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ORIGINAL STUDY

Critical Heavy Metal Contamination in the Tigris River, Baghdad: A Comprehensive Assessment Using the Metal Index (MI)

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ABSTRACT

One of the most important rivers in Iraq is the Tigris River, which serves as the primary source of drinking water and irrigation for agricultural purposes. In recent events, researchers have identified growing concerns about heavy metal contamination in the river. To decide the status of the Tigris River, the metal index (MI) was used in this study. To conduct this study, three locations were chosen along the river, and eight likely harmful heavy metals were examined: iron (Fe), lead (Pb), nickel (Ni), zinc (Zn), chromium (Cr), cadmium (Cd), manganese (Mn), and copper (Cu). The results were worrying. The metal index (MI) shows a clear sign of water quality, and it surpassed the safety measures of all the monitoring stations. Throughout the same locations, the MI values during the dry season were 5.8, 10.21, and 12.22 at stations S1, S2, and S3, although during the wet season, concerning results appeared with values of 5.78, 7.08, and 12.22. The most notable pollutant that exceeded the allowed limits persistently throughout the study period was lead at S2 and S3 (0.092 mg/L and 0.191 mg/L) during the dry season, and at S3 0.181mg/L during the wet season, followed by a large amount of chromium and iron. This can be seen as one of the reasons for the increase in the concentration of heavy metals in industrial waste released from many factories throughout the river, and the direct flow of untreated sewage into the water. These discoveries shed light on the urgent need for environmental intervention on the Tigris River to help protect human health and aquatic ecosystems.

Keywords: Tigris river, Metal index, Pollution indices, MI, Heavy metal, Baghdad, Iraq

1. Introduction

Heavy metals are naturally occurring elements with high atomic weights and densities at least five times greater than that of water [1]. Some heavy metals are necessary in trace amounts for biological functions, such as iron, zinc, and copper, while others cause serious environmental and health risks when present in elevated concentrations, such as lead (Pb) and cadmium (Cd). Industrial discharges, mining operations, agricultural runoff, and irregular waste disposal are the main causes of river water contamination with heavy metals. When released into aquatic ecosystems, if these metals continue for long periods, they can bioaccumulate in organisms and cause toxicity to aquatic life and humans through the food chain.

Chronic exposure to heavy metals is associated with severe health consequences, including Lead (Pb) neurotoxicity and Chromium (Cr)/Cadmium (Cd) induced renal and developmental disorders [2–4]. It is important to keep track of and evaluate heavy metals using reliable indicators due to their durable nature and serious health implications. The Metal Index (MI) is well known for giving a comprehensive evaluation

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of water quality by adding up the amounts of different metals and comparing them to their regular limits [5]. MI causes the successful classification of pollution levels and supports environmental status assessment and decisions in environmental management. using these indices is needed for the protection of water resources and public health [6].

Baghdad is one of the most populated cities in Iraq and the Middle East [7], and it suffers from environmental pollution, which has led to the contamination of the Tigris River and other drinking water sources in the city. This pollution has reached critical levels, in certain areas exceeding national water quality standards. chemical pollutants, especially those affecting the Tigris River, may eventually lead to tens of thousands of cancer cases and other life-threatening diseases if they aren't addressed efficiently [8].

Pollution indices are one of the most important tools for assessing water quality. Many mathematical models and water quality index methods have been developed to evaluate the natural status of aquatic environments. A water pollution index is a single numerical value that serves multiple purposes, such as deciding and clarifying untouched environmental data to help scientists, policymakers [9]. A lot of the research has concentrated on using heavy metal pollution indices to assess surface water quality in Iraq. Among these tools, the Metal Index (MI) is the most effective because it evaluates water quality by comparing the measured value to the maximum allowable concentration. It's also used as a comparative tool for assessing pollution levels across different locations [10].

The main purpose of this study is to use the metal index to assess the contamination levels of selected heavy metals in the Tigris River.

