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Spatiotemporal Assessment of Heavy Metal Pollution in the Tigris River

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Abstract

The emphasis of the world on sustainable water quality and frequent monitoring of pollutants has grown greater to protect public health and biodiversity, aimed at limiting human activities that lead to water pollution and conserving water resources. The objective of this study was to evaluate the levels of pollution and concentrations of different heavy metals in sediment and water samples taken from four locations along the Tigris River at Baghdad City, Iraq, during 2024. In order to investigate the variations in conditions between the wet and dry seasons, samples were collected during each. Among the elements under analysis were lead, nickel, chromium, zinc, and iron. The samples were analyzed for heavy metals using Atomic Absorption Spectrophotometry (AAS) following standardized procedures (APHA). Data on the pollution index (PI) showed that the effect on water quality ranged from very little to modest. Reading on the Metal Index (MI) ranged from 1.87 to 3.66. River sediments were evaluated using geochemical markers, including the geoaccumulation factor and contamination factor. For nickel, zinc, lead, and chromium, the geoaccumulation index values showed no pollution. Iron tests turned up moderate to significant contamination at several sites. Except for iron, which showed notable contamination, the index values for contamination variables were essentially within the low contamination range. The Sediment Quality Guidelines (QSm) ranged in value from 3.752 to 8.44. Since QSm exceeded 0.5, all sites fell into the third category of potential danger for aquatic life (possible hazard for aquatic life), implying that negative effects on aquatic life could not be excluded. The Tigris River is not heavily polluted; it has moderate contamination.

Keywords: Assessment, Baghdad, Heavy metal indices, Tigris River, Spatiotemporal.

1. Introduction

Heavy metal pollution is considered an emerging global issue toward sustainability and public health [1,2]. Deposition of heavy metals has been reported in the atmosphere, marine environment, and soil, subsequently causing problems with drinking water sources besides raising the toxic levels of metal contaminants in food[3]. Industrialization and urbanization have increased metal emissions and contamination, putting more pressure on the environment. Metals are contaminants generated from human activities. The primary sources include mining, smelting, and metal processing-which are directly related to mineral resources-oil and gas extraction, municipal and industrial wastewater, and traffic, which are related to mineral resources, and waste disposal site, which negatively affect the environment and human health[4]. Essential and non-essential are the two main classifications of heavy metals. Examples of heavy metals are zinc, iron, manganese, copper, and chromium. Toxicity to a living organism increases with concentration if it relates to essential heavy metals. Non-essential heavy metals are toxic at low concentrations; for example, cadmium, lead, mercury, and arsenic [5]. Like many urban rivers, the

Tigris can be affected by municipal discharges, agricultural runoff, and industrial wastewater, which can lead to the buildup of heavy metals in its sediments. Heavy metals are considered one of the most harmful environmental pollutants due to their toxicity, persistence, and capacity to enter food chains[6], originating from both natural and artificial sources. Erosion, volcanic activity, and weathering of minerals from eruptions are the main natural sources. Anthropogenic causes involve activities like mining, metallurgy, farming with pesticides and phosphate fertilizers, electroplating, cleaning sludge from sewers, waste from factories, and air pollution [7] Assessing pollution levels of heavy metal in sediment and water samples was the goal of this investigation of the Tigris River within Baghdad city.

Numerous studies on the utilization of indicators for heavy metal contamination in the Tigris River water [8-13,2830,] Baghdad, in the core of Iraq, is among the most densely inhabited cities and significantly contributes to the pollution of the Tigris River and other drinking water sources in the region. This pollution is, at certain points, significantly critical and exceeds national standards. If unaddressed, chemical contaminants in the Tigris River will ultimately result in the proliferation of tens of thousands of cancer cases and other lethal diseases[13]. The objective of the study was to evaluate the contamination levels of heavy metals in sediment and water samples from the Tigris River in Baghdad city.

