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Hydrochemical Variations, Sediment-Associated Heavy Metals, and Estimated Pollutant Loads along the Baghdad–Wasit Reach of the Tigris River, Iraq

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Abstract

This study assessed spatial variations in selected hydrochemical parameters, sediment-associated heavy metals, and estimated pollutant mass loads along the Baghdad–Wasit reach of the Tigris River, Iraq. Three monitoring locations were considered: Al-Fahama, north of Baghdad; Al-Rustamiya, within Baghdad; and upstream of Kut Barrage in Wasit Governorate. The investigated water-quality parameters included biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), lead (Pb), and cadmium (Cd). Sediment-associated Pb and Cd concentrations were also evaluated relative to selected background reference values. The study employed a secondary-data approach based on previously published studies and available environmental monitoring records.

The compiled results indicated substantial spatial differences in the reported water-quality parameters. Al-Rustamiya exhibited the highest concentrations of all six investigated water-quality parameters, with BOD_5 and COD reaching 78.0 and 215.0 mg/L, respectively. TN and TP concentrations at this location were 28.4 and 4.20 mg/L. Waterborne Pb concentrations were 0.005, 0.012, and 0.008 mg/L at Al-Fahama, Al-Rustamiya, and upstream of Kut Barrage, respectively, while the corresponding Cd concentrations were 0.0001, 0.0018, and 0.0012 mg/L. Sediment Pb concentrations were 12.5, 92.0, and 68.0 mg/kg, whereas sediment Cd concentrations were 0.4, 7.2, and 4.5 mg/kg. The latter two locations exceeded the selected background reference values reported in the compiled dataset.

Pollutant mass loads were estimated using an assumed river discharge of 200 m^3/s. At this discharge, the estimated daily loads upstream of Kut Barrage were 138.24 kg/day for Pb, 20.736 kg/day for Cd, 423.36 tonnes/day for BOD_5, 1,175.04 tonnes/day for COD, 193.536 tonnes/day for TN, and 31.968 tonnes/day for TP. These estimates represent hypothetical discharge-based calculations rather than directly measured pollutant fluxes. The available data also do not establish statistically significant relationships among the investigated parameters or demonstrate a causal influence of river morphology on sediment-metal accumulation.

The findings identify Al-Rustamiya as a priority location for further investigation and indicate the need for coordinated water-quality monitoring, sediment characterization, wastewater-source assessment, and concurrent river-discharge measurements. Verification of the original data sources and background reference values is necessary before definitive conclusions about contamination levels and environmental risks can be established.

1. Introduction

The Tigris River is a major water resource in Iraq, supporting domestic water supply, agriculture, industrial activities, and aquatic ecosystems. Its importance is particularly evident in the densely populated regions surrounding Baghdad and in the downstream areas that depend on the river for multiple water uses. However, increasing urbanization, inadequate wastewater-treatment infrastructure, and competing demands for water resources create substantial challenges for maintaining river-water quality (Al-Ansari, 2013).

Municipal wastewater, industrial effluents, agricultural runoff, and other anthropogenic discharges can introduce organic matter, nutrients, and potentially toxic elements into river systems. Elevated biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) may indicate increased concentrations of oxygen-demanding substances, while excessive nitrogen and phosphorus inputs can contribute to nutrient enrichment and eutrophication under suitable environmental conditions. The magnitude and consequences of these impacts depend on pollutant concentrations, river discharge, hydrological conditions, and the characteristics of the receiving ecosystem.

Heavy metals are of particular environmental concern because they may persist in aquatic systems and accumulate in sediments. Lead (Pb), cadmium (Cd), nickel (Ni), and chromium (Cr) can enter river systems through a combination of natural geological processes and human activities. Their distribution between water and sediment depends on factors such as pH, redox conditions, particle size, organic matter content, mineral composition, and metal speciation (Alloway, 2013; Tchounwou et al., 2012). Sediments can act as temporary or long-term reservoirs for metals, although their total concentrations alone do not establish metal bioavailability or ecological risk.

