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Spatial modeling of water pollution parameters using inverse distance weighting in the Batanghari River, Indonesia

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Abstract: The Batanghari River, one of the largest rivers in Sumatra, Indonesia, serves as a vital transportation corridor and supports domestic, agricultural, and socio-economic activities. Water quality in the middle reaches of the river is associated with increasing anthropogenic pressures, including settlements, agriculture, sand and gravel mining, and domestic waste disposal. This study models the spatial distribution of water pollution parameters in the Batanghari River, Indonesia, using the Inverse Distance Weighting (IDW) method. The river, which serves as the study site, is 2.5 km long, and sampling was conducted at 16 points in Terusan Village, Maro Sebo Ilir District, Batang Hari Regency. The parameters analysed were pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD). pH measurements were conducted in situ, while TSS and COD were analysed in the laboratory. The measured values were evaluated using the Indonesian Class II river water quality specifications in accordance with Government Regulation No. 22/2021. Spatial distribution modelling was performed using the Inverse Distance Weighting (IDW) interpolation method in ArcGIS 10.8, with model performance evaluated via cross-validation using Root Mean Squared Error (RMSE). The results showed that pH values ranged from 6.76 to 6.91 and were within the class II standard limits. Total Suspended Solids (TSS) ranged between 230.12 and 313.93 mg/L, and Chemical Oxygen Demand (COD) ranged between 35.44 and 93.92 mg/L, exceeding the permitted limits. Areas with higher pollution concentrations were associated with settlements and mining activities, as indicated by the spatial distribution map. These findings suggest that IDW can be applied to the spatial representation of water quality and its improvement as an indicator for pollution control and river management.

Keywords: inverse distance weighting, spatial water quality modelling, water quality assessment, water pollution, GIS, spatial interpolation, environmental monitoring

1. Introduction

The rapid expansion of anthropogenic activities along riverbanks has made river-water pollution a serious environmental concern in many developing regions (Fachrudin & Rismawati, 2026; Li et al., 2022; Wan et al., 2026). Rivers support domestic consumption, agriculture, fisheries, transportation, and other local economic activities, yet their water quality is highly vulnerable to pollution from settlements, agricultural runoff, erosion, and mining activities (Chabib et al., 2025; Firoozi & Firoozi, 2024; Kamarudin et al., 2026). The Batanghari River, one of the major rivers in Sumatra, Indonesia, is an essential water resource for communities living along its course. However, direct domestic wastewater discharge and sand and gravel mining within the river corridor may increase suspended sediment and organic pollutant loads (Gavrilaş et al., 2025; Weber et al., 2023). These pressures may impair ecological functions and threaten local communities' ability to use river water safely and sustainably (Azha et al., 2023; Gutiérrez-Rial et al., 2023).

Previous water-quality studies on the Batanghari River and other river systems have commonly relied on conventional laboratory analyses and pollution-index assessments (Narsan et al., 2023; Warsa et al., 2025). Although these methods are useful for determining water-quality conditions at individual sampling locations, point-based measurements alone provide limited information about how pollutants are distributed across a river segment (Liu et al., 2023; Sultana & Dewan, 2021). Spatial modeling is therefore required to identify pollution gradients and potential hotspots and to support location-specific river management (Ijumulana et al., 2020; Pérez-García et al., 2026).

Despite the importance of such spatial information, evidence on the distribution of pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD) in the middle section of the Batanghari River remains limited, particularly around Terusan Village, Maro Sebo Ilir District, Batang Hari (Warsa et al., 2025). Existing studies have not adequately explained whether these parameters remain within applicable Class II water-quality standards, how their concentrations vary from upstream to downstream, or where sediment- and organic-pollution hotspots are located (Armijos-Arcos et al., 2025; Gong et al., 2025; Zheng et al., 2024). Moreover, limited attention has been given to validating local-scale spatial interpolation results against field measurements. This knowledge gap limits local stakeholders' ability to identify priority areas for monitoring, pollution control, riverbank protection, and wastewater management.

This study addresses this gap by integrating field-based water-quality measurements with Geographic Information System (GIS)- based inverse distance weighting (IDW) interpolation. Water samples were collected from 16 sampling points distributed along approximately 2.5 km of the Batanghari River. The analysis focused on pH, TSS, and COD because these parameters represent acidity conditions, suspended sediment pressure, and organic pollution loads, respectively. The measured values were compared with the applicable Indonesian Class II river-water quality standards. ArcGIS 10.8 was then used to model the spatial distribution of each parameter, while cross-validation using Mean Error and Root Mean Square Error was applied to assess interpolation performance. Accordingly, this study addresses the following research questions:

RQ1. What are the measured concentrations of pH, TSS, and COD along the studied segment of the Batanghari River, and to what extent do these values comply with Class II water-quality standards?
RQ2. How are pH, TSS, and COD spatially distributed across the upstream, middle, and downstream sections of the study area?
RQ3. Where are the principal sediment and organic-pollution hotspots, and how are they associated with nearby settlements, agricultural activities, riverbank disturbance, and mining operations?
RQ4. How accurately does the IDW interpolation model represent the spatial distribution of the measured water-quality parameters based on cross-validation results?

