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Characteristics of sediment pollution study with trace elements in the Kufa River, Iraq

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Abstract
The deterioration of water quality due to increasing industrial and urban activities poses a growing threat to riverine ecosystems. Sediments, acting as both carriers and sinks for contaminants, are critical in evaluating environmental pollution and identifying its potential sources. This study investigates the concentrations and spatial distribution of selected heavy metals (Cd, Pb, Zn, Cu, Ni) in the bottom sediments of the Kufa River, located in Najaf Governorate, Iraq. Fine sediment fractions (<0.02 mm) were analyzed using the Geoaccumulation Index (I-geo) to assess pollution levels. The findings indicate that heavy metal concentrations were generally low and spatially homogeneous across the three selected sites. Most metals fell within the "unpolluted" to "moderately polluted" categories according to the I-geo classification. Nickel exhibited slightly elevated values at some sites, suggesting localized influence. Areas with low hydrodynamic activity showed marginally higher concentrations due to potential accumulation. These results provide a baseline understanding of heavy metal behavior in the Kufa River and highlight the importance of continuous sediment monitoring. The study supports the development of long-term environmental management strategies to preserve river health and prevent future degradation.

Keywords: *sediment monitoring, pollution assessment, heavy metals, geo-accumulation index, water quality, environmental management.*

Introduction

Iraq faces numerous environmental challenges as a result of recent industrial activities, agricultural expansion, and urbanization (Jasim and Walli 2023a). Pollution from increased industrial production, poor waste management, and industrial effluents contribute to the degradation of the environment's natural resources (Hussein, Neama Jabbar, and Ali 2020). Aquatic ecosystems are increasingly affected by human activities due to industries that have increased with population growth, leading to significant deterioration in natural water quality (Hussein, Nhabih, and Jabbar 2020). Sediments play a dual role as potential sinks and sources of environmental pollutants, especially heavy metals, and their impact on the natural environment (Jasim and Walli 2023a). Understanding sediment pollution is critical for assessing environmental risks and developing effective pollution control measures (Jasim and Walli 2023b). This study aims to analyse sediment pollution patterns, classify pollution levels, and propose strategies to mitigate environmental risks (Khazaal et al. 2019). The matter has become more complex and of increasing concern when various industries and technologies have grown and what they produce of chemical waste, toxins, and environmentally hazardous waste, in addition to the massive expansion in the use of pesticides, disinfectants, and sterilization materials and the discharge of sewage and industrial water and the process of random spread of service workshops (Khazaal et al. 2019). All of these activities pollute water resources, especially rivers, streams, canals, and inland lakes, with various types of pollutants, including toxic metals (Çapa et al. 2022). As far as the matter is concerned with aquatic environments and freshwater en-