2. Materials and Methods

2.1. Study Area

The length of the river within Baghdad is almost 50 km; the width varies along its course. Four locations along the Tigris River in Baghdad were selected during this study **(Figure 1)**, and their coordinates were recorded using GPS (**Table 1**): Gherai'at, the first site, is a natural island to the northeast of Baghdad. There are several palm trees and submerged vegetation in the area, and food and plastic waste can be observed close to the river. Soil texture analysis showed that it consists of 69% sand, 18% silt, and 13% clay during the wet season, while during the dry season it was recorded as 63.76% sand, 21.24% silt, and 15% clay. The second site, Atifiyah, meanders and is characterized by agricultural and human activities with certain macrophytes. Soil texture analysis showed that it consists of 82.4% sand, 10% silt sand, and 7.6% clay during the wet season, while during the dry season it was recorded as 93.3% sand, 4.2% silt, and 2.5% clay. The third site, Jadriya, is characterized by macrophytes like *C. demersum*, *P. australi*s, and *Eichhornia crassipes*. Soil texture analysis showed that it consists of 46.25% sand, 27.75% silt, and 26% clay in the wet season, while during the dry season it was recorded as 24.92% sand, 41.08% silt, and 34% clay. The fourth site, Za'franiya, is located in the southeastern part of Baghdad. This area is influenced by industrial activities, including vegetable oil plants and the Rasheed Power Plant. Because of urbanization and the expansion of municipal services, the area is densely populated; the majority of municipal and industrial trash was released directly into the river without adequate treatment. Soil texture analysis showed that it consists of 67.02% sand, 19.98% silt, and 13.0% clay during the wet season, while during the dry season it was recorded as 16.75% sand, 48.25% silt, and 35% clay.

Table 1. The study site's geographic Coordinates (GPS) along the Tigris River, Baghdad

All Sites	Latitude (φ)	Longitude (λ)	X- Coordinate (UTM)
S 1 Gherai'at	33.392899	44.354599	440006.5915
S 2 Atifiyah	33.359501	44.370399	441438.1001
S 3 Jadriya	33.283298	44.375301	441813.0375
S 4 Za'franiya	33.220901	44.505798	453954.1259

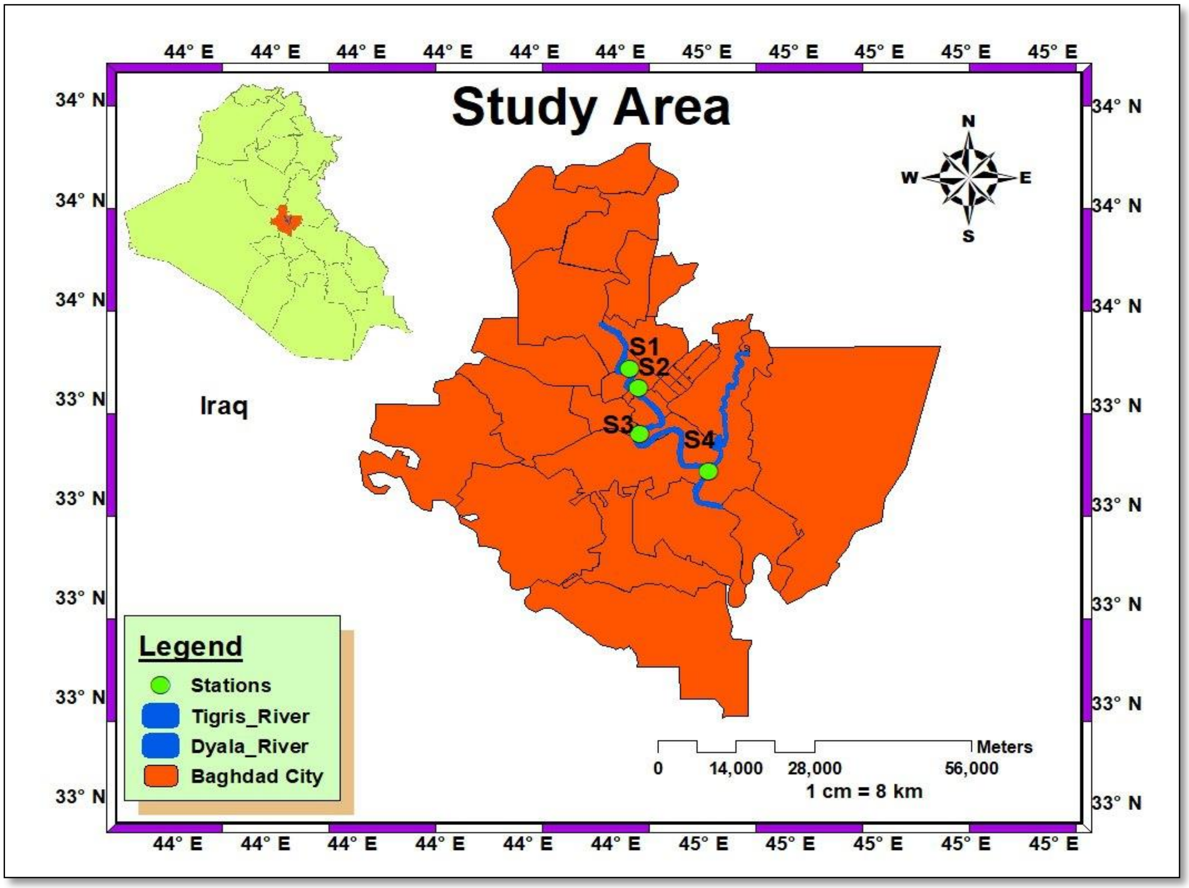

Figure 1. Tigris River within sites.

