Ibn Al-Haitham Journal for Pure and Applied Sciences
Journal homepage: jih.uobaghdad.edu.iq
PISSN: 1609-4042, EISSN: 2521-3407
IHJPAS. 2026; 39(3)

The Sediments of the Tigris as an Indicator of Environmental Pollution: The Relationship between the Nature of the Sediments, the Accumulation of Pollutants and their Effects on Health

Ameerah Khattab Mahdi[1*], Raad Mahmoud Nasif Al-Khafaji[2], and Jinan S. Al-Hassany[3]

[1,2]Department of Biology, College of Education Pure Sciences (Ibn Al-Haitham), University of Baghdad, Baghdad, Iraq.
[3]Department of Biology, College of Sciences for Women, University of Baghdad, Baghdad, Iraq.
*Corresponding Author.

Received: 29/August/2025
Accepted:30/November/2025
Published: 20/July/2026
doi.org/10.30526/39.3.4291

Abstract

The Tigris, a vital source of fresh water in Iraq, is a major source of pollution. Its sediments act as sinks and carriers of pollutants and pose a burden on the environment and a health risk to the population. A study analyzed the chemical and biological pollution of sediments from five areas affected by domestic wastewater discharges in the winter of 2025. The study examined the physico-chemical properties of the sediments, including particle size distribution, organic matter content, pH, electrical conductivity, and total dissolved solids, as well as their relationship to pollutants such as heavy metals and total coliform bacteria. The results showed a significant increase in cadmium and nickel concentrations, especially in areas with high organic content. In contrast, iron remained within the globally permitted limits, while concentrations of chromium and lead were relatively low. Grain size analysis revealed that all sediments were of the sandy silt type, which is associated with the stabilization of heavy elements within the sediments, especially in a slightly alkaline environment with normal EC values. High levels of total coliform bacteria were detected at all sites, indicating widespread microbial contamination directly related to wastewater discharge. The non-cancer health risk (HQ, HI) and cancer risk (CR) coefficients were then calculated to assess potential human health impacts of heavy metals on human health. Some sites had levels that exceeded the permitted limits, indicating potential health risks that require attention and monitoring. These results underline the need to improve wastewater management and strengthen river pollution monitoring programs to reduce potential environmental and health risks.

Keywords: Tigris River, heavy metal pollution, total coliforms, physical and chemical properties, risks to human health, environmental pollution.

1. Introduction

Sediments are ecologically important components of aquatic ecosystems, a source of pollutants, and play a crucial role in maintaining the nutritional status of any water body[1]. Natural sources of sediment pollution include runoff, geological weathering, and erosion, while many industries discharge their waste and effluents directly into water bodies and indirectly via urban surface runoff[2]. Sediment quality has been defined as an important indicator or geochemical marker of water pollution[3]. Sediment pollution of water bodies refers to the contamination of water bodies by suspended solids, toxic substances, and pollutants resulting from human activities, such as industrial production, construction projects, and agricultural practices. These pollutants can affect plants and wildlife and clog drainage pipes, requiring costly clean-up efforts[4].

Soil texture refers to the relative content of particles of different sizes. Soil consists of varying amounts of sand, silt, and clay. Each soil texture reacts differently to water. Sandy soils are characterized by the largest particle size, which allows water to drain away quickly, so their ability to store water and nutrients is low. In contrast, silty soil has medium-sized particles, which improves its water retention capacity compared to sandy soil[5].

Surface sediments are among the most important reservoirs for organic material and are very dynamic in terms of their inventory[6]. Investigating the physical and chemical properties of sediments, especially organic material, can provide a basis for interpreting ancient climatic and environmental conditions. Sedimentary organic matter, which consists mainly of organic carbon and nitrogen, has an impact on the sustainable performance of ecosystems[7].

Organic matter enters the aquatic environment, including rivers, streams, lakes, and even oceans, through sewage effluents. After entering the aquatic environment, decomposed organic materials do not decompose completely but accumulate in the sediments. In the aquatic environment, decomposed organic materials also participate in biological transformation and form compounds that can be more or less toxic[8]. Physical and chemical factors of sediments, such as electrical conductivity and pH, can control the presence and abundance of the species found in them. Organic and inorganic pollutants dissolve in or are absorbed by suspended solids and sediment particles, depending on their properties[9]. Heavy metals are naturally occurring trace constituents in river sediments, but elevated concentrations can lead to significant pollution of rivers[10]. Pollution from heavy metals is a major problem due to their high concentrations in the environment, which often exceed permissible standards and regulations[11]. Most of the geological makeup of the Tigris consists of sedimentary rocks, with the exception of a small area containing igneous and metamorphic rocks, as found in the north and northeast of the country[12].

These deposits consist of gravel, sand, and clay and cover large areas in central and southern Iraq. The city of Baghdad lies in the alluvial sedimentary plain of the river on the stable shelf of the Arabian Plate; the Tigris represents the western part of this [13]. The river Tigris flows into the city of Baghdad and divides it into two sides: Karkh and Al-Rusafa. The main sources of sediment pollution in the Tigris River include industrial effluents, municipal wastewater, agricultural runoff, and surface erosion from adjacent lands. These inputs contribute heavy metals and other contaminants that accumulate in river sediments and serve as long-term indicators of environmental degradation[14].

This study aims to evaluate the levels and spatial distribution of heavy metals in the sediments of the Tigris River and to assess their environmental significance as indicators of pollution. The novelty of this research lies in focusing on sediment contamination rather than water quality alone, providing a clearer picture of long-term pollutant accumulation and potential ecological risks. The findings are expected to support future monitoring and management strategies for river ecosystems in Iraq.