The novelty of this study lies in its fine-scale integration of field measurements, regulatory comparison, spatial interpolation, hotspot identification, and interpolation validation within a locally significant segment of the middle Batanghari River. Unlike conventional point-based assessments, this approach provides a continuous spatial representation of pollution patterns and reveals differences between relatively stable pH conditions and the more pronounced upstream-to-downstream increases in TSS and COD. The study also provides local evidence on the suitability and limitations of IDW for mapping river water quality using a relatively small number of sampling points.

This study makes empirical, methodological, and practical contributions. Empirically, it provides current information on pH, suspended solids, and organic pollution across a river segment where spatial water-quality evidence remains limited. Methodologically, it demonstrates how field measurements, IDW interpolation, and cross-validation can be combined to interpret local pollution patterns. Practically, the resulting maps can assist local authorities and other stakeholders in identifying areas requiring intensified monitoring, erosion and sediment control, supervision of mining activities, and improved domestic wastewater management. The findings, therefore, provide a spatially informed basis for pollution-control planning and the sustainable management of the Batanghari River.

2. Methods

2.1 Study area

The study was conducted along the Batanghari River in Terusan Village, Maro Sebo Ilir District, Batang Hari Regency, Jambi Province, Indonesia. The selected study area comprised an approximately 2.5 km river segment influenced by several anthropogenic activities, including settlements, agriculture, sand and gravel mining, river-crossing activities, and domestic activities along the riverbanks. This location was selected because local communities use the river for daily and economic activities, while surrounding land-use practices may introduce suspended sediment and organic pollutants into the river. The study segment was divided into upstream, middle, and downstream sections to support the interpretation of spatial variations in water quality. Figure 1 shows the study area and the distribution of sampling points along the Batanghari River.

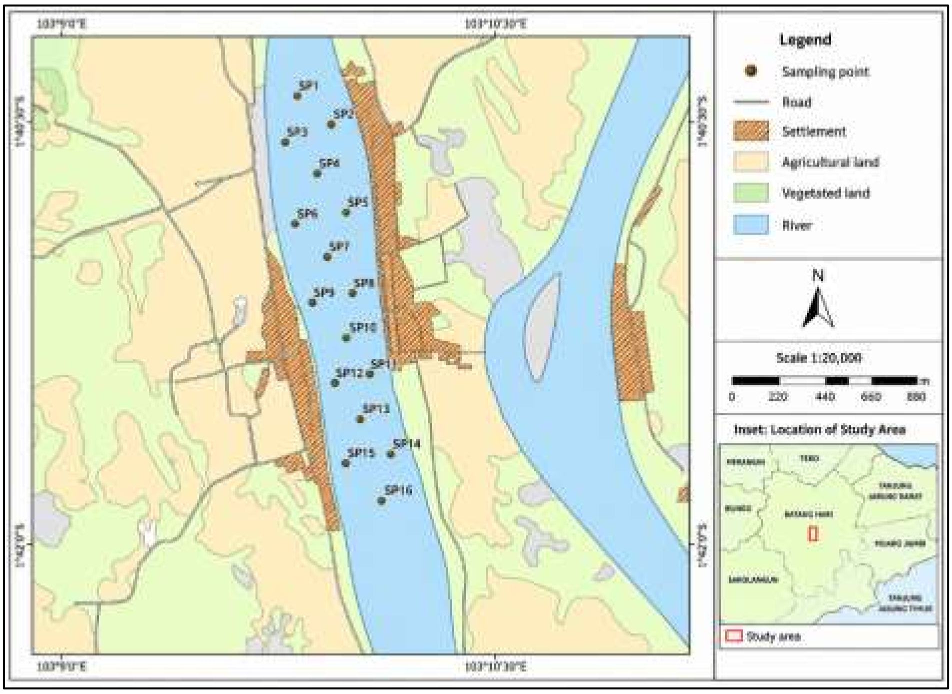

Figure 1. Study area and sampling points along the Batanghari River, Indonesia

2.2 Sampling design

Water samples were collected from 16 sampling points distributed along the selected river segment. The sampling points were selected to represent spatial variations in water quality from upstream to downstream. Site accessibility, surrounding riverbank activities, potential pollutant sources, and the likelihood of pollutant transport from adjacent land-use areas were considered during site selection.

The geographic coordinates of each sampling point were recorded using a Global Positioning System device. These coordinates were subsequently used as spatial inputs in the Geographic Information System analysis. The sampling-point characteristics are presented in Table 1.

Table 1. Coordinates and characteristics of sampling points

Sampling point	Longitude (X)	Latitude (Y)	River segment	Dominant surrounding activity
SP1	103° 9'52.82"E	1°40'33.73"S	Upstream	Agriculture and gold mining activity
SP2	103° 9'59.87"E	1°40'40.30"S		Agriculture and gold mining activity
SP3	103° 9'49.98"E	1°40'42.48"S		Agriculture and gold mining activity
SP4	103° 9'56.22"E	1°40'49.22"S		Settlement
SP5	103°10'2.35"E	1°40'56.36"S		Settlement
SP6	103° 9'51.59"E	1°40'58.69"S		Settlement
SP7	103° 9'58.23"E	1°41'5.52"S	Middle	Settlement and river crossing activity
SP8	103°10'4.16"E	1°41'12.92"S		Settlement and river crossing activity
SP9	103° 9'55.25"E	1°41'14.46"S		Settlement and river crossing activity
SP10	103°10'1.92"E	1°41'21.60"S		Settlement and river crossing activity
SP11	103°10'7.33"E	1°41'28.91"S		Settlement and river crossing activity
SP12	103° 9'59.80"E	1°41'30.33"S		Settlement and river crossing activity
SP13	103°10'5.02"E	1°41'37.59"S	Downstream	Agriculture and gravel mining
SP14	103°10'11.45"E	1°41'44.58"S		Agriculture and gravel mining
SP15	103°10'1.93"E	1°41'46.33"S		Agriculture and gravel mining
SP16	103°10'9.36"E	1°41'53.53"S		Agriculture and sand mining