2.2. Sampling

Three samples were collected from each site throughout the months of the dry and wet season of the 2024 sampling period. Twenty to thirty centimeters below the surface was where the sample was taken. Before the necessary sample was added to the polyethylene bottles, they were thoroughly washed with river water. The samples were stored at 4 °C in a refrigerator until they arrived at the lab. Sediment samples were obtained at a depth of 5–7 cm using a sterile steel scoop and preserved in polyethylene bags. Three samples, approximately 300 g each, were collected from each location.

Standardized procedures for diagnosing heavy metals in the study area samples are provided by the American Public Health Association (APHA) (APHA, 2017, Standard Methods for the Examination of Water and Wastewater)[14]. Acid digestion is required for sample preparation and digestion, which involves carefully heating a solution of strong nitric and hydrochloric acids or a strong acid digestion using hydrofluoric acid based on the metal and matrix. Techniques for analysis in terms of heavy metal quantification comprise PG-990 Atomic Absorption Spectrophotometry (AAS) .The determined concentration in comparison with Iraqi rivers corresponds to water quality standards [21]and interim freshwater sediment quality guidelines (ISQG) for sediment[29].

2.3. Pollution indices for assessing metal pollution in water and sediment

Numerous indices are frequently employed to assess heavy metal pollution in water and sediments, demonstrating various equations (**Table 2**).

Table 2. Equations and classification of heavy metal pollution indices used in water and sediment quality assessment.

Indices	Equation	Classes	Description	Ref.
Pollution Index	$PI = \sqrt{\frac{\left(\frac{Ci}{Si}\right)^2 \max + \left(\frac{Ci}{Si}\right)^2 min}{2}}$ Ci: Concentration of each metal in the water, Si: Standard concentration level or permissible limit of each metal based on water quality guidelines.	PI<1	No effect	15
		1–2	slightly affected	
		2–3	Moderately affected	
		3–5	strongly affected	
		>5	seriously affected	
Metal Index	$MI = \sum_{i=1}^{n} \frac{Ci}{MAC}$ (MAC): Defines the highest permissible level of each metal, providing a benchmark for safe exposure limits.	MI Value>1	Threshold of warning	16
Geo accumulation index	I-geo =log 2 (Cn/1.5 Bn) Cn is the measured concentration of the element in the collected sample and Bn represents the concentration of the element in the background sample.	<0	practically unpolluted	17
		0-1	unpolluted - moderately polluted	
		1-2	moderately polluted	
		2-3	moderately - strongly polluted	18
		3-4	strongly polluted	
		4-5	strongly - extremely polluted	
		>5	extremely polluted	
Contamination Factor (CF)	CF = Cn Sample / Cn (2) Cn Sample: the metal content concentration in the sample. Background (Cn): the metal concentration at the background level.	<1	Class1: LOW contamination	19
		1≤CF<3	Class2: Moderate contamination	
		3≤CF≤6	Class3: Considerable contamination	
Sediment quality criteria	$Q = \frac{Cmi}{sqci}$ $QSM = \sum QSI/n$	< 0.1 QSm > 0.5	toxicity risk is negligible; 0.1 < QSm risk is non-negligible, and it is a possible hazard for aquatic life.	20

3. Results

We Presents average metal concentration in the water for each site in **Table 3**. The metal concentration was contrasted with the standards maintained within the Iraqi permission limits. Nickel levels in Tigris River water evaluated from all four exposure stations represented relatively uniform contamination, indicating minimal industrial or anthropogenic activity. Zinc levels varied moderately with localized pollution sources such as industrial or agricultural. Moderately high iron levels were also identified, which potentially indicated either naturally occurring iron within riverbed sediments or agricultural or industrial runoff. Chromium levels were found to be healthy at all sites, suggesting that there are no major pollution sources along the river.

Table 3. Detailed statistics on metal levels in Tigris water in Baghdad during study period.