2. Materials and Methods

2.1. Description of the study area

The study included five main areas spread over the urban area and nearby suburbs of Baghdad province in central Iraq, namely Al-Kuraiaat, Al-Shuhada Bridge, Al-Doura, Diyala Bridge, and Al-Swaira. The locations were determined using the Global Positioning System (GPS), and the coordinates ranged from the northernmost point of the study area in Al-Kuraiaat (33.390517, 44.358589) to the southernmost point in Al-Swaira in Wasit province (32.928432, 44.794017), thus within a relatively narrow geographical range that ensures similarities in environmental conditions. **Figure 1** illustrates the study area.

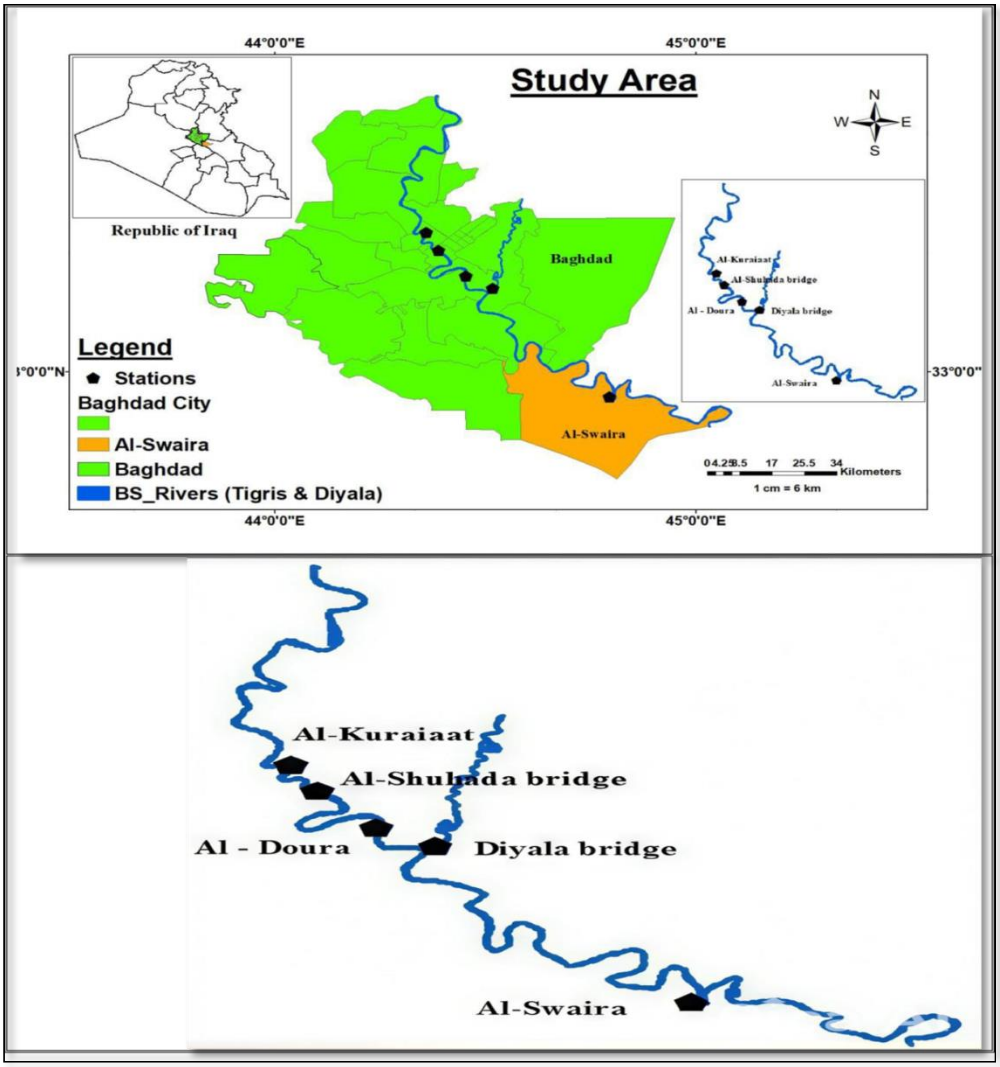

Figure 1. Shows an image of the study area that was designed using GIS software.

2.2. Sampling

Sediment samples were collected at five different locations along the Tigris River on three consecutive days in winter (December and January 2025), between 8:30 and 11:00 am. Samples were collected in clean 200 g plastic containers, with pre-labeled samples to avoid mixing, and packed in special boxes to protect them before shipment to the laboratory.

2.3. Laboratory analysis

The sediment texture was analyzed using the pipette method to determine fine particle fractions (silt and clay). The sediment texture was analyzed using the pipette method to determine fine particle fractions (silt and clay). It is then allowed to settle in a cylinder, and samples are taken with a pipette from a specific depth and at a specific time. The samples are dried and weighed to determine the percentage of grain size[15]. The pH of a 1:2.5 (w/v) sediment–water suspension was measured after 30 min of shaking and equilibration using a calibrated pH meter[16].