2. Materials and methods

The river extends approximately 50 Km within Baghdad; this river alone is the raw water source for several water treatment facilities on both sides. Moreover, the river unfortunately serves most industrial waste, which is discharged into the river directly without adequate treatment [11]. Also, the river serves the purpose of irrigation. Several water samples were collected along the Tigris River within Baghdad in 2023. Samples were collected in July, representing the dry season, and in November, representing the wet period. The locations of Al-Muthanna Bridge, Bab Al-Muaadham Bridge, and the Diyala Bridge area were located using a GPS device (Garminetrax Legend HCx). A polyvinyl chloride bottle was rinsed three times with river water before it was filled with the required sample. The sample was contained in an ice-cool box and transferred to the laboratory within hours. Upon arrivial the samples were stabilized and examined directly to prevent any adsorption of the heavy metals on the wall of the bottle. Fig. 1 and Table 1 include specific details that show the surface water sampling location, and their longitude and latitude. Elements such as Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn were measured using Atomic Absorption Spectrophotometry (AAS-6300, Shimadzu, Japan) according to (APHA, 2005). Based on the manufacturer's specification of the AAS-3600, the LOD is 0.005-0.01 mg/L, and the values below the LOD level would be considered "trace".

Table 1. Sample locations along the Tigris river in Baghdad.

Stations	District	Lat.	Lon.
S1	Al-Muthanna Bridge area	33.442431	44.337424
S2	Bab Al-Muaadham Bridge area	33.346225	44.371021
S3	Diyala Bridge area	33.262	44.453

In order to calculate the variance in MI between dry and wet, statistical analysis was performed. SPSS program 16.1 was used. The paired t-test was conducted at a significant threshold alpha = 0.05, which was used to analyze this variance. This analysis was used to conclude whether seasonal hydrological changes had an overall impact on the heavy metal burden.

2.1. Metal index (MI)

Metal index (MI) depends on a total evaluation of the present status trend. The higher the concentration of metal, the worse the quality of the water. When compared to its respective Mac value. MI value > 1 is a threshold of warning [5]. and categorized into 6 classes as shown in Table 2. According to [12], the MI is calculated by using the following formula:

$$\textbf{Metal Index MI} = \sum_{i=1}^{n} \frac{Ci}{MACi} \quad (1)$$

Ci: the concentration of each element.

MAC: maximum allowable concentration.

Iraqi river maintenance parameters have been used to compensate in the equation of metal index calculation, as shown in Table 3.

3. Results and discussion

3.1. Dry-wet MI values

According to the metal index values, it is evident that all selected stations along the river are severely threatened by metal pollution. The MI results show