Sites Metal mg/L	Site1 Mean ±SD Min Max	Site2 Mean ±SD Min Max	Site3 Mean ±SD Min Max	Site4 Mean ±SD Min Max	within limits or above limits	Standard value Law 25/1967
Ni	0.04±0.02 0.02-0.07	0.04±0.02 0.03-0.07	0.05±0.02 0.03-0.07	0.05±0.02 0.03-0.07	Within the permissible limits	0.1
Zn	0.09 ± 0.05 0.04-0.17	0.09 ±0.06 0.04-0.19	0.10 ±0.07 0.04-0.20	0.10 ±0.07 0.05-0.21	Within the permissible limits	0.5
Pb	0.03 ±4.84 0.03 -0.04	0.04±8.21 0.03-0.05	0.04 ±0.01 0.03-0.05	0.04±0.01 0.03-0.05	Within the permissible limits	0.05
Fe	0.09±0.04 0.05-0.15	0.11±0.04 0.07-0.17	0.11±0.04 0.07-0.16	0.12±0.03 0.08-0.16	Within the permissible limits	0.3
Cr	0.03 ±4.00 0.03-0.04	0.04±5.61 0.04-0.05	0.04 ±0.01 0.03-0.06	0.04±0.02 0.03-0.07	Within the permissible limits	0.05

3.1 Pollution index (PI)

To assess water Individual heavy metal computations, which serve as the basis for PI results can be categorized into five types (**Table 2**). Most sites during the dry season had no pollution effects from Zn, Ni, Cr, Pb, and Fe, according to the Pollution Index (PI) statistics. The PI values, which ranged from 0.21 to 1.55, showed "no effect" to "slightly affected." Except at Site 4, which had values between 1 and 2, most elements had PI values under 1 in the wet season, indicating "slightly affected'. Environmental effects may be characterized as "slightly impacted." This level, which neither approaches a tipping point nor attains significant contamination thresholds, yet is above natural and tolerable levels, is usually seen as indicative of mild environmental dissimulations. This could significantly affect local ecosystems over time. **(Table 4, Figure 3)**

Table 4. Pollution index for Tigris River in 2024

Pollution index								
Dry Season								
Metals	S1		S 2		S 3		S 4	
Zn	0.176	No effect	0.197	No effect	0.216	No effect	0.245	No effect
Ni	0.322	No effect	0.401	No effect	0.502	No effect	0.562	No effect
Cr	0.480	No effect	0.589	No effect	0.641	No effect	0.734	No effect
Pb	0.603	No effect	0.767	No effect	0.884	No effect	0.906	No effect
Fe	0.367	No effect	0.658	No effect	0.405	No effect	0.409	No effect
Wet Season								
Metals	S1		S 2		S 3		S 4	
Zn	0.294	No effect	0.323	No effect	0.350	No effect	0.375	No effect
Ni	0.579	No effect	0.581	No effect	0.743	No effect	1.550	slightly affected
Cr	0.727	No effect	0.898	No effect	0.941	No effect	1.463	slightly affected
Pb	0.651	No effect	0.919	No effect	0.986	No effect	1.153	slightly affected
Fe	0.215	No effect	0.242	No effect	0.278	No effect	0.316	No effect

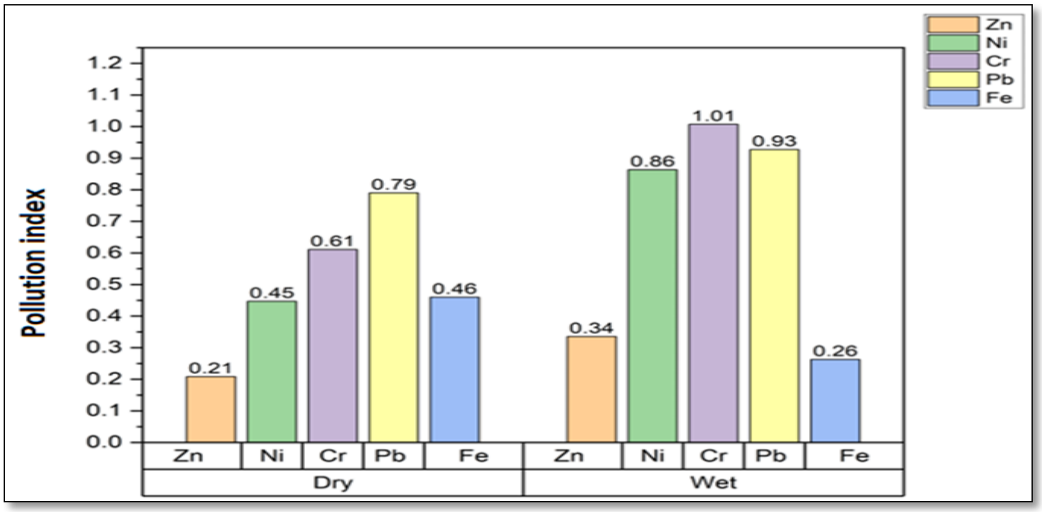

Figure. 3. Pollution index for Tigris River.

3.2 Metal index (MI)

The Metal Index evaluates the quality of water and whether it is suitable for a variety of uses. In the dry season, the MI findings ranged from 1.87 to 2.47, and in the rainy season, they ranged from 2.42 to 3.66 **(Table 5** and **Figure 4).** The fact that the MI remained above the danger level throughout the examination raises the possibility that industrial and human activity are the source of the heavy metal contamination in the Tigris River.