Electrical conductivity (EC) and total dissolved solids (TDS) were determined on a 1:5 (w/v) sediment–water extract; EC was measured directly with a conductivity meter, and TDS was calculated as TDS = 0.64 × EC (μS/cm). Organic matter was determined by loss on ignition: samples were first dried at 105 °C for 24 h, then ignited in a muffle furnace at 550 °C for 4 h; OM (%) was calculated from mass loss[17]. Total coliforms were enumerated by multiple tube fermentation (Standard Methods APHA 9221 B), with 10 g of wet sediment in 90 mL of buffered peptone water, serial dilutions to 10^{-3}, and incubation at 35±2 °C for 24±2 h[16]. For this purpose, ten grams of wet sediment were homogenized in 90 ml of buffered sterile peptone water, serial dilutions were performed, and they were incubated at a temperature of 35 degrees Celsius for a period of 24 to 48 hours. The tubes that showed positive gas formation were considered, and the most probable number (MPN) of total coliform bacteria per gram of sediment was calculated using the standard tables for the MPN method[16].

Heavy metals were analyzed using an X-ray fluorescence spectrometer (XRF; Thermo Fisher Niton XL3t). The instrument was calibrated with certified reference materials (NIST SRM 2709a and 2710a) to ensure accuracy. Method detection limits ranged approximately from 0.5–5 ppm for Cd, 5–20 ppm for Cr, Ni, and Pb, and 50–200 ppm for Fe. Quality control included analysis of duplicates and blanks, with recoveries between 85–115% and relative standard deviation below 10%. All reported concentrations represent the average of duplicate measurements within accepted precision limits[18].

2.4. Assessment of health risks of heavy metals

2.4.1. Assessment of non-carcinogenic health risks using indicators (HI, HQ)

Hazard Quotient (HQ): It expresses the ratio of the daily dose to which one is exposed by each of the three routes (ingestion, inhalation, and dermal contact) divided by the toxicity threshold, known as the reference dose (RFD) for a given chemical substance, the values of which are given in **Table 1.** The hazard quotient is determined according to the following **Equations (1-4)**:

$$\mathrm{HQ} = \frac{\mathrm{ADD}}{\mathrm{RFD}} \tag{1}$$

$$\mathrm{ADDing} = \frac{(\mathrm{C \times Ring \times EF \times ED \times 10{-}6})}{(\mathrm{AT \times BW})} \tag{2}$$

$$\mathrm{ADDinh} = \frac{(\mathrm{C \times Rinh \times EF \times ED})}{(\mathrm{AT \times BW \times PEF})} \tag{3}$$

$$\mathrm{ADDdermal} = \frac{(\mathrm{C \times SA \times ED \times EF \times ABS \times 10{-}6})}{(\mathrm{AT \times BW})} \tag{4}$$

Table 1. Shows the values of the data for adults and children for the equations (ADD inh, inh, dermal)[19].

Exposure parameters	Symbol	Unit	Categories	
			Adult	**Child**
Concentration of heavy metal	C (mean)	ppm	200	100
Rate of ingestion	R ing	mg / day	10	20
Rate of inhalation	R inh	m3 / day	350	350
Exposure Frequency	EF	day / year	6	30
Exposure Duration	ED	year	15	70
Body weight	BW	kg	1.36*109	
Particle Emission Factor	PEF	m3 / day	2800	5700
Skin Area avalable for soil contact	SA	cm3	0.2	0.07
Adherence Factor	AF	mg /cm3/ day	0.001	0.001
Dermal absorption factor	ABS	unit less	ED*365	ED*365
Average Time- Non carcinogenic	AT	day	ED = 6	ED = 30

Where ADD represents the daily dose for the three pathways (ADD ing, inh, der), RFD represents the reference dose for the element[19]. According to the Environmental Protection Agency (EPA)[20], if the hazard quotient (HQ > 1) indicates the potential for non-carcinogenic effects of heavy metals, while if its value is (HQ < 1), this indicates the absence of any non-carcinogenic health effects.

B- Hazard Index (HI) for children and adults to assess overall non-cancer effects according to the following **Equation (5).**

$$\mathrm{HI} = \sum_{i=1}^{n} HQ = HQ\ ing + HQinh + HQder \tag{5}$$

If the value of (HI ≤ 1), it indicates the absence of non-carcinogenic health risks for the heavy metal; however, if the value is (HI > 1), it is considered an indication of the potential presence of non-carcinogenic health effects[21].

2.4.2. Carcinogenic risk assessment

The health risks of carcinogens are assessed by multiplying the value of the daily dose for the three pathways (ADD ing, ADD inh, ADD der) by the Slope Factor (SF) provided in **Table 2** for the inhalation pathway (**Equation 6)**.

$$CR = ADD(ing, inh, der) \times SF(ing, inh, der) \quad \textbf{(6)}$$

Then, determine the total cancer risk (TCR) using the following **Equation (7)**[20]

$$TCR = \sum_{i=1}^{n} CR\ ing + CR\ inh + CR\ der \quad \textbf{(7)}$$

It was indicated that if the carcinogenic risk value (CR) is less than $1*10^{-6}$, it signifies that the risk of developing cancer is very low. If it ranges between $1*10^{-4}$ and $1*10^{-6}$, it indicates the possibility of developing carcinogenic diseases, while if CR is greater than $1*10^{-4}$, it indicates a high likelihood of developing cancerous diseases[21].

Table 2. Represents the reference dose for the heavy element (RFD, SF).