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vironments in particular, following the subject of pollution and its effects on aquatic life has taken up a wide space among the environmental sciences, old and new, and the human being is one of the biological factors affecting the aquatic environment through various activities that lead to the pollution of the aquatic environment with many pollutants, so the interest of international organizations has increased in limiting the excessive use of it and trying to get rid of it, Environmental scientists have defined water pollution as the increase in the values of chemical, physical, or biological properties in a concentration or in a manner that makes water harmful to humans, living things, or property(PANHWAR et al. 2014). Heavy metals are released into aquatic environments naturally through geological processes, including erosion(Gonnelli and Renella 2013). These metals enter the aquatic environment from their original natural source—rocks and sediments (Haque 2022). These released metals dissolve or are suspended in rainwater flowing from the Earth's surface, or they are suspended in the air and carried by the wind(Zak et al. 2022). They can enter the aquatic environment through acid rain, which carries various pollutants, including elements(Ewaid, Abed, and Kadhum 2018). This rain can also dissolve soil and release heavy elements into the water, Industrial activity is a major source of heavy metal pollution in the environment (Duan et al. 2020). Many industries are sources of metal pollution, including petroleum refineries, iron and steel plants, copper, glass, aluminum, tanning plants, fertilizers, pesticides, gasoline, and other industries (Alloway 2013). This study integrates data and methods from Iraqi government reports, Arab environmental studies, and foreign scientific research. Primary sources include the Iraqi Ministry of Environment, United Nations environmental agencies, and scientific journals indexed in Scopus (Bello et al. 2022). The methodology includes field sampling, laboratory analyses, and a literature review to ensure a comprehensive understanding of pollution trends in the Kufa River, as well as a broader understanding of the behavior of these elements ,Water Pollution in Iraq: Water pollution is a critical problem in Iraq, primarily due to industrial wastewater, agricultural runoff, and inadequate wastewater treatment (Birch 2020). Studies by the Iraqi Ministry of Water Resources highlight the presence of heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) in major rivers such as the Tigris and Euphrates, Arab sources confirm these findings, while foreign research provides comparative data on global water pollution levels (Saeed et al. 1999). Soil and Heavy Metal Pollution: Soil pollution results from the overuse of pesticides, industrial waste disposal, and oil extraction activities, Research conducted by Iraqi universities and environmental organizations indicates high concentrations of arsenic (As), chromium (Cr), and nickel (Ni) in agricultural areas (Jasim and Walli 2023b). A comparative analysis with Arab and international studies shows that soil pollution levels in Iraq are far above international safety standards, Air pollution and industrial emissions: Air quality in Iraq has deteriorated due to vehicle emissions, industrial pollution, and recurring dust storms (Haroon 2020). Studies from the Iraqi Meteorological Organization and Arab environmental bodies indicate alarming levels of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), Foreign studies provide insights into the health risks associated with prolonged exposure to these pollutants (Saeed et al. 1999). The consequences of pollution in Iraq include respiratory diseases, waterborne diseases, and soil fertility, Research from international health organizations links exposure to pollution to increased incidences of cancer and neurological disorders (Haque, 2022). A comparative analysis with Arab and international health reports emphasizes the urgent need to implement pollution control measures (Haroon 2020).

Geographical location of the study

The Kufa River is a branch of the Euphrates River and flows through the city of Kufa in the Najaf Governorate, central Iraq, The river holds significant environmental and social value in the region, as it is used for both irrigation and drinking purposes, Additionally, it represents an essential ecological component of the area (Alhadad et al., 2024).

Selected Study Locations:

Location 1 – River Entry (Water Inlet Point): Located in the northeastern part of Kufa at coordinates (32.1989993°N, 44.3542344°E), this site marks the point where the river enters the urban area, It serves as a baseline for assessing sediment quality before any major influence from agricultural or urban activities (Jasim and Walli 2023b).

Location 2 – City Center (Midpoint): Located centrally within the city at coordinates (32.0590746°N, 44.3935891°E), near residential and commercial zones, this site monitors the impact of anthropogenic activities on sediment composition (Jasim and Walli 2023b).

Location 3 – River Exit (Water Outlet Point): Located

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in the southwestern part of Kufa at coordinates (31.9761580°N, 44.4620032°E), this site represents the point where the river exits the city, It is used to evaluate the cumulative effects of human and industrial activities along the river's course (Jasim and Walli 2023b).

These locations are illustrated in Figure 1.