Table 5. Metal Index (MI) values for water samples from four sites along the Tigris River during dry and wet seasons in 2024.

Season	Site1	Site2	Site3	Site4
Dry	1.87	2.27	2.29	2.47
Wet	2.42	2.93	3.26	3.66

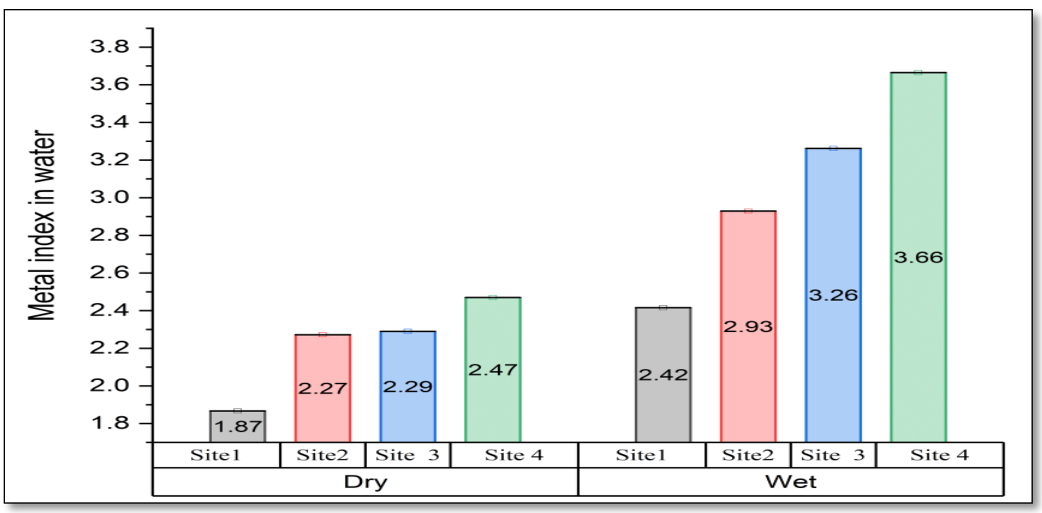

Figure. 4. Seasonal variation of the Metal Index (MI) at four sites along the Tigris River in 2024

The descriptive information for five metals (Ni, Zn, Pb, Fe, and Cr) from sediment samples taken from four sites throughout the Tigris River in Baghdad City is summarized in **Table 6**. The average concentrations of each element were higher than their respective ISQG CCME, 2001 values, with the exception of Pb at site 1 and Ni at sites 1 and 2. Results indicate varying levels of heavy metal accumulation across different sediment locations in the river. All sites observed relatively low quantities of zinc, lead, chromium, and nickel, but elevated concentrations of iron.

The higher average levels of Zn, Ni, Fe, and Cr at site 4 suggest that there might be extra pollution coming from human activities in that area. The standard deviations of some metals (like Zn and Pb) significantly increase, potentially indicating multiple sources of contamination and local variability. The presence of metals below ISQG criteria shows that continuous exposure and the combined effects of different pollutants could be harmful to the environment, particularly in urban river areas.

Table 6. Descriptive statics for metal in Tigris sediment within Baghdad city.

Sites Metal	Site 1 Mean ± SD Min Max	Site 2 Mean ± SD Min Max	Site 3 Mean ± SD Min Max	Site 4 Mean ± SD Min Max	Sediment quality guidelines (mg/kg)ISQG
Ni	35.15 ± 19.31 11.50 - 67.50	29.25±10.41 15.57 -44.33	33.93±7.66 22.50 -45.00	43.80 ±8.63 34.33 -56.70	45
Zn	37.74±27.78 12.13 -74.00	41.17±28.03 9.43 -89.00	48.91±32.42 13.93 -104.00	52.16 ±29.87 21.07 -102.00	123
Pb	11.00 ±1.51 8.83-13.03	13.70±5.21 9.23 -21.83	19.98 ±17.10 1.12 -46.00	19.68 ±13.87 1.18 -37.00	35
Fe	892.72 ±367.93 427.33 -1385.00	1058.83±407.05 547.33 -1550.00	952.83 ±360.00 422.33-1434.67	1001.11±337.81 522.33 -1448.33	30
Cr	15.72±5.72 7.50 -22.50	17.25±9.05 9.00 -33.00	16.87±4.32 10.50 - 22.93	19.60±4.89 12.50 - 25.30	37.3

3.3 Geo-accumulation Index (I-geo)

The I-geo values for heavy metal pollution in sediment are presented in (**Table 7** and **Figure 5**). During both the dry and wet seasons, the values of the I-geo for Zn, Cr, Ni, and Pb were less than zero according to Muller's classification[22], suggesting that the sediments at all sites were uncontaminated with these elements, while The values for FeI-geo on the other hand had significantly values that ranged between 2.81-3.18 in the wet season (moderate to severe pollution), and from 3.95 to 4.06 (heavy to extreme pollution) in the dry season Zn, Cr, Ni, and Pb levels in the sediments of Tigris River are within natural limits , according to values of I-geo, indicating non pollution, while increased Fe levels especially during the dry season, indicate severe pollution may be as a result of continuing human impact.