Adults and Children						
Element	**RFD ing**	**RFD inh**	**RFD derm**	**SF ing**	**SF inh**	**SF derm**
Fe	0.7	0.7	0.738	/	/	/
Cr	0.003	0.0000286	0.00006	/	42	/
Ni	0.02	0.0206	0.0054	/	0.84	/
Cd	0.001	0.001	0.00001	/	6.3	/
Pb	0.0035	0.00352	0.000525	/	/	/

2.5. Statistical analysis

The collected data were organized in IBM SPSS version 25.0 for statistical analysis. That means the standard division and minimum and maximum of all measured variables, including physical, chemical, microbial, and heavy metal parameters, were calculated. Significant differences among sites and variables were assessed using one-way analysis of variance (ANOVA), followed by the least significant difference (LSD) test at a significance level of $p \leq 0.05$. Furthermore, Pearson's correlation coefficient was applied to examine relationships among sediment characteristics, microbial load, and heavy metal concentrations. This approach allowed for identifying significant interactions and potential environmental indicators in the study area[22].

3. Results

The physical and chemical properties of the deposits sampled in the study area are summarized in **Table 3**. Sediment texture analysis at all sites indicates a silty clay classification, comprising predominantly silt and clay fractions. The silt content ranged between 45.87% in Al-Swaira and 51.27% in Al-Doura, while clay content ranged between 37.30% in Al-Doura and 43.97% in Al-Shuhada Bridge. Sand was present in smaller proportions, ranging from 8.17% in Al-Shuhada Bridge to 11.87% in Al-Swaira. Statistical analysis showed significant differences in clay, silt, and sand content among the studied sites ($p \leq 0.05$). Clay content was significantly lower at Al-Doura (37.30%) compared to other sites, while Al-Shuhada bridge had the highest clay content (43.97%). Silt percentages were significantly higher at Al-Doura (51.27%) and Diyala Bridge (50.47%) compared to Al-Swaira (45.87%), while sand percentages were significantly higher at Al-Swaira (11.87%) and Al-Doura (11.47%) compared to Al-Shuhada Bridge (8.17%). The organic matter (OM) content ranged between 2.27% at Al-Kuraiaat and 13.10% at Diyala Bridge, with highly significant differences between stations (p=0.001). Diyala Bridge had the highest OM (13.10%), followed by Al-Swaira (7.23%); Al-Kuraiaat and Al-Doura recorded the lowest OM (2.27% and 2.90%, respectively). The pH values ranged between 7.10 at Diyala Bridge and 7.77 at Al-Doura, with significant differences among sites ($p \leq 0.001$). All values indicate slightly alkaline conditions. Electrical conductivity (EC) values varied significantly (p=0.001), ranging between 0.50 mmhos/cm at Al-Kuraiaat and 0.93 mmhos/cm at Diyala bridge. Similarly, total dissolved solids (TDS) values differed significantly (p=0.003), ranging from 421.67 ppm at Al-Kuraiaat to 591.67 ppm at Diyala bridge. According to Soil Science Division Staff[23], the studied deposits are classified as sandy mud, slightly alkaline, and non-saline, with site-specific significant differences in organic matter, EC, TDS, and particle size distribution.

Table 3. Physical and chemical properties of the deposits in the study area.

Site	Sand %	Silt%	Clay%	Type of texture	pH	EC Mmhos/cm	TDS ppm	OM%
Al-Kuraiaat	11.23[a]	47.97[a]	40.80[a]	Sandy mud	7.50[a]	0.50[a]	421.67[a]	2.27[a]
Al-Shuhada bridge	8.17b	47.87[a]	43.97[b]	Sandy mud	7.20[b]	0.64[b]	547.33[b]	3.57[b]
Al-Doura	11.47[a]	51.27[b]	37.30[c]	Sandy mud	7.77[c]	0.77[c]	483.33[c]	2.90[a]
Diyala bridge	8.60[b]	50.47[b]	40.93[a]	Sandy mud	7.10[b]	0.93[d]	591.67[d]	13.10[c]
Al-Swaira	11.87[a]	45.87[c]	42.27[b]	Sandy mud	7.53[a]	0.67[b]	552.33[b]	7.23[d]
p-value	0.05*	0.01*	0.03*	1.000[No]	0.01*	0.001*	0.003*	0.001*

*Significant differences at a probability levels p≤0.05.
Different small letter in same columns indicated that significant differences.

Total coliform results are shown in **Table 4.** Significant differences were observed between the studied sites (p=0.001). The highest mean concentration was recorded at Al-Shuhada Bridge with 561,666.67 cells/100 ml, followed by Al-Kuraiaat at 120,000 cells/100 ml. Intermediate values were observed at Diyala Bridge (14,333.33) and Al-Swaira (7,466.66). The lowest concentration was found at Al-Doura, with only 266.67 cells/100 ml. The ranges of coliform counts also varied considerably between sites. The minimum values ranged from 200 cells/100 ml at Al-Doura to 70,000 cells/100 ml at Al-Shuhada Bridge, while the maximum values ranged from 400 cells/100 ml at Al-Doura to 1,100,000 cells/100 ml at Al-Shuhada Bridge. Standard deviation values were particularly high at Al-Shuhada Bridge (521,973.82), indicating great variability in coliform counts.

Table 4. Shows the microbial load (cell/100 ml total coliform) in the sediments of the study area.

	Al-Kuraiaat	Al-Shuhada bridge	Al-Doura	Diyala bridge	Al-Swaira	p-value
Min	20000	70000	200	9000	1400	
Max	170000	1100000	400	17000	17000	
S.D	52535	521973.82	103.28	4131.18	7475.47	
Mean	120000[a]	561666.67[b]	266.67[c]	14333.33[d]	7466.66[e]	0.001 *

*Significant differences at a probability levels p≤0.05.
Different small letter in same row indicated that significant differences.