2.3 Water quality parameters

The water-quality parameters examined in this study were pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD). These parameters were selected because they represent important physical and chemical characteristics of river water. The pH value indicates the acidity or alkalinity of river water. TSS represents suspended particles originating from sources such as soil erosion, surface runoff, riverbank disturbance, and sediment resuspension caused by mining or other river-related activities. COD represents the amount of oxygen required to oxidize organic and inorganic substances in water and is commonly used as an indicator of organic pollution load (Abu Sama et al., 2024; Istomi et al., 2025). The pH value was measured directly in the field using a portable pH meter. TSS and COD were analyzed in the laboratory using standard water-quality testing procedures. The measured values were subsequently compared with the Indonesian Class II river-water quality standards stipulated in Government Regulation No. 22 of 2021. The parameters, units, measurement methods, analysis locations, and applicable standards are presented in Table 2.

Table 2. Water quality parameters, units, methods, and standards

Parameter	Unit	Measurement method	Analysis location	Class II standard
pH	-	Portable pH meter	Field	6-9
Total Suspended Solids (TSS)	mg/L	Laboratory analysis	Laboratory	50 mg/L
Chemical Oxygen Demand (COD)	mg/L	Laboratory analysis	Laboratory	25 mg/L

2.4 Water quality standard assessment

The measured pH, TSS, and COD values were evaluated against the Indonesian Class II river-water quality standards. Class II water is designated for water-recreation infrastructure, freshwater aquaculture, livestock farming, irrigation, and other uses requiring a comparable level of water quality. Compliance was assessed separately for each parameter at every sampling point. A pH value was classified as compliant when it remained within the range of 6–9. TSS and COD were classified as compliant when their concentrations did not exceed 50 mg/L and 25 mg/L, respectively, as stipulated in Government Regulation No. 22 of 2021 (Fitriana et al., 2025). Table 3 presents the criteria used in the compliance assessment.

Table 3. Water quality standards used for compliance assessment

Parameter	Unit	Class II standard	Compliance criterion
pH	-	6-9	Compliant if value is within 6-9
Total Suspended Solids (TSS)	mg/L	50	Compliant if value ≤ 50 mg/L
Chemical Oxygen Demand (COD)	mg/L	25	Compliant if value ≤ 25 mg/L

2.5 Spatial interpolation using inverse distance weighting

The spatial distributions of pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD) were estimated using the Inverse Distance Weighting (IDW) method in ArcGIS 10.8. IDW is a deterministic interpolation technique that predicts values at unsampled locations from nearby observations, assuming that points closer in space have greater influence than those farther away (Workneh et al., 2024). The contribution of each sampling point is therefore determined by an inverse function of its distance from the prediction location (Barudžija et al., 2024). The predicted value at an unsampled location was calculated using Equation (1).

$$Z(x0) = \Sigma[Zi / di^p] / \Sigma[1 / di^p] \quad (1)$$

Where Z(x0) is the predicted value at an unobserved location, Zi is the observed value at sampling point i, di is the distance between the predicted and sampling point i, and p represents a power parameter. A higher value enhances the local influence of nearby points rather than distant ones, while a lower power value yields a more gentle spatial surface. Spatial interpolation was performed separately for pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD). The outcome of this method is a set of maps depicting the spatial distribution of each water quality parameter along the Batanghari River segment.

2.6 Model validation

Cross-validation was performed to assess the accuracy of the spatial interpolation model. In this approach, we left out each observation at a time and estimated its value from other sampling points. Interpolation error was observed by comparing the predicted and observed values. We use Root Mean Squared Error to evaluate the performance of these models. The optimal threshold for RMSE is 0—the lower the value, the better the agreement between observed and predicted values (Khoshvaght et al., 2025). In this paper, the RMSE using Equation (2).

$$RMSE = \sqrt{[\Sigma(Pi - Oi)^2 / n]} \quad (2)$$

where (P_i) is the predicted value, (O_i) is the observed value, and (n) is the number of sampling points. The validation indicators used in the study are presented in Table 4.

Table 4. Model validation indicators used in this study

Indicator	Formula	Variables	Interpretation
Root Mean Square Error (RMSE)	RMSE = $\sqrt{[\Sigma(Pi - Oi)^2 / n]}$	Pi = predicted value; Oi = observed value; n = number of sampling points.	Lower RMSE indicates better interpolation performance.
Cross-validation	Leave-one-out estimation	Each observed value is temporarily removed and estimated using the remaining sampling points.	Used to evaluate the difference between observed and predicted values.