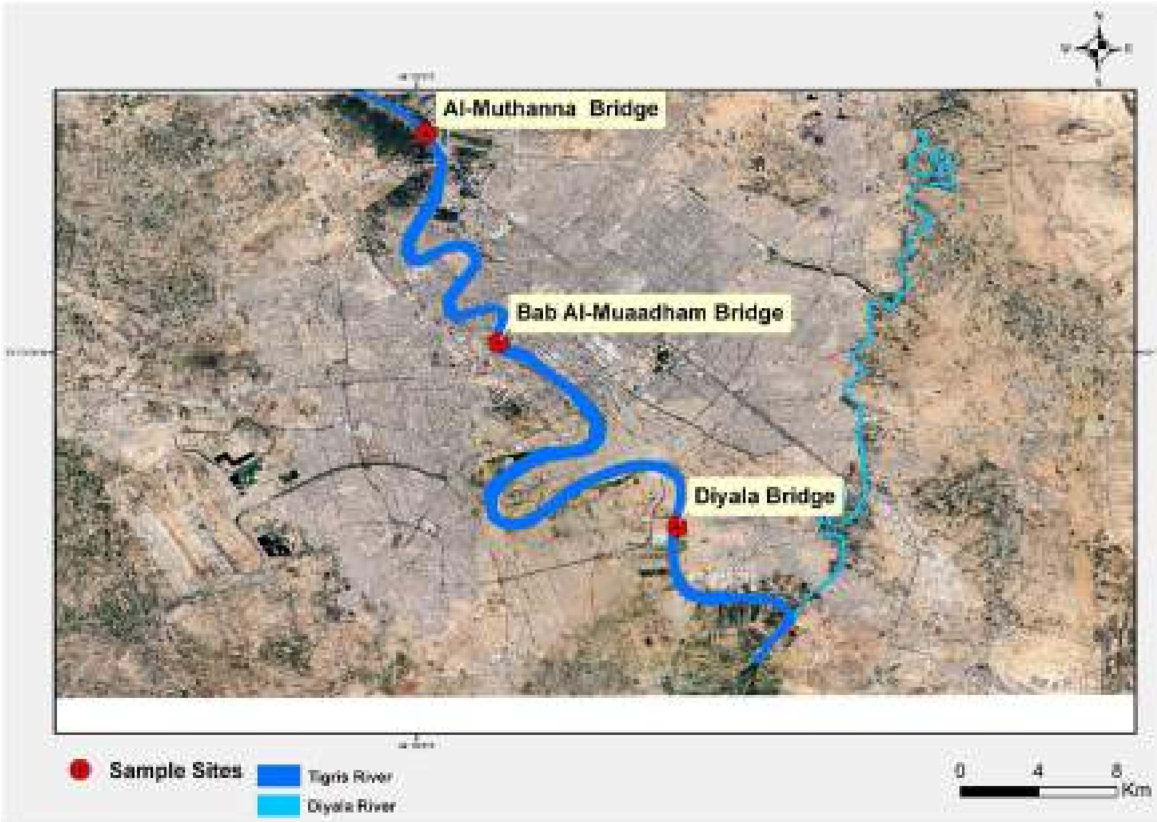

Fig. 1. Map showing the study area.

Table 2. The classification categories of the Metal Index classes.

Class	Property/ characteristics	MI Values
1	Very pure	0.3 >
2	Pure	0.3–1
3	Slightly affected	1–2
4	Moderately affected	2–4
5	Strongly affected	4–6
6	Seriously affected	6 <

ranges between 5.80-10.47 in the dry season and 5.78-12.22 in the wet season, as illustrated in Table 4. There are several significant patterns evident in the MI values. In both seasons, as the river flows, metal contamination increases throughout Baghdad, from the north to the south, with the highest values consistently recorded at S3 (south). Furthermore, there is a significant difference between the dry and wet season periods, as shown in Fig. 2 and Fig. 3. S3 shows a significant increase in mineral index values (around 12 compared to 10.3) during the rainy season, suggesting that rainfall may carry additional pollutants into the river, specifically from Sheikh Omer metalworking and Al Za'franiya industrial area. This is consistent with the study that uses the GIS to assess the effect of wastewater pollutants on the quality of the river [16].

Also, given Baghdad's urban layout, the geographic pattern is understandable, as the river flows through a city of 10 million people. It builds up several pollutants from urban pollution, municipal waste, agricultural runoff, and industrial activities [17]. As the river passes through the more developed areas, there is a significant increase from the north to the south, indicating cumulative contamination. The southern site shows the full effect of upstream pollution sources. These patterns show how water quality in the river is affected by human activities and urban development.

There appears to be a distinct feature that shows a spatial pattern of the metal index (MI) values in Fig. 4 and Fig. 5. Including what seems to be the Tigris River in Baghdad, Iraq, which shows differences between wet and dry seasons. During the wet season, there's a significant increase in MI values from the north to south, starting with lower concentrations (5.78-7.92) near Al-Muthanna Bridge, and in the middle section showing moderate values (7.92-10.07), finally showing peak values (10.07-12.22) around the Diyala Bridge area. This data suggests that there's cumulative metal contamination as water flows through the

Table 3. Comparison of national and international regulatory standards (IQS, WHO, and US-EPA) for heavy-metal concentrations.