Water-quality deterioration in Iraq must also be considered in the context of water scarcity and changing hydrological conditions. Reduced discharge may increase the concentrations of some pollutants when their inputs remain relatively constant, whereas higher flows can increase the transport of suspended material and associated contaminants. Consequently, pollutant concentrations and pollutant mass loads provide complementary information and should be evaluated together when suitable data are available.

Previous research has examined water quality and pollution patterns in the Tigris River. Varol et al. (2012), for example, assessed water quality and pollution-source patterns in the Turkish section of the river. Studies of sediments in Iraqi river systems have also investigated trace-element distributions and their environmental significance. However, differences in sampling locations, analytical procedures, and sampling periods can limit direct comparisons among studies.

An integrated assessment of water chemistry, sediment-associated metals, and potential pollutant transport can help identify locations requiring additional monitoring and management attention. Such an assessment is especially relevant along the Baghdad–Wasit reach, where urban wastewater inputs and downstream water-resource demands are important considerations.

The present study compares selected hydrochemical parameters and sediment-associated heavy metals at three monitoring locations along the Tigris River: Al-Fahama, Al-Rustamiya, and upstream of Kut Barrage. It also estimates pollutant mass loads under a specified river-discharge scenario. The objectives were to:

1. Describe the reported spatial variations in BOD_5, COD, TN, TP, Pb, and Cd in river water.
2. Compare reported sediment-associated Pb and Cd concentrations with selected background reference values.

3. Estimate potential daily pollutant mass loads using an assumed discharge of 200 m^3/s.
4. Identify monitoring and pollution-control priorities while distinguishing observed concentration differences from mechanisms and relationships requiring further investigation.

The study uses a descriptive secondary-data design. Accordingly, its findings are interpreted in relation to the available documentation and are not intended to represent a new field-sampling campaign, an independently validated laboratory investigation, or a definitive source-apportionment analysis.

2. Materials and Methods

2.1. Study design and locations

This study employed a secondary-data approach to examine reported water-quality conditions and sediment-associated heavy-metal concentrations along the Baghdad–Wasit reach of the Tigris River, Iraq.

Three monitoring locations were considered:

- **Al-Fahama**: located north of Baghdad.
- **Al-Rustamiya**: located within Baghdad.
- **Upstream of Kut Barrage**: located in Wasit Governorate.

The locations were compared using reported measurements of selected water-quality parameters and sediment-associated metals. Their selection provides a spatial framework for examining differences among an upstream location north of Baghdad, an urban location within Baghdad, and a downstream location in Wasit Governorate.

The compiled parameters included BOD_5, COD, TN, TP, Pb, and Cd in water, together with Pb and Cd in sediment. Additional literature-derived concentration ranges for Pb, Cd, Ni, and Cr were considered separately to provide regional context for sediment-metal concentrations.

2.2. Data sources and compilation

The dataset was compiled from previously published investigations and available environmental monitoring records. The references identified for the reported measurements include Abood (2025), Issa et al. (2020), and the environmental statistics published by the Republic of Iraq's Central Statistical Organization (2022).

Reported concentrations were organized according to monitoring location, environmental medium, and measured parameter. Water concentrations were expressed in mg/L, and sediment concentrations were expressed in mg/kg.

Where available, the original source documentation was reviewed for sampling dates, sample numbers, analytical methods, measurement units, and quality-control procedures. Information that could not be verified was treated as undocumented rather than assumed.

Because the compiled data may originate from different studies and sampling periods, the resulting comparisons were interpreted descriptively. Differences in analytical methods, sampling frequency, sample preservation, detection limits, and reporting practices were recognized as potential limitations.

Before submission, every value in the tables should be linked to its original source and verified against the corresponding publication or monitoring record. In particular, the correspondence between individual source measurements and the three monitoring locations must be confirmed.

2.3. Laboratory methods and data quality

The present study did not involve independent field sampling or new laboratory analyses. The laboratory measurements were taken from previously reported investigations and available environmental monitoring records.

Information concerning analytical instruments, sample preservation, detection limits, calibration procedures, digestion methods for sediment samples, and laboratory quality-control measures was reviewed where documented in the original sources.