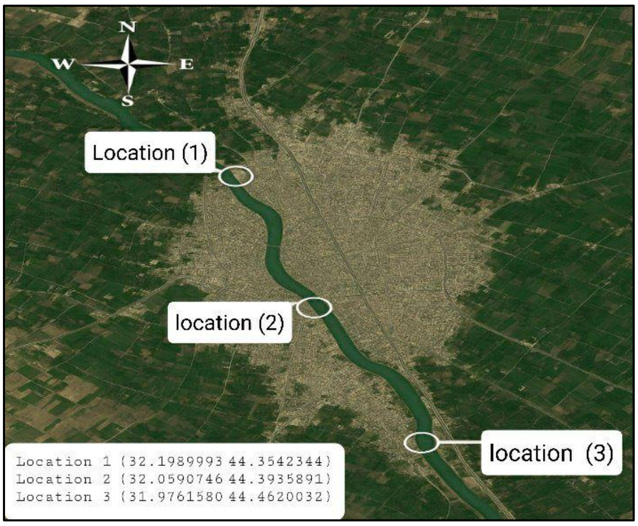

Figure 1. *Shows the sampling areas for the Kufa River.*

Materials and Methods

Sample collection

Sediment samples were collected using a Van Veen grab sampler after removing visible debris and foreign materials such as plastics, vegetation, or other non-natural matter not considered part of the native sediments, This instrument is well-suited for retrieving undisturbed surface layers from the riverbed, The sampling process focused on fine sediment particles (<0.02 mm), where 0.02 mm refers to the maximum diameter of the targeted fraction, This size was selected due to its high surface area and enhanced capacity to adsorb heavy metals, thereby improving the accuracy of contamination assessment (Bonsignore et al. 2018). The collected sediments were predominantly composed of fine-grained silty clay, based on visual inspection and geological characteristics of the Kufa River region, These sediments are expected to include typical alluvial minerals such as quartz, feldspar, kaolinite, and illite. Chemically, they likely contain elevated levels of silica (SiO_2), alumina (Al_2O_3), iron oxides (Fe_2O_3), and minor organic matter, all of which enhance the sediments' metal adsorption potential, After collection, samples were transferred into acid-washed polyethylene containers, kept refrigerated, and transported to the laboratory for further processing, In the lab, the samples were oven-dried at 60–70°C for 48 hours, ground with a ceramic mortar, and sieved through a 65 µm nylon mesh, The prepared samples were stored in clean, labeled polyethylene containers for subsequent analysis (Morillo, Usero, and Gracia 2004).

:

Sample digestion and elemental analysis

The measured elements included cadmium (Cd), lead (Pb), zinc (Zn), copper (Cu), and nickel (Ni), In the laboratory, approximately 0.5 grams of each dried and sieved sediment sample was accurately weighed and subjected to acid digestion using a mixture of 9 mL of nitric acid (HNO_3) and 3 mL of hydrochloric acid (HCl), Digestion was performed in sealed Teflon vessels using a microwave-assisted digestion system, following the USEPA 3051A standard protocol (Santos Bermejo, Beltrán, and Gómez Ariza 2003). After cooling, the digested solutions were filtered and diluted to a final volume of 50 mL with ultrapure deionized water, The samples were then analyzed for heavy metals—including Pb, Cd, Ni, Cr, Cu, and Zn—using atomic absorption spectroscopy (AAS), All glassware and equipment were thoroughly acid-cleaned and rinsed with ultrapure water to minimize contamination. The analysis targeted the exchangeable fraction of the sediment, which represents loosely bound metal ions that are susceptible to mobilezation under varying environmental condition (Bost et al. 2016; Morillo, Usero, and Gracia 2004). To assess the extent of contamination, the Geo-accumulation Index (I-geo) was applied by comparing measured concentrations with background reference levels, resulting in classification into distinct pollution categories. Furthermore, sequential extraction techniques were employed to investigate the chemical forms and mobility of the heavy metals. This approach provided deeper insight into their potential bioavailability and environmental risks (Santos Bermejo, Beltrán, and Gómez Ariza 2003).

Geo-Accumulation Index (I-geo)

The geoaccumulation index (I-geo) is a widely used geochemical tool for assessing the degree of metal contamination in sediments, It was proposed by Müller (1969) to assess contamination by comparing current concentrations of heavy metals in sediments with their pre-industrial levels. The formula used to calculate I-geo is:

$$\mathrm{Igeo} = \log 2 \frac{\mathrm{CN}}{1.5\ \mathrm{BN}} \qquad [1]$$

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where: I-geo = geoaccumulation index, Cn = measured concentration of the element in the sediment, Bn = background geochemical concentration of the same element, 1.5 = a constant factor added to account for natural (lithogenic) variations in background geological levels resulting from regional geological variations.