2.7 Data analysis

The analysis began with a descriptive examination of the measured pH, TSS, and COD values. Minimum, maximum, and mean values were calculated to summarise water-quality conditions across the 16 sampling points. Each observation was then compared with the Indonesian Class II water-quality standards to determine whether the corresponding parameter complied with the applicable threshold. The geographic coordinates and measured values were subsequently integrated in ArcGIS 10.8. Separate IDW models were generated for pH, TSS, and COD to visualize their spatial distributions and identify concentration gradients along the upstream, middle, and downstream sections of the river. Model performance was evaluated through leave-one-out cross-validation using ME and RMSE. The final interpretation considered the spatial correspondence between relatively high concentrations and the dominant activities recorded around each sampling point, including settlements, agriculture, river crossings, and sand, gravel, or gold mining. These relationships were treated as indications of potential pollution pressure rather than evidence of direct causality because the study did not measure pollutant discharge, river flow, rainfall, or seasonal variation.

3. Results and discussion

3.1 Characteristics of water quality parameters

Water-quality measurements at the 16 sampling points showed different patterns for pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD). The pH values ranged narrowly from 6.76 to 6.91. The lowest value was recorded at SP1, while the highest occurred at SP4. All measured values were within the Indonesian Class II water-quality standard of 6–9, indicating relatively neutral conditions throughout the observed river segment. In contrast, TSS concentrations were elevated at all sampling points. The values ranged from 230.12 mg/L at SP1 to 313.93 mg/L at SP16 and generally increased from upstream to downstream. Even the lowest concentration was more than four times the Class II standard of 50 mg/L, demonstrating a substantial suspended-solids load throughout the study area. COD concentrations also showed an upstream-to-downstream increase, ranging from 35.44 mg/L at SP1 to 93.92 mg/L at SP16. All measured concentrations exceeded the Class II standard of 25 mg/L. Table 5 presents the measured values of the three water-quality parameters at each sampling point.

Table 5. Measured values of pH, TSS, and COD at sampling points

Sampling point	pH	TSS (mg/L)	COD (mg/L)
SP1	6.76	230.12	35.44
SP2	6.79	231.40	37.45
SP3	6.80	232.15	40.15
SP4	6.91	233.18	44.30
SP5	6.89	240.25	48.91
SP6	6.88	245.30	52.42
SP7	6.87	265.36	58.48
SP8	6.85	281.70	61.94
SP9	6.86	285.18	65.73
SP10	6.81	301.80	70.88
SP11	6.80	303.53	72.33
SP12	6.78	305.12	74.92
SP13	6.77	306.30	76.20
SP14	6.77	308.72	81.12
SP15	6.77	310.43	86.40
SP16	6.77	313.93	93.92

3.2 Comparison with class II water quality standards

The compliance assessment showed that pH was the only parameter meeting the Class II standard at all sampling points. Measured pH values remained within the prescribed range of 6–9. This result indicates compliance with pH requirements but does not imply that overall water quality met Class II requirements, as TSS and COD exceeded their respective limits. TSS concentrations ranged from approximately 4.60 to 6.28 times the Class II threshold of 50 mg/L. Exceedances were observed at every sampling point, indicating suspended solids as a major water-quality concern in the studied segment. COD concentrations ranged from approximately 1.42 to 3.76 times the applicable standard of 25 mg/L. The consistent exceedance indicates elevated oxygen demand associated with oxidizable substances in the water. The progressive increase in COD toward the downstream section also indicates a spatial accumulation pattern along the observed river reach.

3.3 Spatial distribution of pH

The IDW interpolation revealed a relatively uniform spatial distribution of pH across the study area, with values ranging from 6.76 to 6.91. As shown in Figure 2, pH increased slightly from SP1 to SP4, then gradually declined toward the downstream section. Despite this variation, the differences between sampling points were small, and no distinct acidic or alkaline hotspot was identified. All interpolated values remained within the Indonesian Class II water-quality standard of 6–9, indicating stable and near-neutral river conditions throughout the observed segment. This limited spatial variability suggests that pH was less sensitive to local anthropogenic pressures than TSS and

COD, possibly because dilution, river mixing, and natural buffering helped maintain relatively consistent acidity–alkalinity conditions along the river reach.

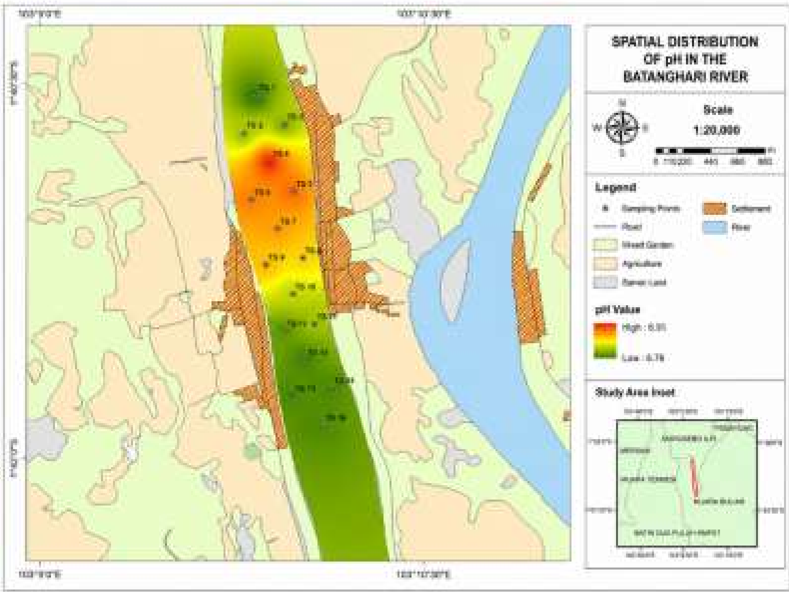

Figure 2. Spatial distribution of pH in the Batanghari River using IDW interpolation

3.4 Spatial distribution of total suspended solids

The IDW interpolation revealed a distinct upstream-to-downstream gradient in Total Suspended Solids (TSS) concentrations. Relatively lower values occurred in the upstream section around SP1–SP6, whereas concentrations increased through the middle section and reached their highest levels around SP10–SP16 in the downstream area. Despite this spatial variation, all interpolated concentrations remained above the Indonesian Class II water-quality standard of 50 mg/L, indicating that suspended solids were a widespread water-quality problem throughout the observed river segment.