These procedures were not independently repeated or validated. Therefore, the reliability of the compiled values was interpreted according to the documentation available for each source. Missing methodological information was treated as a limitation of the secondary dataset rather than as evidence that appropriate laboratory procedures had not been performed.

For sediment measurements, interpretation was further limited by the availability of information on grain size, organic matter, mineral composition, and the analytical basis of the reported concentrations. These characteristics can affect the distribution and interpretation of sediment-associated metals.

2.4. Statistical approach

The spatial assessment was based on descriptive comparisons of the reported concentrations at the three monitoring locations. No inferential statistical tests were applied to the three station-level values.

Pearson's correlation coefficient was not calculated because the available summary values do not provide a sufficient number of independent paired observations for reliable statistical inference. Correlation coefficients and significance levels cannot be reconstructed from the three station-level concentrations alone.

Likewise, standard deviations, coefficients of variation, and confidence intervals were not independently calculated because a consistently documented set of replicate observations was not available in the

supplied dataset. Such statistics should only be included if the underlying observations, sample sizes, and sampling structure can be verified.

Observed differences among locations were interpreted as spatial contrasts in the compiled data, not as statistically significant differences or evidence of causation.

2.5. Comparison with reference values

Reported concentrations were compared with selected reference values presented in the compiled dataset. These comparisons were used to identify concentrations above or below the stated references.

The applicability of each reference value depends on its original source, the environmental medium, the intended water use, and the purpose of the comparison. Drinking-water guidelines, river-water quality criteria, effluent limits, and sediment-quality guidelines are not interchangeable.

Consequently, the comparisons are treated as provisional until the original sources and regulatory scope of the listed values have been verified.

2.6. Pollutant mass-load estimation

Daily pollutant mass loads were estimated using reported concentrations and an assumed river discharge of 200 m^3/s. The calculation was intended to illustrate potential mass transport under a specified discharge scenario.

The daily load was calculated as:

$L = C \times Q \times 86.4$

where:

- L is the pollutant load in kg/day;
- C is the concentration in mg/L;
- Q is the river discharge in m^3/s; and
- 86.4 is the unit-conversion factor.

For a discharge of 200 m^3/s:

$L = C \times 17{,}280$

Loads expressed in kg/day were converted to metric tonnes/day by dividing by 1,000 where appropriate.

The equation was applied to BOD_5, COD, TN, TP, Pb, and Cd at each monitoring location. The same assumed discharge was used for all locations to provide a standardized concentration-based comparison.

Because the discharge was not established through concurrent measurements at each location, the calculated values are scenario-based estimates rather than verified river pollutant fluxes. They do not independently establish the amount of pollution entering, leaving, or being removed from any section of the river .

3. Results and Discussion

3.1. Spatial variation in water-quality parameters

Table 1 summarizes the reported concentrations of the six water-quality parameters at the three monitoring locations

Table 1
Reported water-quality parameters at the three monitoring locations along the Tigris River.

Parameter	Unit	Al-Fahama	Al-Rustamiya	Upstream of Kut Barrage
BOD_5	mg/L	3.2	78.0	24.5
COD	mg/L	14.5	215.0	68.0
Total nitrogen (TN)	mg/L	1.8	28.4	11.2
Total phosphorus (TP)	mg/L	0.10	4.20	1.85
Lead (Pb) in water	mg/L	0.005	0.012	0.008
Cadmium (Cd) in water	mg/L	0.0001	0.0018	0.0012

Source : Authors' compilation based on previously published studies and environmental monitoring records, including Abood (2025), Issa et al. (2020), and the Central Statistical Organization (2022), Republic of Iraq. The original source of each individual value should be verified.

3.1.1. Organic pollution indicators

BOD_5 concentrations were 3.2 mg/L at Al-Fahama, 78.0 mg/L at Al-Rustamiya, and 24.5 mg/L upstream of Kut Barrage. COD concentrations were 14.5, 215.0, and 68.0 mg/L, respectively.

The highest reported values for both indicators occurred at Al-Rustamiya. Relative to the other locations, the concentrations indicate a pronounced spatial contrast in oxygen-demanding substances within the compiled dataset.