The results of heavy metal analysis (**Table 5**) showed significant differences between sites (p≤0.05). Iron concentrations ranged from 36,537.25 ppm at Diyala Bridge to 44,492.25 ppm at Al-Shuhada Bridge (p=0.012). Chromium recorded the lowest value at Al-Kuraiaat (69.70a ppm) and the highest at Diyala Bridge (258.98c ppm) (p=0.01). Cadmium levels were elevated at all sites, ranging between 9a ppm at Al-Kuraiaat and 41.38c ppm at Diyala Bridge (p=0.002). Nickel concentrations varied significantly (p=0.001), with the lowest at Al-Kuraiaat (122.49a ppm) and the highest at Al-Swaira (197.24e ppm). Lead values ranged between 11.99a ppm at Al-Kuraiaat and 39.43d ppm at Al-Swaira, also showing significant differences (p=0.003). Overall, Al-Shuhada Bridge, Diyala Bridge, and Al-Swaira recorded the highest levels of heavy metals, particularly Cr, Cd, and Ni, which exceeded the permissible limits.

Table 5. Shows the concentration rates of heavy metal elements in ppm in the sediment samples from the study area.

Site	Fe	Cr	Cd	Ni	Pb
Al-Kuraiaat	38468[a]	69.70[a]	9[a]	122.49[a]	11.99[a]
Al-Shuhada bridge	44492.25[b]	168.02[b]	26[b]	155.32[b]	19.81[b]
Al-Doura	37925.85[c]	224.10[c]	10.33[a]	168.68[c]	14.34[c]
Diyala bridge	36537.25[c]	258.98[c]	41.38[c]	190.30[d]	19.58[b]
Al-Swaira	42383.12[b]	162.27[b]	21.5[d]	197.24[e]	39.43[d]
p-value	0.012*	0.01*	0.002*	0.001*	0.003

The correlation matrix of physical, chemical, microbial, and heavy metal parameters is presented in **Table 6.** The analysis showed a significant positive correlation between sand content and pH (r=0.888, p=0.044). A highly significant positive correlation was also observed between EC and TDS (r=1.000, p=0.000) as well as between EC and Cr (r=0.968, p=0.007). Organic matter (OM) showed a significant positive correlation with Cd (r=0.890, p=0.043). In contrast, a negative relationship was noted between pH and Cd (r=-0.860, p=0.061, nearly significant). Other correlations, such as between total coliform and Fe (r=0.728) and OM with Ni (r=0.727), were positive but not statistically significant (p>0.05). Overall, the results indicate strong interrelations between some soil physicochemical properties and heavy metals, particularly the role of EC, TDS, and OM in influencing the accumulation of Cr, Cd, and Ni in sediments.

Table 6. Pearson correlation between soil texture, physicochemical properties, organic matter, microbial load, and heavy metals in the study area sediments.

	Sand	**Silt**	**Clay**	**pH**	**EC**	**TDS**	**OM**	**Total coliform**	**Fe**	**Cr**	**Cd**	**Ni**	**Pb**
Sand	1												
Silt	-.221	1											
Clay	-.510	-.726	1										
pH	.888*	.062	-.679	1									
EC	-.372	.623	-.288	-.320	1								
TDS	-.372	.623	-.288	-.320	1.000**	1							
OM	-.385	.149	.138	-.613	.789	.789	1						
Total coliform	-.642	-.259	.683	-.453	-.364	-.364	-.363	1					
Fe	-.164	-.717	.750	-.129	-.457	-.457	-.340	.728	1				
Cr	-.375	.627	-.288	-.231	.968**	.968**	.647	-.239	-.305	1			
Cd	-.741	.103	.430	-.860	.713	.713	.890*	.095	-.036	.633	1		
Ni	-.032	.008	.016	-.140	.741	.741	.727	-.390	.009	.746	.601	1	
Pb	.235	-.681	.436	-.026	.076	.076	.358	-.159	.493	.088	.269	.717	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

The results of **Table 7** for non-carcinogenic and carcinogenic risks indicated that all HQ (hazard quotient) and HI (hazard index) values for all exposure pathways (ingestion, inhalation, and dermal contact) and all age groups were below 1.

Therefore, there is no significant likelihood of non-carcinogenic health risks. For carcinogenic risks (CR), the values for cadmium (Cd) and nickel (Ni) for both adults and children were below the reference limits. In contrast, chromium (Cr) showed CR values exceeding the recommended limits, indicating potential carcinogenic concern and suggesting that there must be continuous monitoring of its concentrations.

Table 7. Presents the average daily dose (ADD), hazard quotients (HQ) for the three exposure pathways (ingestion, inhalation, and dermal contact), hazard index (HI), and inhalation carcinogenic risk (CR) for adults and children in the study areas.