Parameter mg/L	Iraq 1967 (MAC) [13]	WHO (2022) [14]	US EPA standard [15]
Cd	0.05	0.003	0.005
Cr	0.05	0.05	0.1
Cu	0.05	2	1.3
Fe	0.3	0.3	0.3
Pb	0.05	0.01	0.015
Mn	0.1	0.4	0.05
Ni	0.1	0.07	N/A
Zn	0.5	3	5

Table 4. Metal index values in the dry and wet periods and sampling sites.

No.	Station	Name	MI-Dry	MI-Wet	X	Y
S1	North of Baghdad	Al-Muthanna Bridge	5.80	5.78	44.337424	33.442431
S2	Middle of Baghdad	Bab Al-Muaadham Bridge	10.21	7.08	44.371021	33.346225
S3	South of Baghdad	Diyala Bridge	10.47	12.22	44.453	33.262

urban landscape due to the progressive increase in Mi values.

In the dry season, the geographical pattern shows more contamination with overall higher MI values throughout the system. While the Al-Muthanna, located in the northern section, maintains lower values, such as (5.80-7.36), most central and southern areas seem to experience a rapid transition to peak contamination levels showing the highest MI values (9.69-10.47). The difference between seasons indicates that in dry periods, there is a reduced water volume, which likely leads to metal pollutants. During the wet period, there is a higher water volume, which provides a dilution effect. Especially in the middle and the northern part of the waterway.

3.2. Dry-period concentrations

During the dry season, Pb, Cr, Cu, and Fe peaked, consistent with the buildup of industrial/sewage pollutants. This was during July in S2-S3 (central and south) where it showed the highest peak.

Starting with S1, it showed lower values overall. S2 had high Cu (0.025 mg/L), Fe (0.21 mg/L), Mn, and Cr/Pb were the second highest. S2 was influenced by the Shekh Omer industrial zone, an area of coating workshops and metalworking. Finally, S3 showed the highest levels of Pb (0.19 mg/L) and Cr (0.21 mg/L) elements as a result of the Za'franiya industrial cluster, which is the main area for tanning and textile industries. This location discharges high

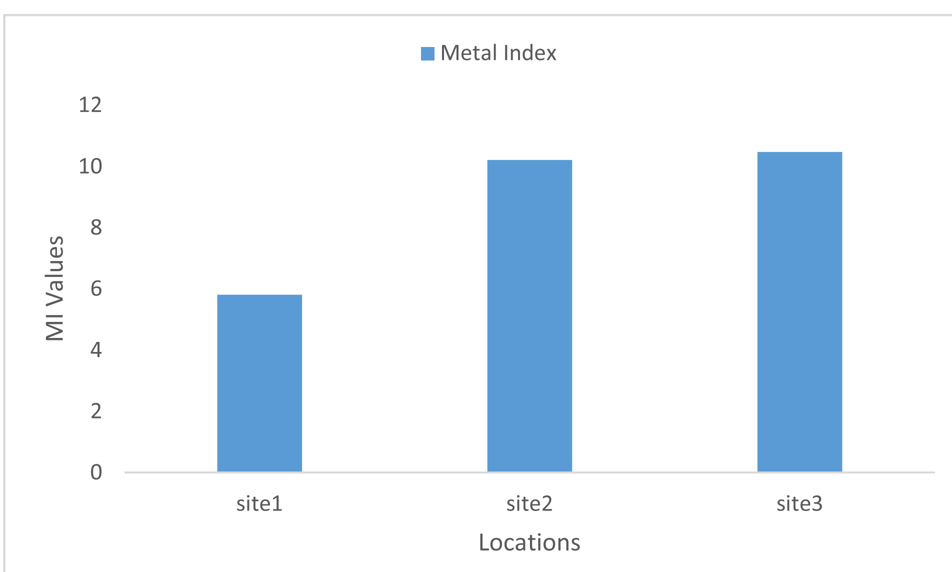

Fig. 2. Calculated metal index values at the study sites during the dry period in July.