Elevated BOD_5 can reflect increased biodegradable organic matter, whereas COD represents a broader measure of chemically oxidizable substances. Nevertheless, these parameters alone cannot identify the specific wastewater sources responsible for the observed concentrations.

The reported values warrant further investigation of wastewater inputs and local water-quality conditions at Al-Rustamiya. Their interpretation as representative of prevailing or year-round conditions requires confirmation through measurements collected under consistent sampling protocols and comparable hydrological conditions.

3.1.2. Nutrient concentrations

TN concentrations were 1.8 mg/L at Al-Fahama, 28.4 mg/L at Al-Rustamiya, and 11.2 mg/L upstream of Kut Barrage. TP concentrations were 0.10, 4.20, and 1.85 mg/L, respectively.

Both nutrients followed the same broad spatial pattern as BOD_5 and COD, with the highest reported concentrations at Al-Rustamiya and the lowest at Al-Fahama.

These concentrations suggest that nutrient inputs should be investigated at Al-Rustamiya and along the downstream reach. Elevated nutrient concentrations may contribute to eutrophication when other environmental conditions support excessive biological production. However, the compiled values do not establish that eutrophication occurred at the monitoring locations.

Assessment of eutrophication would require additional measurements, including dissolved oxygen, chlorophyll-a, algal abundance, nutrient speciation, and relevant ecological observations.

3.1.3. Heavy metals in water

Waterborne Pb concentrations were 0.005 mg/L at Al-Fahama, 0.012 mg/L at Al-Rustamiya, and 0.008 mg/L upstream of Kut Barrage. Cd concentrations were 0.0001, 0.0018, and 0.0012 mg/L, respectively.

The highest reported concentrations of both metals occurred at Al-Rustamiya, while Al-Fahama had the lowest values.

These results demonstrate spatial differences in the compiled measurements but do not establish the sources of Pb and Cd or the processes governing their distribution. Interpretation also depends on analytical detection limits, sampling dates, and the comparability of the original measurements.

Comparisons with drinking-water guideline values should be made only when the intended water use and applicable guideline are clearly identified. Such comparisons cannot, by themselves, establish ecological safety or suitability for all uses

3.2. Sediment-associated heavy metals

Reported sediment-associated Pb and Cd concentrations are presented in Table 2.

Table 2
Reported sediment-associated Pb and Cd concentrations at the three monitoring locations.

Parameter	Unit	Al-Fahama	Al-Rustamiya	Upstream of Kut Barrage	Selected background reference
Lead (Pb)	mg/kg	12.5	92.0	68.0	15.0
Cadmium (Cd)	mg/kg	0.4	7.2	4.5	0.5

Source: Compiled sediment data and selected reference values. Original data sources and the applicability of the background values require verification.

Sediment Pb concentrations were 12.5 mg/kg at Al-Fahama, 92.0 mg/kg at Al-Rustamiya, and 68.0 mg/kg upstream of Kut Barrage. Relative to the selected reference value of 15.0 mg/kg, the reported concentrations at Al-Rustamiya and upstream of Kut Barrage were higher.

Sediment Cd concentrations were 0.4, 7.2, and 4.5 mg/kg, respectively. The values at Al-Rustamiya and upstream of Kut Barrage exceeded the selected reference value of 0.5 mg/kg.

These comparisons indicate that the reported concentrations at Al-Rustamiya and upstream of Kut Barrage were elevated relative to the selected references. However, exceeding a background value does not independently establish anthropogenic enrichment. Natural geological variability, sediment composition, and the suitability of the reference values for the study area must also be considered.

Sediments can retain metals through adsorption and association with mineral particles and organic matter. Their capacity to accumulate metals depends on grain size, organic matter content, mineralogy, pH, redox conditions, and other sediment–water interactions (Alloway, 2013).

Total sediment-metal concentrations alone cannot establish metal bioavailability, ecological risk, or the likelihood of remobilization. Further investigation should include sediment characterization, locally representative geochemical background values, and appropriate sediment-quality assessment methods.

3.2.1. Regional context from literature-reported sediment concentrations

The compiled literature ranges in Table 3 provide a broader regional context for sediment-associated heavy metals. They should be distinguished from the site-specific measurements in Table 2.