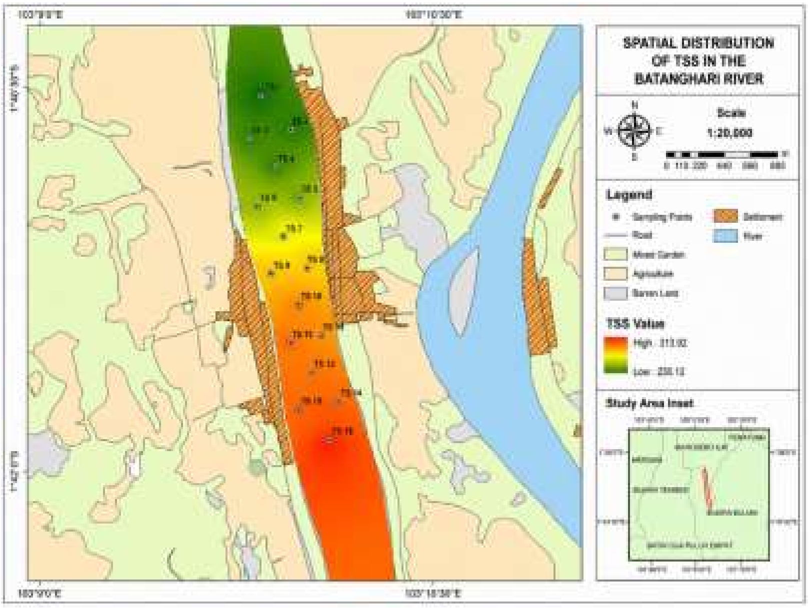

Figure 3. Spatial distribution of TSS in the Batanghari River using IDW interpolation

As shown in Figure 3, the transition from lower concentrations in the upstream area to higher concentrations downstream is spatially associated with increasingly intensive human activities, including settlements, river crossings, agriculture, and sand or gravel mining. These activities may contribute to riverbank disturbance, surface runoff, sediment resuspension, and the transport of fine particles into the river. However, because individual sediment sources were not measured directly, these relationships should be interpreted as spatial indications rather than confirmed causal effects. The middle-to-downstream section can therefore be identified as the principal suspended-sediment hotspot and should receive priority for field verification, riverbank protection, mining supervision, and sediment-control monitoring.

3.5 Spatial distribution of chemical oxygen demand

The IDW interpolation revealed a clear upstream-to-downstream increase in Chemical Oxygen Demand (COD). Lower concentrations were observed around SP1–SP7, whereas values increased through the middle section and reached their highest levels around SP13–SP16. This spatial pattern was consistent with the measured concentrations presented in Table 5, which ranged from 35.44 mg/L at SP1 to 93.92 mg/L at SP16. All measured and interpolated values exceeded the Indonesian Class II water-quality standard of 25 mg/L, indicating elevated loads of oxidizable substances throughout the study segment.

Figure 4 illustrates the progressive increase in COD from the upstream area toward the downstream section. The highest-concentration zones coincided with settlements, agricultural land, river crossings, and mining activities. Domestic wastewater, organic residues, agricultural runoff, and disturbed riverbank materials may contribute to the observed pattern. However, because pollutant discharges and source-specific loads were not measured directly, these relationships should be interpreted as spatial associations rather than confirmed causal effects. The middle and downstream sections can therefore be considered priority areas for further source investigation, wastewater monitoring, and pollution-control measures.

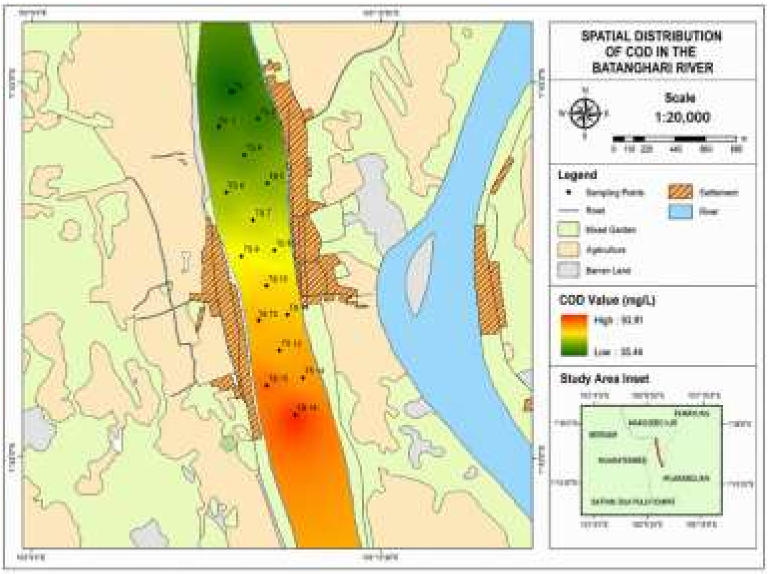

Figure 4. Spatial distribution of COD in the Batanghari River using IDW interpolation

As shown in Figure 4, the downstream concentration gradient indicates that oxidizable pollutant pressure was more pronounced in areas exposed to multiple anthropogenic activities than in the upstream section.