	Fe		**Cr**		**Ni**		**Cd**		**Pb**	
	Adult	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Child**
ADD ing	5.47×10^{-2}	5.10×10^{-1}	2.41×10^{-4}	2.25×10^{-3}	2.28×10^{-4}	2.13×10^{-3}	2.96×10^{-5}	2.77×10^{-4}	2.88×10^{-5}	2.69×10^{-4}
ADD inha	8.05×10^{-6}	1.88×10^{-5}	3.55×10^{-8}	8.30×10^{-8}	3.36×10^{-8}	7.84×10^{-8}	4.36×10^{-9}	1.02×10^{-8}	4.23×10^{-9}	9.89×10^{-9}
ADD der	2.18×10^{-5}	1.43×10^{-4}	9.65×10^{-8}	6.32×10^{-7}	9.11×10^{-8}	5.97×10^{-7}	1.18×10^{-8}	7.75×10^{-8}	1.14×10^{-8}	7.53×10^{-8}
HQ ing	7.82×10^{-2}	7.29×10^{-1}	8.06×10^{-2}	7.75×10^{-1}	1.14×10^{-2}	1.06×10^{-1}	2.96×10^{-2}	2.76×10^{-1}	8.23×10^{-3}	7.68×10^{-2}
HQ inha	1.15×10^{-5}	2.68×10^{-5}	1.24×10^{-3}	2.90×10^{-3}	1.63×10^{-6}	3.80×10^{-6}	4.36×10^{-6}	1.02×10^{-5}	1.23×10^{-6}	2.89×10^{-6}
HQ der	2.95×10^{-5}	1.94×10^{-4}	1.60×10^{-3}	1.05×10^{-2}	1.68×10^{-5}	1.10×10^{-4}	1.18×10^{-3}	7.74×10^{-3}	2.19×10^{-5}	1.43×10^{-4}
HI	7.82×10^{-2}	7.30×10^{-1}	8.35×10^{-2}	7.66×10^{-1}	1.11×10^{-2}	1.06×10^{-1}	3.08×10^{-2}	2.84×10^{-1}	8.25×10^{-3}	7.69×10^{-2}
CR inh	/	/	1.49×10^{-6}	3.49×10^{-6}	2.82×10^{-8}	6.58×10^{-8}	2.74×10^{-8}	6.41×10^{-8}	/	/

4. Discussion

The dominance of sandy mud texture in the sediments reflects the geomorphological characteristics of the study area, which lies within Iraq's alluvial sedimentary plain. This texture, composed mainly of silt and clay, influences both the transport and deposition of particles, as well as the geochemical behavior of contaminants. The observed variation in grain-size distribution among sites indicates differing hydrodynamic conditions and sediment sources, consistent with findings by [24] and [25], who reported that floodplain deposits of the Tigris River are dominated by fine particles. Fine-grained sediments provide a larger surface area for sorption and thus serve as effective sinks for pollutants, particularly heavy metals and organic matter.

The relatively high levels of organic matter, especially at Diyala Bridge and Al-Swaira, likely result from the discharge of domestic and agricultural wastewater that enriches the sediments with decomposed organic material[26,27]. Under slightly alkaline and reducing conditions, organic compounds resist decomposition and become incorporated into the fine-grained fraction, where oxygen diffusion is restricted[28]. The preservation of organic matter within aquatic sediments is strongly influenced by both physicochemical and biological interactions. Under slightly alkaline and reducing conditions, organic compounds tend to resist degradation and become incorporated into the fine-grained fraction of sediments, especially clays and silts, where microbial activity is limited and oxygen diffusion is restricted[9, 29]. This stabilization process facilitates the binding of heavy metals through complexion and adsorption mechanisms, as organic matter contains functional groups such as carboxyl, phenolic, and hydroxyl that readily form chelates with metal ions such as Cd, Pb, Ni, and Cr[30]. Consequently, sediments enriched in organic matter often exhibit elevated concentrations of heavy metals, not necessarily due to increased pollution input but as a result of the strong sportive capacity of organic–mineral complexes[31]. These interactions indicate that organic matter plays a dual environmental role: it acts as a preservative matrix for organic residues while simultaneously functioning as a natural scavenger that immobilizes toxic metals and reduces their bioavailability[32]. This process ultimately affects sediment geochemistry, influencing both pollutant persistence and ecological risk levels in aquatic systems.

Microbial contamination patterns were consistent with the physicochemical conditions of the sediments. The significantly elevated total coliform counts at Al-Shuhada Bridge and Al-Kuraiaat correspond to their proximity to untreated sewage outfalls, indicating the influence of domestic wastewater on microbial load. Fine-textured and organic-rich sediments promote microbial colonization by providing moisture, nutrients, and microhabitats that protect bacteria from environmental stress[33]. This phenomenon explains why sites with higher organic matter also exhibited greater bacterial abundance compared to Al-Doura, where both organic matter and coliform levels were lowest.

The concentrations of heavy metals varied significantly among sites, with Cr, Cd, and Ni exceeding permissible limits in several areas. Elevated Fe levels largely reflect the geochemical composition of Iraqi soils and the erosion of iron structures[29]. Lead contamination likely originates from domestic plumbing and storage materials[34]. Nickel and chromium enrichment is linked to vehicular emissions, industrial waste, and agricultural runoff[35]. The positive correlations between organic matter and Cd ($r = 0.890$, $p = 0.043$) and between EC and Cr ($r = 0.968$, $p = 0.007$) suggest that both physicochemical parameters and organic content strongly influence metal accumulation within sediments. Clay-rich and organic sediments act as effective adsorbents for heavy metals[31,33], limiting their mobility and controlling their distribution.

The health risk assessment revealed that all HQ and HI values were below 1 for both adults and children, indicating no significant non-carcinogenic risks. However, the elevated carcinogenic risk (CR) values for chromium indicate potential long-term concern, consistent with previous reports highlighting its carcinogenicity and environmental persistence[36,37]. Continuous monitoring of Cr levels and improved control of industrial effluents are therefore necessary to reduce potential human exposure through sediment contact and resuspension.