Table 3
Literature-reported sediment-metal concentration ranges and selected background reference values.

Metal	Selected background (mg/kg)	Reported range (mg/kg)	Concentration/background ratio
Pb	15	45–85	3.00–5.67
Cd	0.5	2.5–6.0	5.00–12.00
Ni	40	90–150	2.25–3.75
Cr	60	120–200	2.00–3.33

Source: Literature-derived ranges and reference values in the compiled dataset. The original publications corresponding to each range and background value must be explicitly cited and verified.

The concentration-to-background ratios were calculated by dividing the minimum and maximum reported concentrations by the corresponding selected reference value. Cd showed the highest ratios, followed by Pb, Ni, and Cr.

These ratios describe relative differences from the selected reference values. They should not be interpreted as definitive measures of anthropogenic contamination or ecological risk without confirming the origin and suitability of the references.

The regional concentration ranges also cannot be assigned directly to Al-Fahama, Al-Rustamiya, or upstream of Kut Barrage unless the original studies confirm that correspondence.

3.2.2. Potential influence of river morphology

River morphology may affect sediment transport and deposition through differences in flow velocity, turbulence, channel geometry, and the distribution of depositional and erosional zones. Fine-grained particles may accumulate in low-velocity environments and retain metals through interactions with mineral surfaces and organic matter.

However, the present dataset does not include direct measurements of channel morphology, flow velocity, sediment grain size, or deposition rates. Therefore, the observed sediment-metal patterns do not demonstrate that river meanders caused metal accumulation.

Evaluating this hypothesis would require coordinated measurements of channel geometry, hydraulic conditions, sediment characteristics, and metal concentrations at contrasting depositional and erosional locations.

Potential metal sources include municipal wastewater, industrial discharges, agricultural runoff, and natural geological materials. The relative contribution of these sources cannot be established from the reported concentrations alone.

3.3. Integrated interpretation of the spatial patterns

The compiled water-quality and sediment data consistently identify Al-Rustamiya as the location with the highest reported concentrations of BOD_5, COD, TN, TP, waterborne Pb, waterborne Cd, sediment Pb, and sediment Cd.

Al-Fahama generally had the lowest reported concentrations, while the location upstream of Kut Barrage showed intermediate values.

The consistency of this pattern supports prioritizing Al-Rustamiya for further investigation. Nevertheless, the dataset does not establish whether the observed differences arise from specific discharge points, differences in river flow, temporal variation, sediment properties, or other factors.

Because the measurements were compiled from secondary sources, differences in sampling periods and analytical procedures may influence the comparisons. The results should therefore be interpreted as descriptive evidence of spatial contrasts in the available data rather than as proof of statistically significant differences or persistent year-round conditions.

Further work should use consistent sampling procedures across all three locations, include seasonal observations, and document analytical methods and quality-control procedures. Concurrent river-discharge measurements and targeted assessment of wastewater discharge points would help distinguish concentration differences from differences in pollutant transport.

3.4. Estimated daily pollutant mass loads

Daily pollutant mass loads were estimated using the concentrations in Table 1 and an assumed river discharge of 200 m^3/s.

The calculations were based on:

$L = C \times Q \times 86.4$

At the assumed discharge, the equation becomes:

$L = C \times 17{,}280$

The estimated daily loads are presented in Table 4.

Table 4
Estimated daily pollutant mass loads under an assumed river discharge of 200 m^3/s

Parameter	Unit	Al-Fahama	Al-Rustamiya	Upstream of Kut Barrage
Pb	kg/day	86.40	207.36	138.24
Cd	kg/day	1.728	31.104	20.736
BOD_5	tonnes/day	55.296	1,347.840	423.360
COD	tonnes/day	250.560	3,715.200	1,175.040
TN	tonnes/day	31.104	490.752	193.536
TP	tonnes/day	1.728	72.576	31.968

Note: All loads are calculated from the reported concentrations using a common assumed discharge of 200 m^3/s. They are scenario-based estimates, not directly measured pollutant fluxes.

Under the common discharge assumption, Al-Rustamiya produced the highest estimated loads for all six parameters, followed by upstream of Kut Barrage and Al-Fahama. This ordering directly reflects the concentration pattern because the same discharge value was used for every location.