Table 7. Geo-accumulation Index (I-geo)for sediment in the Tigris River

Dry Season				
Metals	Site1	Site 2	Site 3	Site 4
Zn	-3.46	-3.33	-2.78	-2.53
Ni	-1.53	-1.96	-1.22	-1.20
Cr	-3.18	-2.55	-2.076	-1.89
Pb	-3.18	-2.55	-2.076	-1.89
Fe	3.951	3.753	4.023	4.066
Wet Season				
Metals	Site1	Site 2	Site 3	Site 4
Zn	-2.00	-1.87	-1.89	-1.76
Ni	-1.17	-1.01	-1.25	-1.16
Cr	-3.16	-3.12	-3.14	-3.05
Pb	-3.47	-3.21	-3.36	-2.83
Fe	2.81	3.03	3.00	3.18

Note : Red indicates values > or =3 strong to extreme pollution
Negtive value mean unpolluted

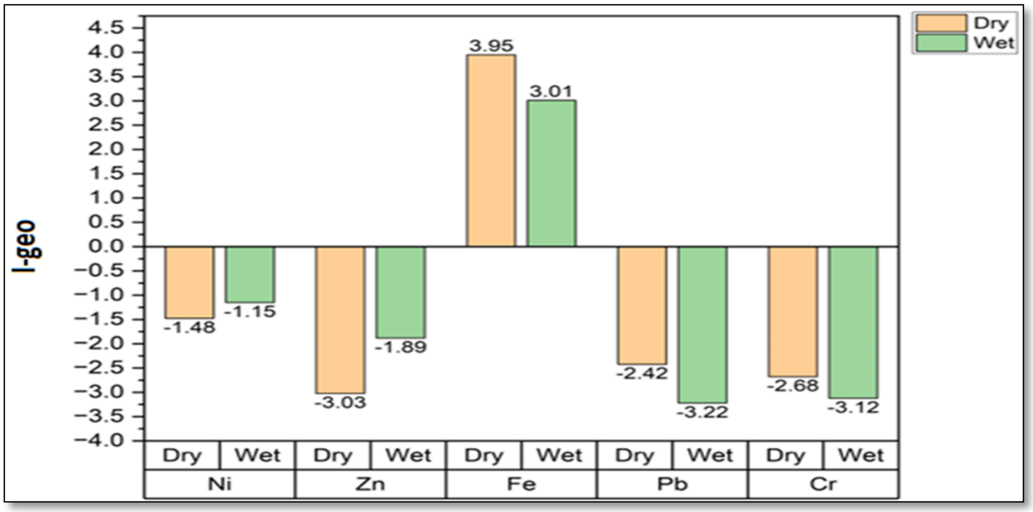

Figure. 5. Geo-accumulation Index (I_geo) of heavy metals in Tigris River sediments during dry and wet seasons.

3.4 Contamination factor (cf)index

The contamination factor (cf) index employed to assess the enrichment level of each metal over a specified duration (**Table 8** and **Figure 6**) values for all metals at each site over the study period indicate insignificant pollution, except for iron (Fe), which exhibits high levels at all locations and in both seasons. Fe ranged from 20.22 to 25.13 throughout the dry season, while Fe ranged from 10.57 to13.624 in the wet season, showing a persistent source of pollution caused by humans' activities. Additionally, it is evident that the majority of the Cf values fall under the low contamination threshold, with the exception of Fe, which falls within the considerable contamination level.