3.6 Cross-Validation of IDW Interpolation

Leave-one-out cross-validation was used to evaluate the predictive performance of the IDW models for pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD). For each iteration, one sampling point was excluded, and its value was estimated using the remaining observations. The resulting predicted values were then compared with the corresponding field measurements. As summarised in Table 6, the Mean Error (ME) values for all three parameters were close to zero, indicating minimal systematic bias. The pH model produced an ME of −0.000000664 and an RMSE of 0.000068645, showing close agreement between the measured and predicted values. For TSS, the ME was −0.000069700, and the RMSE was 0.041962810, whereas the COD model produced an ME of −0.000001998 and an RMSE of 0.015330310. The slightly negative ME values indicate a minor tendency toward underestimation; however, the magnitude of this bias was negligible within the present dataset.

Table 6. Cross-validation results of IDW interpolation for pH, TSS, and COD

Parameter	Mean Error	RMSE	Model Interpretation
pH	-0,000000664	0,000068645	Very low interpolation error
TSS	-0,000069700	0,041962810	Low interpolation error
COD	-0,000001998	0,015330310	Low interpolation error

Because pH, TSS, and COD are expressed on different numerical scales and, in the case of TSS and COD, in different concentration ranges, their RMSE values should be interpreted separately. The values indicate the magnitude of prediction error for each parameter and should not be directly compared across parameters. Figure 5 compares the measured and cross-validated values. In all three panels, the predicted values are closely distributed along the 1:1 reference line, indicating strong agreement between field observations and IDW estimates.

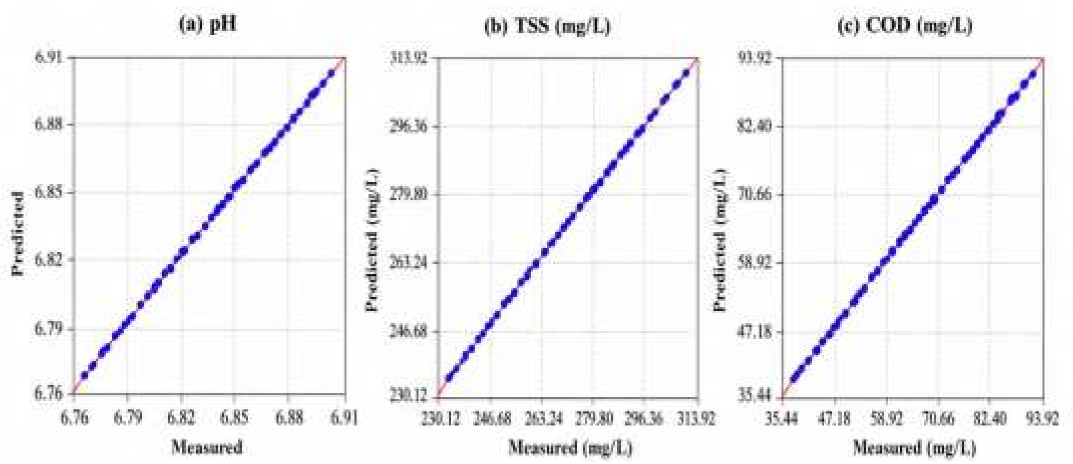

Figure 5. Cross-validation results of IDW interpolation for water-quality parameters

As shown in Figure 5, only minimal deviations from the reference line were observed for pH, TSS, and COD. This pattern is consistent with the near-zero ME and low RMSE values reported in Table 6 and indicates that the IDW models reproduced the spatial patterns contained in the 16-point dataset with limited prediction error. Nevertheless, the validation results apply specifically to the current sampling density, spatial arrangement, and relatively short river segment. They should therefore not be interpreted as evidence that the models will perform equally well in larger, more heterogeneous, or seasonally variable sections of the Batanghari River.

4. Discussion

4.1 Water quality condition of the Batanghari River

The findings demonstrate contrasting water-quality conditions across the three parameters. The pH remained stable and complied with the Class II standard, whereas TSS and COD exceeded their respective limits at every sampling point. Therefore, the principal water-quality concerns in the study segment were associated with suspended-sediment and oxidizable-pollutant loads rather than acidity or alkalinity. The narrow pH range of 6.76–6.91 indicates that the river water remained near neutral. Flowing river systems may maintain relatively stable pH through dilution, mixing, and natural buffering, thereby reducing short-distance fluctuations in acidity and alkalinity (Huang et al., 2020). Nevertheless, compliance with the pH criterion alone cannot be used to classify the overall river condition as compliant because TSS and COD consistently exceeded the applicable standards.