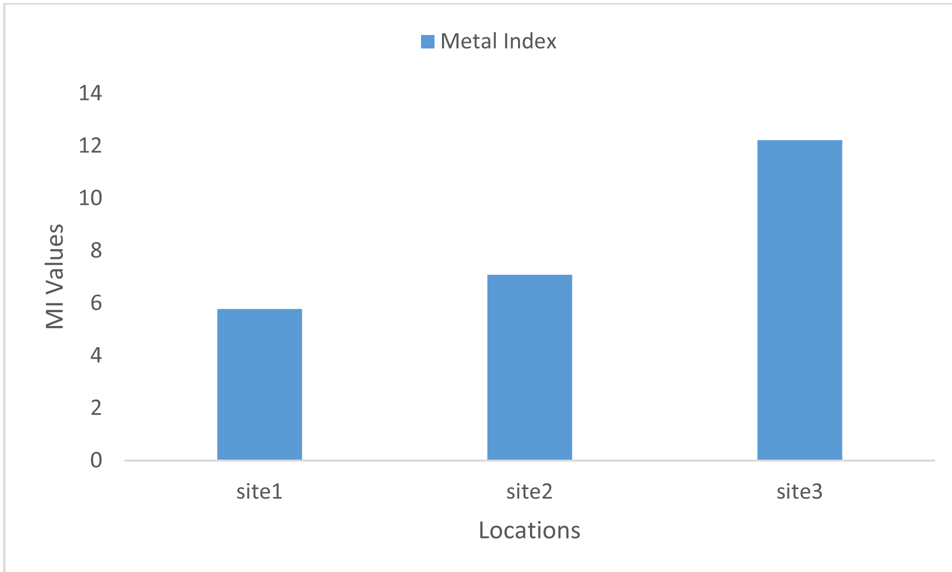

Fig. 3. Calculated metal index values at the study sites during the wet period in November.

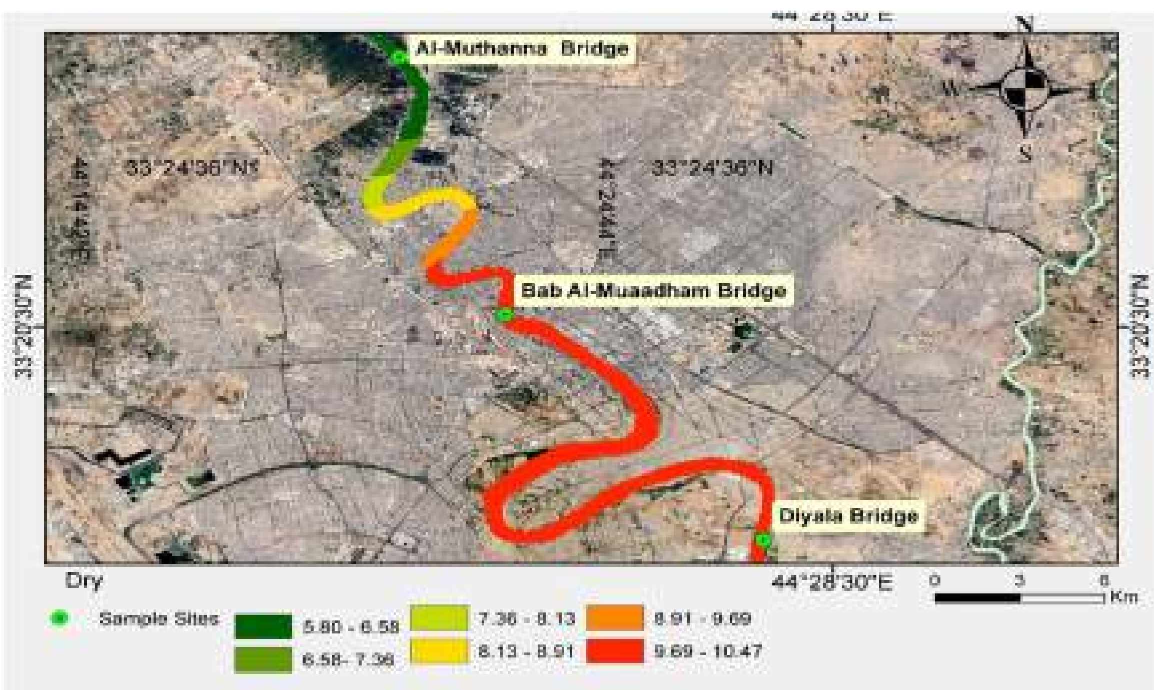

Fig. 4. Spatial distribution of metal index values in the dry period of the Tigris River.

amounts of Pb and hexavalent chromium, which was confirmed by a previous study on the Tigris River [18]. According to this data, it suggests that there are strong local inputs around S2-S3 (central/south).