Table 8. Contamination Factor (Cf) Values of Heavy Metals in Sediments of the Tigris River during Dry and Wet Seasons

Dry Season				
Metals	Site1	Site 2	Site 3	Site 4
Zn	0.136	0.148	0.217	0.258
Ni	0.516	0.384	0.641	0.649
Cr	0.206	0.201	0.251	0.286
Pb	0.165	0.255	0.355	0.402
Fe	23.203	20.225	24.395	25.138
Wet Season				
Metals	Site1	Site 2	Site 3	Site 4
Zn	0.374	0.408	0.402	0.440
Ni	0.665	0.742	0.629	0.669
Cr	0.166	0.172	0.169	0.180
Pb	0.134	0.161	0.145	0.21
Fe	10.574	12.294	12.028	13.624

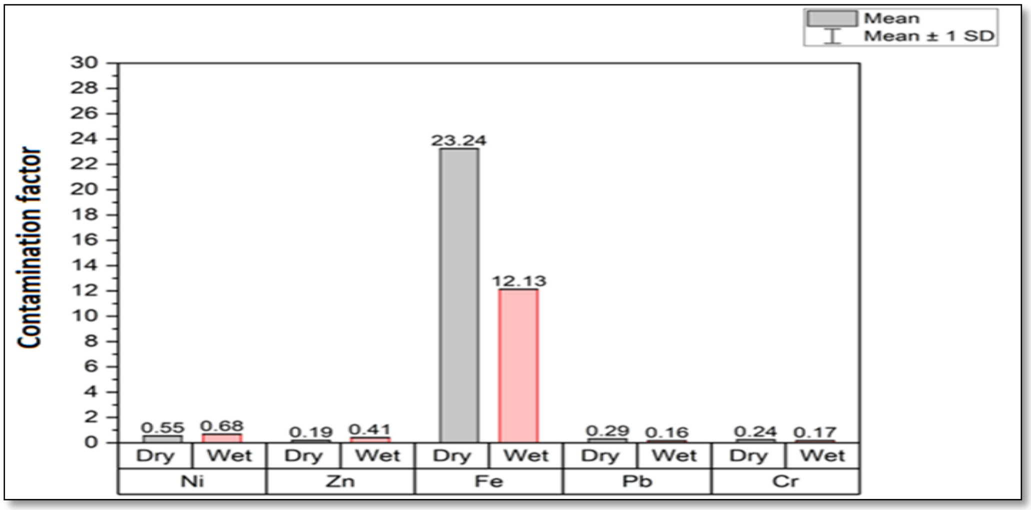

Figure. 6. Contamination Factor (Cf) of heavy metals in Tigris River sediments during dry and wet seasons (mean ± SD.

3.5 Sediment Quality Guidelines (SQG)

Assessing the possible effects of pollutants on organisms is the aim of the sediment quality analysis, which analyzes the results with observed guiding levels (**Table 9** and **Figure 7**). During the dry season, the four sites along the Tigris River had mean sediment quality (QSm) values of 7.62, 6.70, 8.16, and 8.44, respectively. The mean results during the wet season were 3.75, 4.39, 4.20, and 4.71, in that order. Each of the sites was classified under category three of QSm (possible harm to aquatic life) since their QSm values were higher than 0.5 (**Table 2**). While Site 4 had the most value, Site 1 had the lowest.

Table 9. Sediment Quality (QSm) Index values for Tigris River sites during dry and wet seasons.

.Season	Site 1	Site 2	Site 3	Site 4
Dry	3.752	4.394	4.204	4.718
Wet	7.62	6.70	8.16	8.44

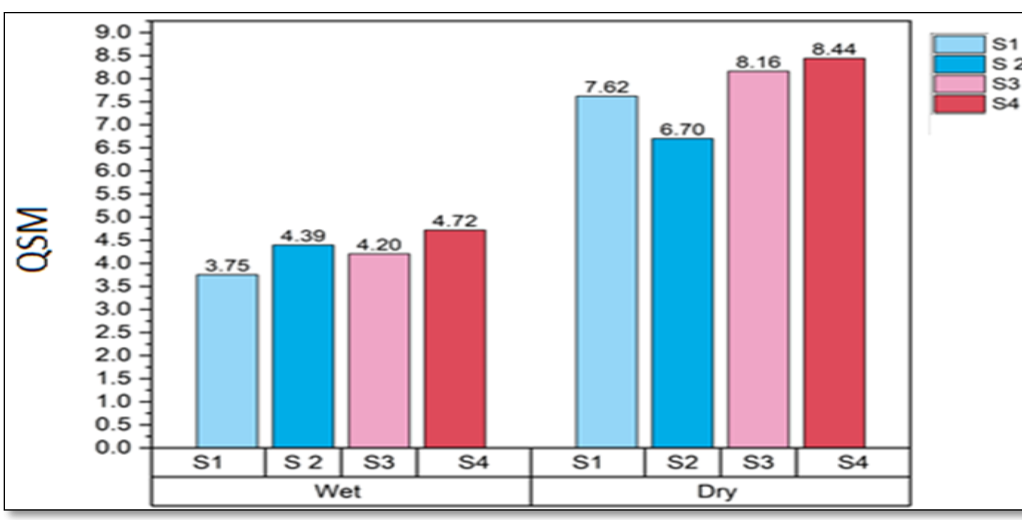

Figure. 7. Seasonal variation in QSm values for Tigris River sediment across four sites.