Therefore, the interdependence of sediment texture, organic matter, and microbial load plays a central role in controlling the geochemical behaviour of heavy metals in the Tigris River sediments. These factors collectively determine pollutant retention, microbial activity, and potential health implications. Effective wastewater management and regular monitoring are essential to mitigate future contamination and ensure sediment quality sustainability in the river system.

5. Conclusion

The Tigris River's riverbed sediments, particularly near domestic sewage discharge points, are prone to high levels of chemical and biological pollution. Significantly elevated cadmium and nickel levels confirm anthropogenic inputs and accumulation in the sediment matrix. The soil texture and organic matter content also contribute to the accumulation of heavy metals, especially under alkaline conditions and normal electrical conductivity. Sediments trap these pollutants, leading to their accumulation over time. Sediments rich in clay and organic matter foster total coliform proliferation, underscoring their role as microbial reservoirs under alkaline conditions. Non-carcinogenic HQ and HI values were below unity, but calculated carcinogenic risk for chromium exceeded acceptable thresholds, warranting ongoing sediment monitoring and pollution control.

Acknowledgment

Many thanks to the Department of Biology at the College of Education for Pure Sciences (Ibn Al-Hitham), University of Baghdad, for their invaluable assistance in facilitating the practical sections of this article.

Conflict of Interest

The authors declare that they have no conflicts of interest.”

Funding

No founding.

References

1. Mahmmod RH, Najam LA, Wais TY, Mansour H. Assessment of the pollution of some heavy metals in the sediments of the Tigris River in the city of Mosul-Northern Iraq. Pollution. 2023;9(2):646-659. https://doi.org/10.22059/poll.2022.348104.1611.
2. Homady AD, Fayidh MA. An integrated suggestion to decolourize Allura red AC dye in the wastewater of pharmaceutical industries using a local bacterial isolates. Int J Drug Deliv Technol. 2022;12:1196-1200. https://doi.org/10.25258/IJDDT.12.3.46.
3. Ustaoğlu F, Tepe Y. Water quality and sediment contamination assessment of Pazarsuyu Stream, Turkey using multivariate statistical methods and pollution indicators. Int Soil Water Conserv Res. 2019;7(1):47-56. https://doi.org/10.1016/j.iswcr.2018.09.001.
4. Reddy S, Osborne WJ. Effect of pollution on sediments and their impact on the aquatic ecosystem. In: Relationship Between Microbes and the Environment for Sustainable Ecosystem Services, Vol. 2. Elsevier; 2022. p. 1-16. https://doi.org/10.1016/b978-0-323-89937-6.00001-2.
5. Martín MA, Pachepsky YA, García-Gutiérrez C, Reyes M. On soil textural classifications and soil-texture-based estimations. Solid Earth. 2018;9(1):159-165. https://doi.org/10.5194/se-9-159-2018.
6. Berberich ME, Beaulieu JJ, Hamilton TL, Waldo S, Buffam I. Spatial variability of sediment methane production and methanogen communities within a eutrophic reservoir: Importance of organic matter source and quantity. Limnol Oceanogr. 2020;65(6):1336-1358. https://doi.org/10.1002/lno.11392.
7. Zhang K, Li D, He X, Xie C, He H. Spatial distribution and sources of organic matter in the surface sediments of Fuxian Lake, SW China. Water. 2023;15(4):794. https://doi.org/10.3390/w15040794.
8. Al-Khafaji RMN, Tovfik SM, Salman BG. Environmental assessment and hydrochemical formula of groundwater wells for selected areas of Maysan province, southern Iraq for 2014. J Phys Conf Ser. 2020;1660(1):012079. http://dx.doi.org/10.1088/1742-6596/1660/1/012079.
9. Förstner U. Inorganic sediment chemistry and elemental speciation. In: Sediments (pp. 61-105). CRC Press; 2022.
10. Sojka M, Jaskuła J. Heavy metals in river sediments: contamination, toxicity, and source identification—a case study from Poland. Int J Environ Res Public Health. 2022;19(17):10502. https://doi.org/10.3390/ijerph191710502.
11. Kadhim AH, Ali MO. Mineralogy of recent sediments of Al-Teeb River Basin, East Missan Governorate, southeastern Iraq. Iraqi J Sci. 2022;63(10):4342-4351. https://doi.org/10.24996/ijs.2022.63.10.20.
12. Al-Sultani NK, Al-Amar HA, Al-Zubaydi JH. Geotechnical properties of soil slopes of the Great Musaiyab project, Babylon, middle of Iraq. Iraqi Geol J. 2023:273-280. https://doi.org/10.46717/igj.56.1B.20ms-2023-2-28.
13. Ewaid SH, Abed SA, Kadhum SA. Predicting the Tigris River water quality within Baghdad, Iraq by using water quality index and regression analysis. Environ Technol Innov. 2018;11:390-398. https://doi.org/10.1016/j.eti.2018.06.013.
14. Gee GW, Or D. Particle-size analysis. In: Dane JH, Topp GC, editors. Methods of Soil Analysis: Part 4–Physical Methods. Madison (WI): Soil Sci Soc Am; 2002. p. 255-293. https://doi.org/10.2136/sssabookser5.4.c12.
15. APHA. Standard methods for the examination of water and wastewater. 23rd ed. Washington, DC: American Public Health Association; 2017.
16. Ryan J, Harmsen K, Rashid A. Soil and plant analysis manual. Aleppo, Syria: International Center for Agriculture Research in the Dry Areas & National Agriculture Research Center; 2001. p.42-165.
17. Conklin AR. Introduction to soil chemistry (Analysis and Instrumentation). 2nd ed. Hoboken, NJ: John Wiley & Sons Inc.; 2014. 347 p.
18. USEPA (United States Environmental Protection Agency). Exposure Factor Handbook (Final Edition). Washington, DC: U.S. Environment Protection Agency; 2011. Report No.: EPA/600/R-09/052F.
19. Miletić A, Lučić M, Onjia, A. Exposure factors in health risk assessment of heavy metal (loid) s in soil and sediment. Metals. 2023; 13(7), 1266. https://doi.org/10.3390/met13071266.
20. Environmental Protection Agency (EPA). Region 4 human health risk assessment supplemental

