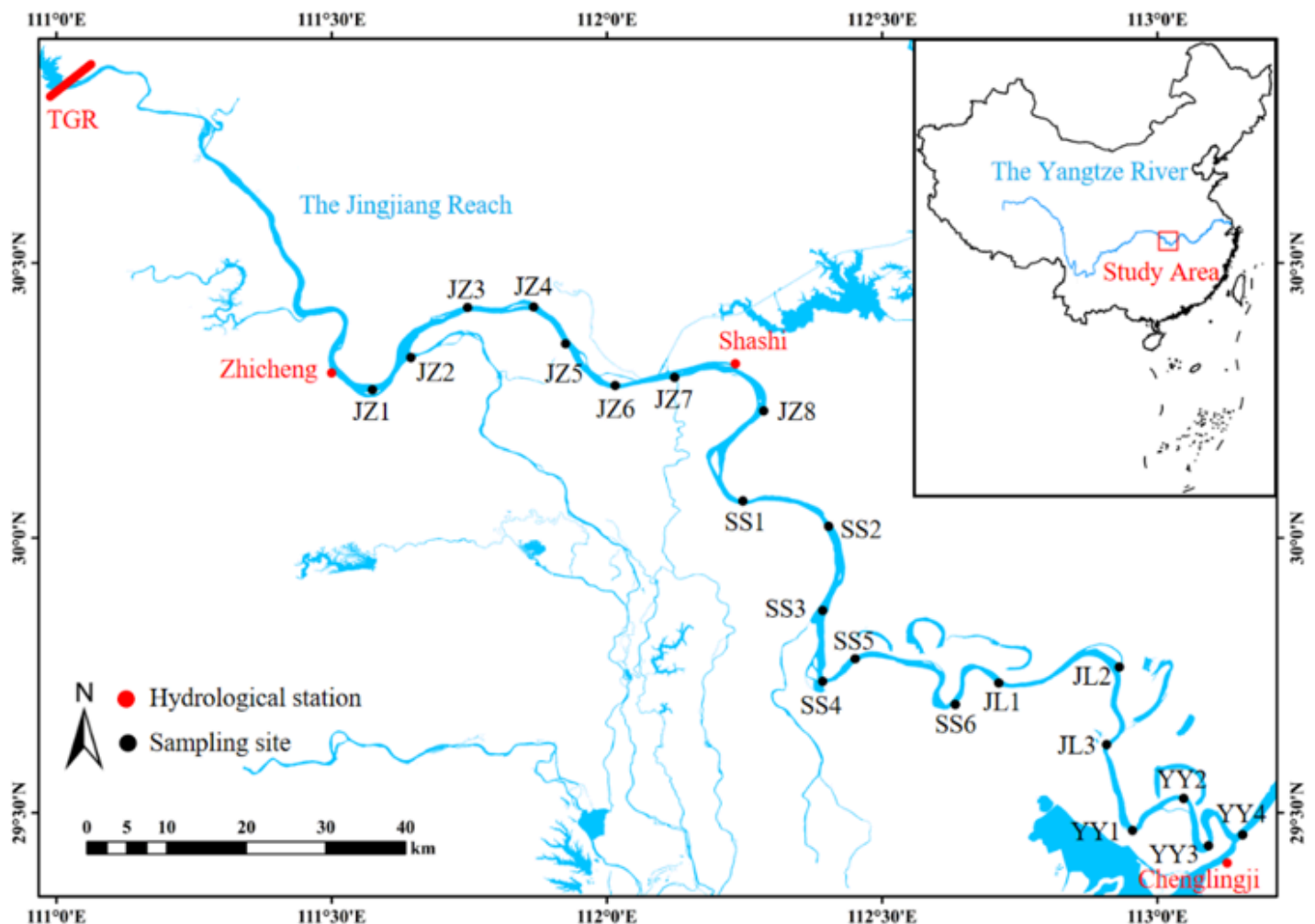


Figure 1

Study area and sampling sites. This figure shows the distribution of the 21 sampling sites in the Jingjiang Reach, along with key hydrological stations (Zhicheng, Shashi, Chenglingji) and the Three Gorges Reservoir (TGR). The inset map in the upper right corner locates the study area within the Yangtze River basin.