COD had the highest estimated mass load, followed by BOD_5, TN, and TP. The calculated Pb and Cd loads were smaller in mass terms, but their environmental significance cannot be inferred from mass alone because toxicity depends on concentration, chemical form, bioavailability, and exposure.

The estimated loads are sensitive to the assumed discharge and the accuracy and temporal representativeness of the compiled concentrations. Actual river discharge may vary among locations and over time because of tributary inflows, water withdrawals, wastewater inputs, and other hydrological factors.

Moreover, the estimates do not represent measured inputs from Baghdad or demonstrate net pollutant gains or losses along the river. Establishing those quantities would require concurrent measurements of concentrations and discharge at appropriate upstream and downstream boundaries, together with information on relevant inflows and outflows.

Consequently, Table 4 should be interpreted as a standardized scenario analysis intended to illustrate the relationship between concentration and potential mass transport.

3.5. Implications for pollution-control management

The compiled results indicate that Al-Rustamiya warrants priority attention in subsequent monitoring and pollution-source investigations. However, specific pollution sources should not be assigned without direct evidence.

An effective management strategy should combine source identification, improved wastewater treatment, river-water monitoring, sediment assessment, and evaluation of the effectiveness of implemented interventions.

Table 5
Proposed pollution-control and monitoring framework.

Component	Recommended action	Primary objective
Wastewater treatment	Improve municipal and industrial wastewater collection and treatment	Reduce organic pollutants, nutrients, and hazardous contaminants
Source identification	Measure pollutant concentrations and discharge rates at major outfalls	Identify important sources and estimate their contributions
River monitoring	Monitor BOD_5, COD, TN, TP, Pb, Cd, and river discharge	Track spatial and seasonal changes in water quality
Sediment assessment	Analyze metal concentrations, grain size, organic matter, and relevant sediment properties	Evaluate metal distribution and potential ecological risks
Wastewater conveyance	Assess alternative conveyance and diversion systems through engineering studies	Evaluate feasible alternatives to direct discharge
Intervention assessment	Compare verified baseline and follow-up measurements	Determine whether management actions produce measurable improvements

Wastewater diversion or conveyance to the Main Outfall Drain should be considered only after an engineering feasibility study and environmental impact assessment. Such an assessment should consider hydraulic capacity, treatment requirements, salinity, effects on agricultural land, and potential impacts on downstream environments.

Similarly, a proposed water-retention basin in Al-Nahrawan would require a separate assessment of storage capacity, hydraulic performance, seepage control, groundwater impacts, and environmental suitability.

Dilution may reduce concentrations under certain conditions but does not eliminate pollutant mass. Effective treatment and prevention of pollutant inputs should therefore remain the primary objectives.

3.6. Wastewater-sludge management and resource recovery

Wastewater-treatment sludge requires separate characterization before treatment, reuse, or disposal options can be selected. The sediment-metal concentrations presented in this study cannot be used as a substitute for direct measurements of wastewater sludge.

A sludge-characterization program should include heavy metals, microbiological indicators, salinity, nutrient content, organic matter, stability, and moisture content.

Solar drying may reduce moisture and improve sludge handling, but drying alone does not remove heavy metals and should not be assumed to provide adequate pathogen reduction without validated treatment conditions and microbiological verification.

Agricultural reuse should only be considered when the treated material meets applicable environmental and public-health requirements. Assessment should include heavy-metal concentrations, pathogen levels, salinity, nutrient availability, and potential impacts on soil and groundwater.

Where these requirements are not met, additional treatment or an alternative disposal method should be selected in accordance with applicable regulations.

Because the present study does not include direct sludge sampling, these measures constitute a proposed management framework rather than demonstrated outcomes of the investigation.

4. Conclusions

This study compared reported hydrochemical parameters, sediment-associated heavy metals, and scenario-based pollutant mass loads at three monitoring locations along the Baghdad–Wasit reach of the Tigris River.