Interpretation of I-geo Values:
I-geo Value Range: Contamination Level
≤ 0: Uncontaminated
0-1: Uncontaminated to Moderately Contaminated
1-2: Moderately Contaminated
2-3: Moderately to Severely Contaminated
3-4: Severely Contaminated
4-5: Severely to Extremely Contaminated
> 5: Severely Contaminated
This index provides a quantitative and comparative understanding of contamination at sampling sites. It helps identify areas of environmental risk and provides insight into anthropogenic versus natural sources of metal concentrations (Santos Bermejo, Beltrán, and Gómez Ariza 2003).

Results and Discussion

Concentrations of heavy metals in sediment samples

Table 1 shows the concentrations of selected heavy metals (cadmium, lead, zinc, copper, and nickel) in sediment samples from the three sampling sites along the Kufa River, The results represent the average of . three replicates and are expressed as mean ± standard deviation, Values reflect relatively consistent distributions across sites, with slight spatial variation There is no indication of significant point contamination, as all measured concentrations fall within the ranges expected for river sediments in areas with moderate human activity, Cadmium concentrations were slightly elevated at Site 2, possibly related to local human inputs, Nickel and lead showed higher values at Sites 1 and 2 com-pared to Site 3, but the differences remained within natural variation, Figure 2 graphically represents the spatial distribution of heavy metals across the three sampling sites, The figure shows a clear increase in cad-mium and lead concentrations at Site 2, while the distribution of zinc and copper appears more even, Nickel shows a gradual decrease from site 1 to site 3, supporting the tabulated data (Yücesoy and Ergin 1992; Miao et al. 2020).

Table 1. *Mean concentrations (mg/kg) ± standard deviation of heavy metals in sediments from the Kufa River*

Element	Location 1	Location 2	Location 3
	mg/kg		
Cd	0.5 ± 0.1	0.8 ± 0.1	0.3 ± 0.05
Pb	15 ± 1.2	18 ± 1.4	12 ± 1.1
Zn	25 ± 2.0	22 ± 1.9	20 ± 1.7
Cu	20 ± 1.1	15 ± 1.3	15 ± 1.0
Ni	30 ± 2.2	28 ± 1.8	25 ± 2.0

Note: Values are presented as mean ± standard deviation (n = 3).