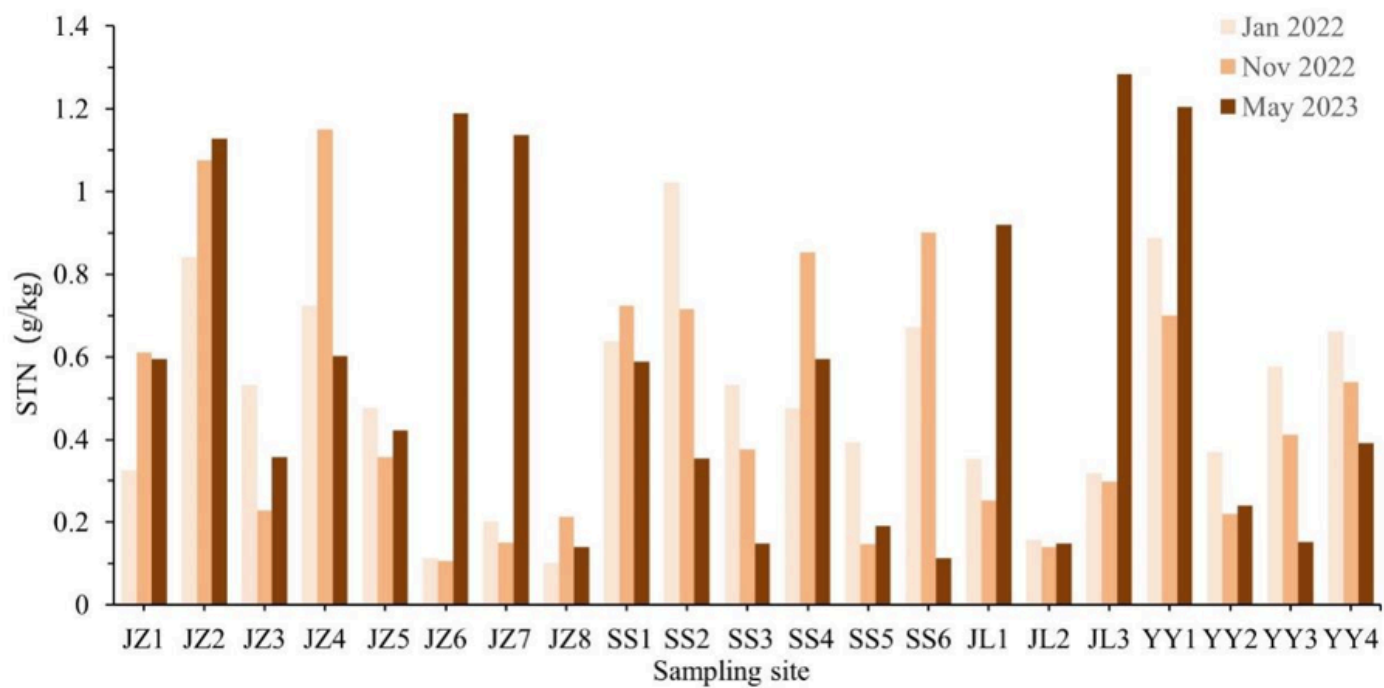


Figure 2

STN concentrations at the 21 sampling sites for the three sampling events. This figure shows the sediment total nitrogen (STN) concentrations (g/kg) at each site in the Jingjiang Reach during Jan 2022, Nov 2022, and May 2023.