The principal conclusions are as follows:

1. **Spatial variation in water quality.** Al-Rustamiya exhibited the highest reported concentrations of BOD_5, COD, TN, TP, Pb, and Cd in water, whereas Al-Fahama generally had the lowest concentrations. Upstream of Kut Barrage showed intermediate values. These differences identify Al-Rustamiya as a priority location for further investigation, although the temporal persistence and statistical significance of the observed pattern remain unverified.
2. **Sediment-associated heavy metals.** Reported Pb and Cd concentrations in sediments were higher at Al-Rustamiya and upstream of Kut Barrage than at Al-Fahama. The corresponding values exceeded the selected background references at the former two locations. However, these comparisons do not independently establish anthropogenic sources, metal bioavailability, or ecological risk.
3. **Literature-derived sediment-metal ranges.** The compiled ranges for Pb, Cd, Ni, and Cr exceeded the selected background references. These comparisons provide regional context but require verification of the original concentration data and the applicability of the reference values before definitive conclusions about metal enrichment can be drawn.
4. **Estimated pollutant mass loads.** Calculations using an assumed discharge of 200 m^3/s produced substantial scenario-based estimates of pollutant mass transport. The estimates are conditional on

the selected discharge and the accuracy of the compiled concentrations and must not be interpreted as direct measurements of pollutant fluxes or pollution inputs attributable to Baghdad.
5. **Potential role of sediment retention and river morphology.** Sediments may retain metals and redistribute them under changing hydraulic and geochemical conditions. Nevertheless, the available data do not demonstrate that river meanders caused the observed sediment-metal patterns. Evaluating this possibility requires measurements of channel morphology, flow conditions, sediment characteristics, and locally representative background concentrations.
6. **Need for integrated pollution management.** The results support coordinated monitoring of river water, sediments, wastewater discharge points, and river flow. Improving wastewater treatment and verifying the effectiveness of management interventions are important priorities for protecting water quality along the investigated reach.

Overall, the study provides a descriptive basis for prioritizing further environmental assessment along the Baghdad–Wasit reach of the Tigris River. Stronger conclusions will require verified source data, consistent seasonal sampling, appropriate sediment-quality assessment, and concurrent discharge and concentration measurements.

5. Recommendations

Based on the findings and limitations of the study, the following recommendations are proposed:

1. **Verify the compiled dataset.** Trace every reported concentration and reference value to its original source. Document the sampling location, sampling period, analytical method, sample number, and measurement uncertainty where available.
2. **Strengthen monitoring at Al-Rustamiya.** Conduct repeated seasonal sampling to determine whether the high reported concentrations of organic pollution indicators, nutrients, and waterborne metals persist under different hydrological conditions.
3. **Measure river discharge concurrently.** Obtain discharge measurements at all three monitoring locations during water sampling to support more reliable estimates of daily pollutant loads.
4. **Investigate major pollution sources.** Measure pollutant concentrations and flow rates at major municipal and industrial discharge points to determine their potential contributions to the river.
5. **Improve sediment assessment.** Analyze Pb, Cd, Ni, and Cr together with grain size, organic matter content, and other relevant sediment properties. Use locally appropriate background values and recognized sediment-quality assessment methods.
6. **Assess wastewater-conveyance alternatives.** Investigate the technical and environmental feasibility of proposed wastewater conveyance to the Main Outfall Drain and a potential water-retention basin in Al-Nahrawan. Implementation should depend on engineering studies, treatment requirements, and environmental impact assessment.

7. **Manage wastewater sludge separately.** Require chemical and microbiological characterization before selecting treatment, agricultural reuse, or disposal options.
8. **Evaluate management effectiveness.** Establish verified baseline measurements before implementing pollution-control projects and conduct follow-up monitoring to assess changes in water quality, sediment contamination, and pollutant mass loads.

Declarations

Conflict of interest

The author declares no conflict of interest.

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Author contributions

The manuscript identifies one author. The final contribution statement should reflect the work actually performed by the author and comply with the target journal's requirements.

Data availability

The study uses secondary data from published studies and environmental monitoring records. The sources identified in the manuscript are listed in the References section. The compiled dataset and its source-level documentation should be made available by the corresponding author upon reasonable request, subject to the availability and terms of the original records.

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