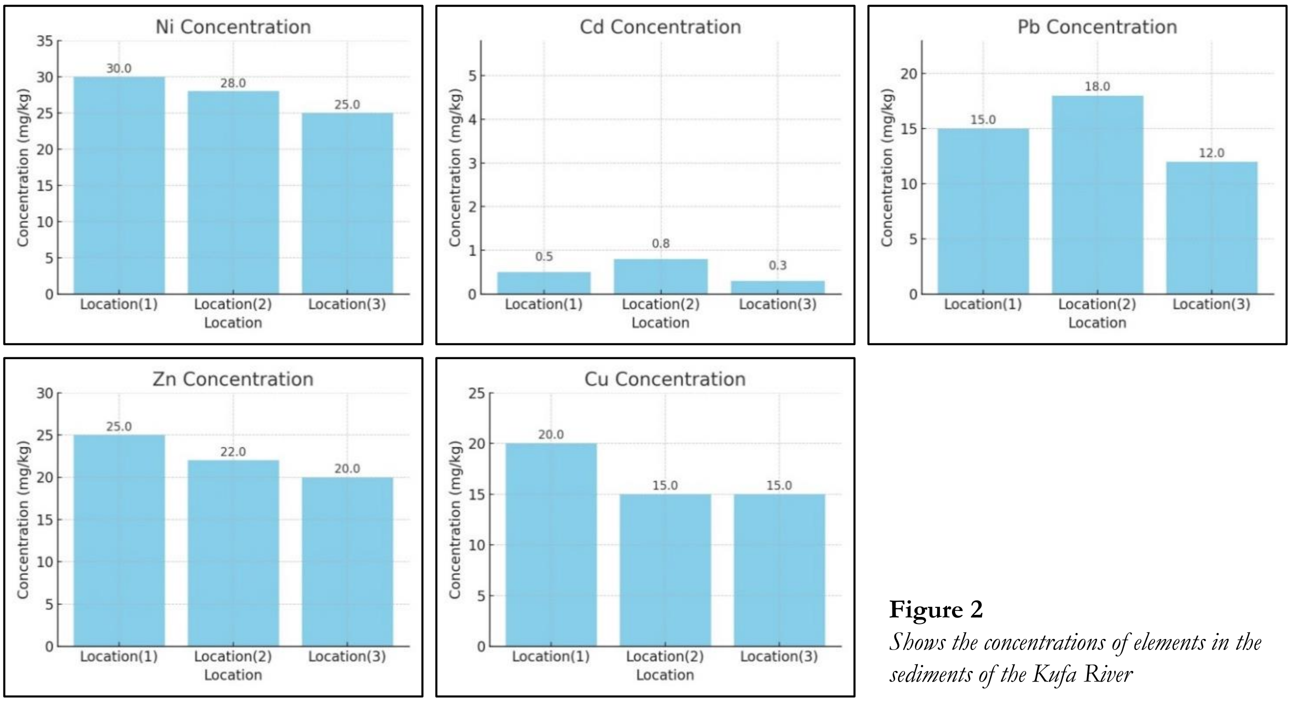

Figure 2
Shows the concentrations of elements in the sediments of the Kufa River

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Pollution assessment using the I-geo system

Using the I-geo classification system (see Table 2 and Figure 3), sediment samples collected from the three locations along the Kufa River were evaluated to determine pollution levels, The I-geo values for Cd, Zn, and Cu were negative or near zero across all sites, indicating that sediments are unpolluted by these elements, Pb also showed slightly positive values but still remained within the "unpolluted" category, In contrast, Ni exhibited higher I-geo values, with Location 1 and Location 2 both classified as "moderately polluted," while Location 3 fell in the range of "unpolluted to moderately polluted, These findings suggest that nickel is the main contributor to localized pollution, and targeted mitigation may be necessary at upstream and midstream sites, The overall low I-geo values confirm the absence of severe contamination, though continued monitoring is recommended to detect any emerging pollution threats, The I-geo system proves to be a reliable indicator for spatial assessment of heavy metal pollution and supports sustainable management of river sediments (Halldin Stenlid et al. 2020).

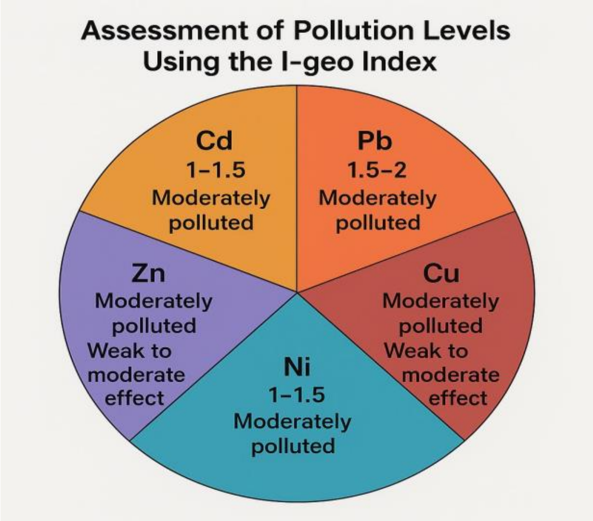

Figure 3. *Pollution level assessment using the I-geo index in the Kufa River.*

Table 2. *Geo-accumulation index (I-geo) values and pollution classification of heavy metals in sediments from the Kufa River.*