4. Discussion

The presence of metallic elements in aquatic systems should be of great concern due to their toxic features as well as bioaccumulation in living organisms. Heavy metals are natural ingredients, but human activities have increased and mobilized them into the aquatic ecosystem. Because heavy metals are non- biodegradable and stay adsorbent on the earth's surface, they cause the biggest threat. These compounds can bioaccumulate in human bodies and livestock, subsequently triggering health problems within human beings. The general water quality of the aquatic habitat is a state of consideration. It is in trace amounts in the freshwater system, derived from sources such as rock weathering. Metal elements can become immobile within stream sediment in various ways, which include absorption, co-precipitation, and complex formation[24,27].

The study found that there were several heavy metals in both the water and sediments of the Tigris River, with different levels of contamination at sampling sites, and in fact, the burden of pollution is moderate with some slightly higher contamination in the wet period. Heavy metals, such as nickel, zinc, lead, and chromium, ecologically endanger the regions with high concentrations of iron in the study area. The study indicates a consensus that heavy metal pollution exists, but it has not reached critical levels that would affect the quality of the river's water. Warning threshold values were recorded for the Metal Index (MI) in the Tigris River because of industrial and human activities[28].

According to the Geoaccumulation Index (Igeo) of the heavy metals of the sediment samples taken from the stations of this study, the heavy metals like nickel, zinc, lead, and chromium do not make the sediments that were analyzed here polluted sediments, though iron was found to have high values, indicating moderate to strong pollution at all sampling sites in both seasons, dry and wet[17,18]. The pollution trend of iron has continued during the wet season, with Igeo values moderately to strongly positive after the Muller classification 1979 (>3), signifying moderate to strong contamination at all sampling sites.

The contamination factor was used to assess heavy metal concentrations in the sediments for both wet and dry periods. The results gave a heavy contamination for iron, while relatively low readings for zinc, nickel, lead, and chromium were obtained for the dry season. These metals were considered moderate contaminants, within their contamination ranges for both seasons. High levels of contamination were consistently recorded for iron. The source of this major contribution to the contamination could be urban runoff, agricultural practices, or industrial dumping, as well as a natural formation of mineral richness in iron. The variation in Cf values of iron may reflect seasonal changes in the environment, such as variations in water flow. Therefore, further research to trace the sources and effects is justified[29].

Sediment quality ratings of the Tigris River show high differentiation observed in mean sediment quality ratings (QSm) among the four sites over both dry and wet months. Variations reflect the potential hazards to aquatic life from pollutants. Results for the dry months fluctuated between 6.70 and 8.44 in the value of QSm, therefore considered a threat to aquatic organisms [20,23], Results for wet months ranged from 3.75 to 4.71 in QSm values; dilution of contaminants by rainfall and flooding may be possible. The lower QSm values for Site 1 point to less pollution loading. On the other hand, higher QSm values for Site 4 point to more buildup of pollutants; it may be due to proximity factors or some environmental characteristics encouraging the assembly of pollutants in the area[30].

5. Conclusions

The rapid expansion of agriculture, mining, urbanization, and industrialization has led to extensive pollution of river water with hazardous waste and effluent. To meet the increasing demand for clean water and restore polluted rivers, alternative water sources must be explored and used. Rapid urbanization has heavily impacted areas within riverine zones, requiring coordinated global efforts to reduce consumption and ensure pollution prevention. Sediment content determination is crucial for assessing environmental health, risk conditions, and human health dangers associated with heavy metal contamination. Monitoring these metals helps detect contamination and inform remediation efforts, forming pollution management plans. The Tigris River is not heavily polluted, but localized areas have moderate contamination. Indexes like PI, MI, I-geo, and CF can guide future monitoring efforts and show high levels of pollution. Continued monitoring and implementation of pollution management strategies are essential for preserving the river's ecological integrity and protecting water sources for Baghdad residents. According to the pollution index (PI), the influence of water quality in the Tigris River is reflected by its Metal Index (MI) ranging from 1.87 to 3.66. A geochemical study of river sediments from the Tigris River revealed no pollution for nickel, zinc, lead, and chromium. However, iron levels observed across different sites indicated that there was moderate to severe contamination present in portions of the river. Other factors of pollution had low values. Guideline values for sediment quality (QSm) are 3.752 to 8.44, giving readings of more than 0.5 at all sites and therefore placing each site into the third potential danger category for aquatic life, suggesting responses from organisms. In summary, the Middle Tigris River shows moderate pollution but is not seriously dirty.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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Ethical Clearance

The research does not require ethical approval.

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