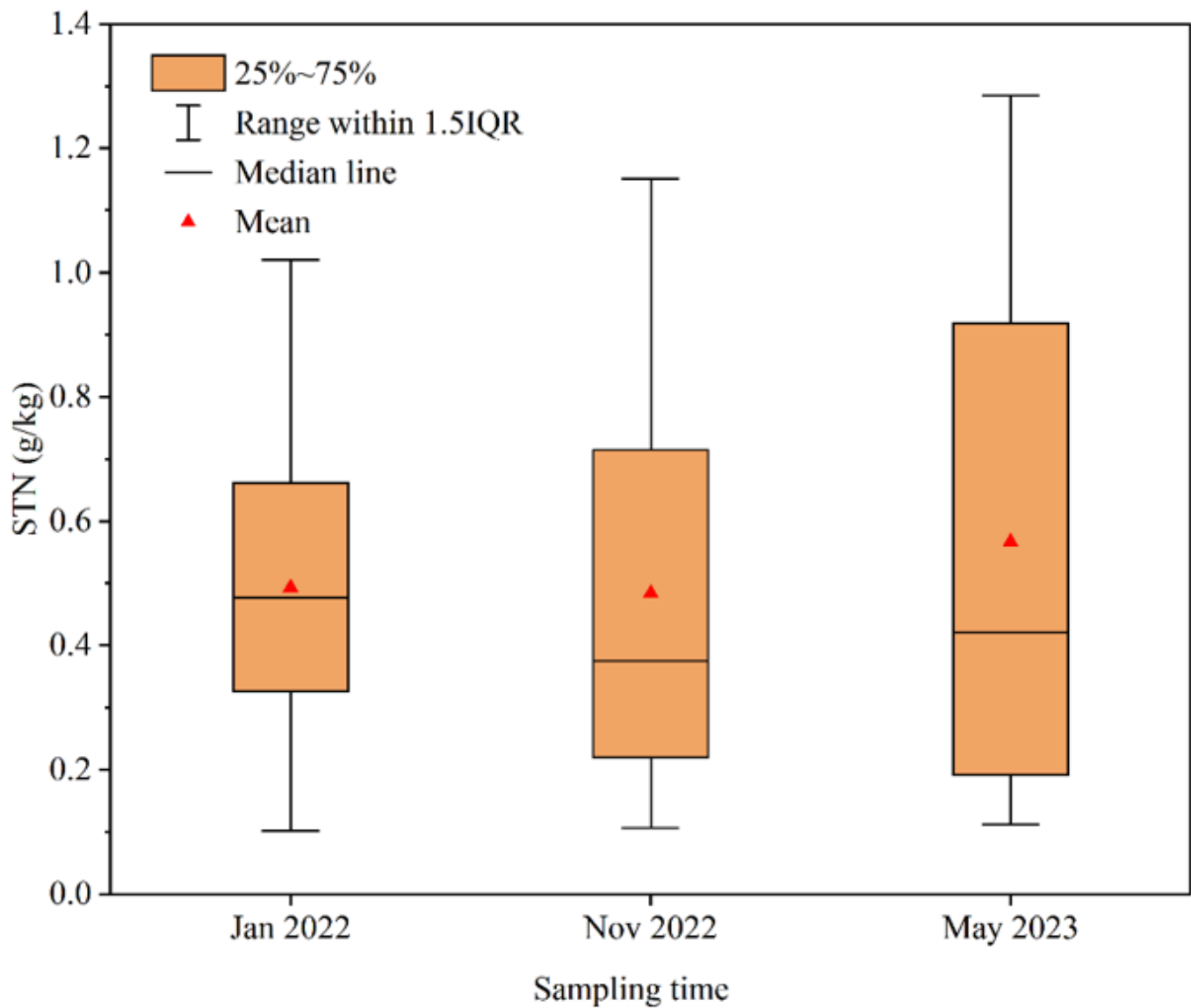


Figure 3

Statistical variations in STN across the three sampling events. This figure presents boxplots of sediment total nitrogen (STN) concentrations (g/kg) for the three sampling events (Jan 2022, Nov 2022, May 2023). The boxes represent the 25th-75th percentiles, the central line is the median, the whiskers show the range within 1.5 times the interquartile range, and the triangles indicate the mean concentrations.