TSS concentrations of 230.12–313.93 mg/L indicate considerable suspended-material pressure. High TSS can reduce water transparency, restrict light penetration, disturb aquatic habitats, and increase sediment deposition within the river channel. The elevated concentrations may be associated with several sources observed in the study area, including surface runoff, riverbank erosion, sediment resuspension, river-crossing activities, and disturbance from sand, gravel, or gold mining. These activities were not measured as individual pollutant sources; therefore, they should be regarded as plausible pressures rather than confirmed causal factors. COD concentrations of 35.44–93.92 mg/L indicate elevated levels of oxidizable substances throughout the study segment. Potential sources include domestic wastewater, organic waste, agricultural runoff, and other land-based inputs. Continued organic loading can increase oxygen demand during decomposition and potentially reduce the oxygen available for aquatic organisms. The high COD values recorded near settlement-dominated and downstream locations reinforce the need for further source-specific monitoring.

4.2 Spatial pattern of pollution

The interpolation results revealed different spatial behaviors among the parameters. The relatively uniform pH distribution suggests that acidity and alkalinity were not the dominant spatial water-quality issues within the observed reach. Although minor variation occurred, all measured and interpolated values remained within the acceptable range. This pattern is consistent with the relatively stable pH behavior reported in spatial river-water assessments (Bronowicka-Mielniczuk & Mielniczuk, 2023). TSS showed a stronger spatial gradient, with concentrations increasing from the upstream to the middle and downstream areas. The highest values occurred near settlements, river crossings, agricultural areas, and mining sites. Disturbance of riverbanks and riverbed materials can increase the availability of fine sediment, while runoff from open or cultivated land can transport additional particles into the river. The downstream TSS hotspots should therefore receive priority in riverbank stabilization, erosion-control assessment, and supervision of mining-related activities.

COD showed a similar, but more pronounced, downstream increase. The higher concentrations recorded from the middle to downstream section indicate that oxidizable pollutant loads may accumulate as water moves through areas exposed to multiple anthropogenic pressures. Domestic wastewater from settlements, agricultural runoff, and organic residues are plausible contributors to this pattern. However, the study did not directly measure wastewater discharge, pollutant flux, or river flow. The spatial correspondence between COD and surrounding activities should therefore be interpreted as evidence of potential association rather than direct source attribution.

Taken together, the TSS and COD maps indicate that the middle and downstream sections experience greater pollution pressure than the upstream section. The similar direction of both gradients suggests that sediment-related and organic-pollution pressures may occur concurrently in areas with more intensive human activity.

4.3 Effectiveness of IDW for river water quality mapping

IDW was used to convert measurements from 16 sampling points into continuous spatial surfaces. The method is suitable for exploratory local-scale mapping because it is straightforward to implement and predicts unsampled values according to the influence of nearby observations (Kamaruddin et al., 2022). The near-zero ME values indicate that the models showed little systematic bias, while the low RMSE values indicate close agreement between cross-validated predictions and field measurements within the available dataset. The stable pH pattern and the gradual downstream increases in TSS and COD were therefore represented consistently by the interpolation surfaces.

Nevertheless, the low validation errors should be interpreted within the scope of the study. The sampling points were located along a relatively short 2.5 km river segment, and TSS and COD followed smooth directional gradients. These conditions may support accurate distance-based predictions, but do not demonstrate that the same model would perform equally well in a larger or more heterogeneous river system. IDW is also a deterministic rather than process-based method. Its predictions depend on spatial distance and the selected interpolation settings, while river-flow direction, discharge, rainfall, channel morphology, pollutant transport, and temporal variability are not explicitly represented. The resulting maps should therefore be interpreted as local spatial estimates, not as hydrodynamic simulations or definitive evidence of pollutant movement. Future assessments could compare IDW with alternative interpolation techniques and integrate hydrological and land-use variables.

4.4 Implications for river management

The findings indicate that Total Suspended Solids (TSS) and Chemical Oxygen Demand (COD) should be prioritized in future monitoring and pollution-control programs, as both parameters exceeded the Indonesian Class II water-quality standards at all sampling points. Monitoring efforts should be intensified in the middle and downstream sections, where the highest concentrations and the most pronounced spatial gradients were identified. Management of elevated TSS should focus on potential sources of sediment input, including riverbank erosion, surface runoff, river-crossing activities, and sand, gravel, or gold mining. Appropriate measures may include riverbank stabilization, erosion-control practices, rehabilitation of disturbed areas, sediment-retention measures, and stronger supervision of activities that may disturb riverbed or riverbank materials. These interventions should be supported by field verification to identify the dominant sediment sources at specific locations.

Elevated COD requires greater attention to domestic wastewater, community sanitation, agricultural runoff, and other organic inputs. Wastewater discharge points from riverbank settlements should be systematically mapped and monitored, while locally appropriate collection, treatment, and sanitation systems should be strengthened. Agricultural areas near the river should also be included in subsequent assessments to determine whether runoff contributes materially to the observed organic-pollution pattern. The spatial distribution maps provide additional management value by identifying concentration gradients and potential pollution hotspots that are not readily apparent from tabular measurements alone. Local authorities may use these maps as preliminary decision-support tools for selecting monitoring locations, prioritizing pollution-control interventions, and coordinating management across settlement, agricultural, and mining areas. However, the maps should not be treated as definitive evidence of pollutant sources, as IDW produces distance-based spatial estimates rather than direct measurements of pollutant transport. Regulatory action and source-specific interventions should therefore be supported by targeted field investigation, repeated sampling, and hydrological assessment.