Element	Location 1 (I-Geo)	Class	Location 2 (I-Geo)	Class	Location 3 (I-Geo)	Class
Cd	-0.51	Unpolluted	0.14	Unpolluted	-0.82	Unpolluted
Pb	0.25	Unpolluted	0.44	Unpolluted	-0.12	Unpolluted
Zn	-0.21	Unpolluted	-0.08	Unpolluted	-0.15	Unpolluted
Cu	0.00	Unpolluted	-0.35	Unpolluted	-0.41	Unpolluted
Ni	0.72	Moderately polluted	0.68	Moderately polluted	0.55	Unpolluted to moderately polluted

Note: I-Geo values were calculated using the formula: $Igeo = \log_2 (Cn / 1.5 \times Bn)$, where Cn is the measured concentration and Bn is the background value.

Factors influencing heavy metal accumulation

The distribution and accumulation of heavy metals in the sediments of the Kufa River are influenced by a combination of natural and anthropogenic factors, The most prominent of these factors are wastewater discharges from residential and industrial areas, surface runoff from urban areas, and the physical and chemical properties of the sediments themselves, such as grain size and organic matter content, Hydrodynamic conditions play a crucial role, Areas with low water velocity tend to favor the deposition of fine-grained sediments, which have a greater capacity to adsorb and retain metal ions due to their larger surface area and chemical reactivity, As a result, these areas often exhibit higher concentrations of sediment-associated heavy metals. Conversely, areas with high flow may inhibit contaminant accumulation due to stronger resuspension and transport dynamics, In addition, the presence of point and non-point pollution sources along riverbanks contributes to spatial variation in metal concentrations. Therefore, understanding these influencing factors is essential for developing effective pollution control strategies, Identifying hotspots of metal accumulation and their main causes can help plan targeted interventions to improve sediment quality and reduce environmental risks(Huang et al. 2019).

Conclusions and Recommendations

Conclusions

Analysis of sediment samples collected from three sites along the Kufa River revealed that heavy metal concentrations were generally low and showed little spatial variation, According to the Geoaccumulation

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Index (I-geo), all sites were classified as "uncontaminated" and "moderately contaminated," with only nickel recording moderately high values at the upstream and midstream sites, The absence of significant differences between the upstream and midstream sites indicates that there is no dominant point pollution affecting metal concentrations in the study area, These results reflect relatively stable environmental conditions and suggest that current anthropogenic pressures, such as industrial discharge and urban runoff, had limited impact on sediment quality during the sampling period, The study highlights the importance of continuous monitoring, especially in areas with moderate geoaccumulation, to prevent future degradation, The use of the I-geo has proven effective in assessing sediment contamination and guiding future environmental management strategies (Bello et al. 2022).

Recommendations

Based on the findings of this study, the following recommendations are proposed to support effective environmental management and mitigate future risks:

1. Strengthening environmental regulations: implementing stricter environmental laws and regulations to reduce pollution from industrial waste and urban runoff.
2. Improving waste management practices: improving solid and liquid waste management through recycling, proper treatment, and environmentally sound disposal methods to prevent river sediment pollution.
3. Promoting the use of renewable energy: encouraging the adoption of clean energy alternatives, such as solar and wind power, to reduce emissions from conventional energy sources that may indirectly impact water quality.
4. Improving water treatment infrastructure: develoling and monitoring the performance of water treatment plants to ensure the effective removal of heavy metals and other harmful substances before discharge into natural water bodies.
5. Promoting international cooperation: cooperating with international environmental organisations to leverage advanced technologies and global expertise in pollution control, assessment, and treatment.
6. Establish long-term monitoring programmes: conduct periodic monitoring of water and sediment quality, with a particular focus on areas at risk or moderately polluted, to enable early detection and timely intervention.
7. Raise public environmental awareness: organise community education and awareness campaigns to promote sustainable practices, water conservation, and local management of the river ecosystem.

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