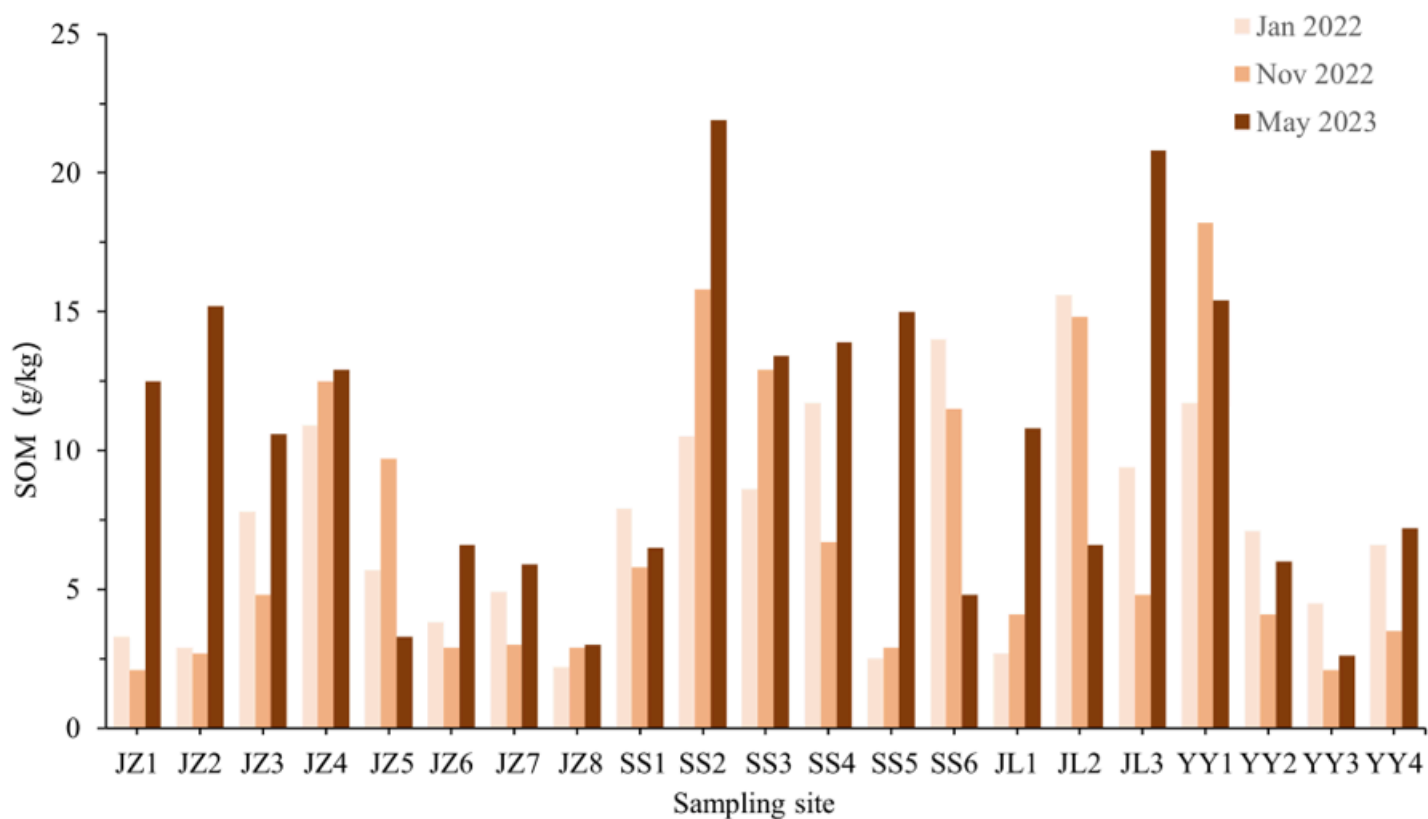


Figure 4

SOM concentrations at the 21 sampling sites for the three sampling events. This figure shows the sediment organic matter (SOM) concentrations (g/kg) at each site in the Jingjiang Reach during Jan 2022, Nov 2022, and May 2023.