4.5 Study limitations

This study has several limitations that should be considered when interpreting the findings. First, water-quality sampling was conducted at 16 points along an approximately 2.5 km segment of the Batanghari River. Although this design was adequate for local-scale spatial interpolation, it does not represent the spatial variability of the entire river system. A denser sampling network covering a broader geographic area would improve the identification of localized pollution gradients and provide a stronger basis for generalization. Second, the assessment was limited to pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD). Other relevant physical, chemical, biological, and hydrological parameters, including Biochemical Oxygen Demand, Dissolved Oxygen, nutrients, heavy metals, microbial indicators, turbidity, rainfall, and river discharge, were not measured. Consequently, the study provides only a partial representation of river water quality and cannot fully explain the ecological effects or the specific sources of pollution.

Third, sampling was conducted during a single observation period. The resulting spatial patterns, therefore, reflect the conditions present at the time of sampling and do not capture seasonal differences, short-term discharge fluctuations, rainfall-related runoff, or changes in surrounding human activities. The findings should not be interpreted as permanent or seasonally representative conditions of the Batanghari River. Fourth, the IDW method estimates values primarily from the distance between sampling points. It does not explicitly incorporate river flow direction, hydrological connectivity, channel morphology, rainfall, discharge, or pollutant transport processes. Although the cross-validation results indicated low prediction errors, the generated maps remain distance-based spatial approximations rather than hydrodynamic representations of contaminant movement. In addition, the observed correspondence between higher pollutant concentrations and nearby settlements, agriculture, river crossings, or mining activities indicates potential spatial associations but does not establish direct causal relationships.

Future research should conduct repeated sampling during both dry and rainy seasons, expand the number and spatial distribution of monitoring points, and include a broader range of physical, chemical, biological, and hydrological parameters. Integrating water-quality measurements with quantified land-use data, rainfall, river discharge, pollutant-source inventories, and flow-based modeling would strengthen the identification of pollution sources and transport pathways. A comparative evaluation of IDW, kriging, and hydrologically informed interpolation methods would also enhance methodological robustness and provide a stronger foundation for sustainable water-quality management in the Batanghari River.

5. Conclusion

This study integrated field measurements, Class II water-quality assessment, IDW interpolation, and cross-validation to examine the spatial distribution of pH, Total Suspended Solids (TSS), and Chemical Oxygen Demand (COD) along a 2.5 km segment of the Batanghari River. The pH values ranged from 6.76 to 6.91 and complied with the Indonesian Class II standard at all 16 sampling points. In contrast, TSS concentrations of 230.12–313.93 mg/L and COD concentrations of

35.44–93.92 mg/L exceeded their respective standards throughout the study area. Both parameters generally increased from upstream to downstream, identifying the middle and downstream sections as areas of greater suspended-sediment and oxidizable-pollutant pressure. These patterns were spatially associated with settlements, agriculture, river crossings, and mining activities, although the study did not establish direct causal relationships. The near-zero Mean Error and low RMSE values indicate that the IDW models represented the spatial patterns within the current sampling configuration with limited prediction error. Accordingly, the resulting maps provide preliminary spatial evidence for prioritizing monitoring, riverbank protection, sediment control, wastewater management, and field verification in identified hotspot areas. Future work should expand the number and geographic coverage of sampling points and conduct repeated observations during both dry and rainy seasons to capture spatial and temporal variability. Further assessments should include additional physical, chemical, biological, and hydrological parameters, such as Biochemical Oxygen Demand, Dissolved Oxygen, nutrients, heavy metals, microbial indicators, turbidity, rainfall, and river discharge. The integration of quantified land-use data, pollutant-source inventories, hydrological connectivity, and flow-based modeling would support more reliable identification of pollution sources and transport pathways. Comparative testing of IDW, kriging, and hydrologically informed interpolation methods is also recommended to evaluate model robustness across larger and more heterogeneous sections of the Batanghari River.

Author's declaration

Author contribution

Adella Masya Putri: Conceptualization; Investigation; Field sampling; Laboratory data compilation; Data curation; Formal analysis; Writing original draft; Project administration. **Yaumal Arbi:** Conceptualization; Methodology; Research design; Supervision; Validation; Spatial modeling guidance; Writing review & editing. **Suci Handayani:** Methodology; Water quality analysis; Interpretation of environmental parameters; Validation of laboratory results; Formal analysis; Writing review & editing. **Shinta Rahayu:** GIS data processing; IDW interpolation; Cross-validation; Visualization; Formal analysis; Writing review & editing. All authors read and approved the final version of the manuscript.

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Conflict of interest

The authors declare that they have no financial or non-financial competing interests related to this study.

Data availability

The data supporting the findings of this study, including field measurements, laboratory results, sampling-point coordinates, and spatial-analysis outputs, are available from the corresponding author upon reasonable request.

Ethical clearance

Not applicable. Formal ethical clearance was not required because this study did not involve human participants, animal subjects, identifiable personal information, or clinical interventions. The research was limited to environmental field sampling and laboratory assessment of river water quality.

AI statement

AI-assisted language tools were used solely to improve grammar, clarity, and academic readability. All suggested revisions were reviewed, verified, and edited by the authors. The authors remain fully responsible for the accuracy, originality, interpretation, and integrity of the final manuscript.

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Universitas Negeri Padang as the publisher, and the Editor of Jurnal Pendidikan Teknologi Kejuruan state that there is no conflict of interest towards this article publication.

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