guidance [Internet]. 2018 [Updated 2018 March]. https://rais.ornl.gov/documents/hhra_regional_supplemental_guidance_report-march-2018_update.pdf.
21. Cai K, Li C, Song Z, Gao X, Wu M. Pollution and health risk assessment of carcinogenic elements As, Cd, and Cr in multiple media-A case of a sustainable farming area in China. Sustainability. 2019; 11(19), 5208. https://doi.org/10.3390/su11195208.
22. Field A. Discovering statistics using IBM SPSS statistics. 4th ed. London: SAGE Publication; 2013.
23. Soil Science Division Staff. Soil survey manual. USDA, United States Department of Agriculture. Handbook No. 18. Washington, DC: USDA; 2017. https://www.iec.cat/mapasols/DocuInteres/PDF/Llibre50.pdf.
24. Kaizal AF, Salman JM, Kot P. Evaluation of some heavy metals, their fate and transportation in water, sediment, and some biota within AL-Musayyib River, Babylon Governorate, Iraq. Baghdad Sci J. 2023;20(2):066-016. https://doi.org/10.21123/bsj.2022.7599.
25. Xu X, Shi R, Lv C, Liu H, Yang W, Qian S, Fujibayashi M. Zhi Y, Wang G, Nomura M, Nishimura O, Li W. Hydrodynamic-driven changes in the source and composition of sedimentary organic matter via grain size distribution in shallow lakes. J Geophys Res Biogeosci. 2021;126(11):e2021JG006502. https://doi.org/10.1029/2021jg006502.
26. Mutlak H, Karim H, Abdullah KA. Physical properties of the alluvial plain soil in Ramadi District. Stud Humanit Soc Sci. 2020;47(2):372-390. https://archives.ju.edu.jo/index.php/hum/article/view/107445.
27. Bouma J. Implications of the nexus approach when assessing water and soil quality as a function of solid and liquid waste management. In: Environmental resource management and the nexus approach. Cham: Springer; 2016. p.179-209.
28. Kleber M, Bourg, IC, Coward EK, Hansel CM, Myneni SC, Nunan N. Dynamic interactions at the mineral–organic matter interface. Nature Reviews Earth & Environment. 2021; 2(6), 402-421. https://doi.org/10.1038/s43017-021-00162-y.
29. Al-Jumaily HAA, Rasheed BR. The geochemical distribution and assessment of heavy metals pollution in soil sediment of Chamchamal city, Sulaimanya Governorate/Northeastern Iraq. J Environ Earth Sci. 2018;8(12):131-147.
30. Lian M, Ma Y, Li J, Sun J, Zeng X. Influence of pH on the particulate-bound Cd speciation and uptake by plants. Pol J Environ Stud. 2022;31(6):5511-5517. https://doi.org/10.15244/pjoes/152224.
31. Mohamed T, Abdelkader E, Nadjia L, Abdelkader D. Study of the interaction of heavy metals (Cu(II), Zn(II)) ions with a clay soil of the region of Naima-Tiaret-Algeria. Bull Chem React Eng Catal. 2020;15(3):765-785. https://doi.org/10.9767/bcrec.15.3.8773.765-785.
32. Yu H, Li C, Yan J, Ma Y, Zhou X, Yu W, Kan H, Meng Q, Xie R, Dong P. A review on adsorption characteristics and influencing mechanism of heavy metals in farmland soil. RSC Adv. 2023;13(6):3505-3519. https://doi.org/10.1039/D2RA07095B.
33. Seaton FM, George PB, Lebron I, Jones DL, Creer S, Robinson DA. Soil textural heterogeneity impacts bacterial but not fungal diversity. Soil Biol Biochem. 2020;144:107766. https://doi.org/10.1016/j.soilbio.2020.107766.
34. Harvey PJ, Handley HK, Taylor MP. Widespread copper and lead contamination of household drinking water, New South Wales, Australia. Environmental research. 2016; 151, 275-285. https://doi.org/10.1016/j.envres.2016.07.041.
35. Rathor G, Chopra N, Adhikari T. Nickel as a pollutant and its management. Int Res J Environ Sci. 2014;3(10):94-98. https://www.isca.me/IJENS/Archive/v3/i10/15.ISCA-IRJEvS-2014-189.pdf.
36. Tavares AM, Viegas S, Louro H, Göen T, Santonen T, Luijten M, Silva MJ. Occupational exposure to hexavalent chromium, nickel and PAHs: a mixtures risk assessment approach based on literature exposure data from European countries. Toxics. 2022; 10(8), 431. https://doi.org/10.3390/toxics10080431.
37. Georgaki MN, Charalambous M, Kazakis N, Talias MA, Georgakis C, Papamitsou T, Mytiglaki C. Chromium in water and carcinogenic human health risk. Environments. 2023; 10(2), 33. https://doi.org/10.3390/environments10020033.