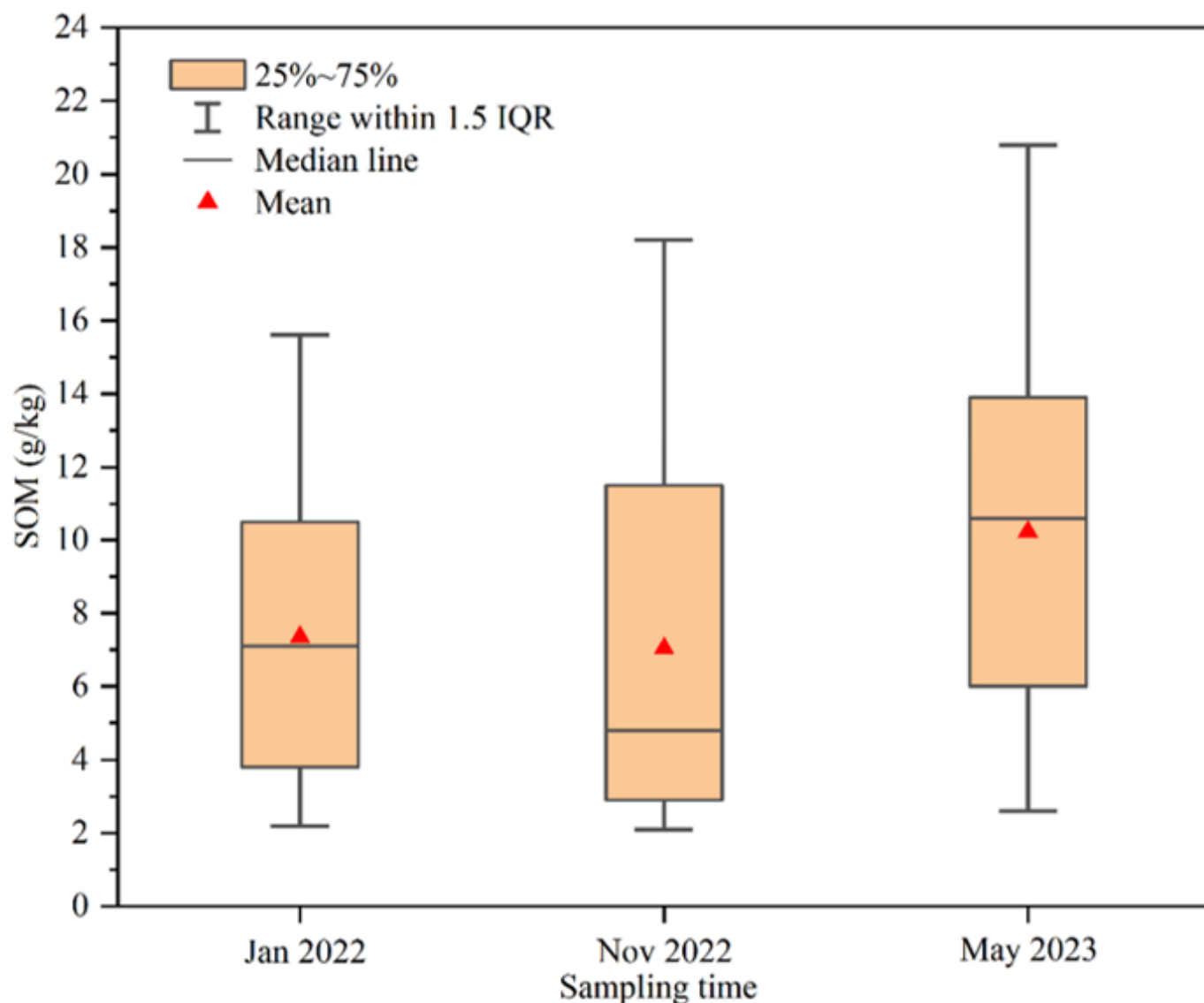


Figure 5

Statistical variations in SOM across the three sampling events. This figure presents boxplots of sediment organic matter (SOM) concentrations (g/kg) for the three sampling events (Jan 2022, Nov 2022, May 2023). The boxes represent the 25th-75th percentiles, the central line is the median, the whiskers show the range within 1.5 times the interquartile range, and the triangles indicate the mean concentrations.

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