Lead (Pb) is 0.092 mg/L at S2 and 0.19 mg/L at S3, which exceeded the higher level of 0.05 mg/L Iraqi standard in all locations. However, when compared with the WHO guideline of 0.01 mg/L and the EPA level of 0.015 mg/L, the results became more alarming. This may be due to industry and waste discharges upstream of those points, which are also affected by the River morphology within Baghdad [19], as shown in Fig. 6.

3.3. Wet-period concentrations

During November, wet period values showed S3 with significant highs of Cr and consistent highs of Pb,

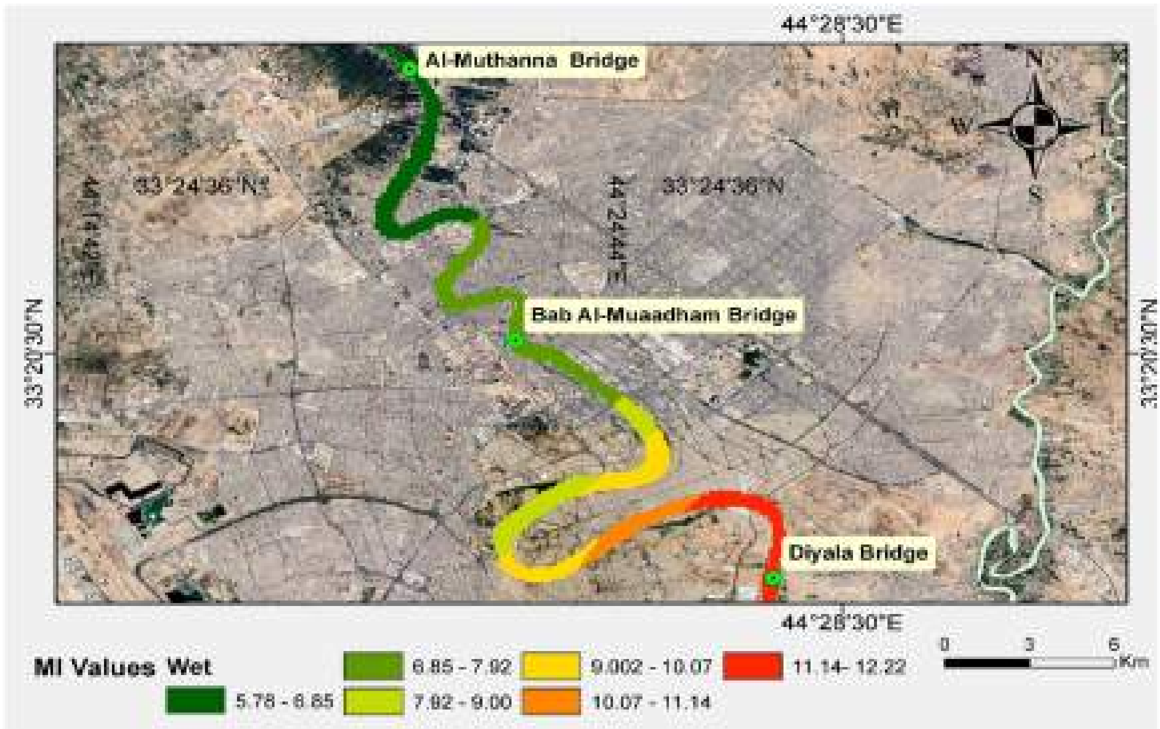

Fig. 5. Spatial distribution of metal index values in the wet period of the Tigris River.

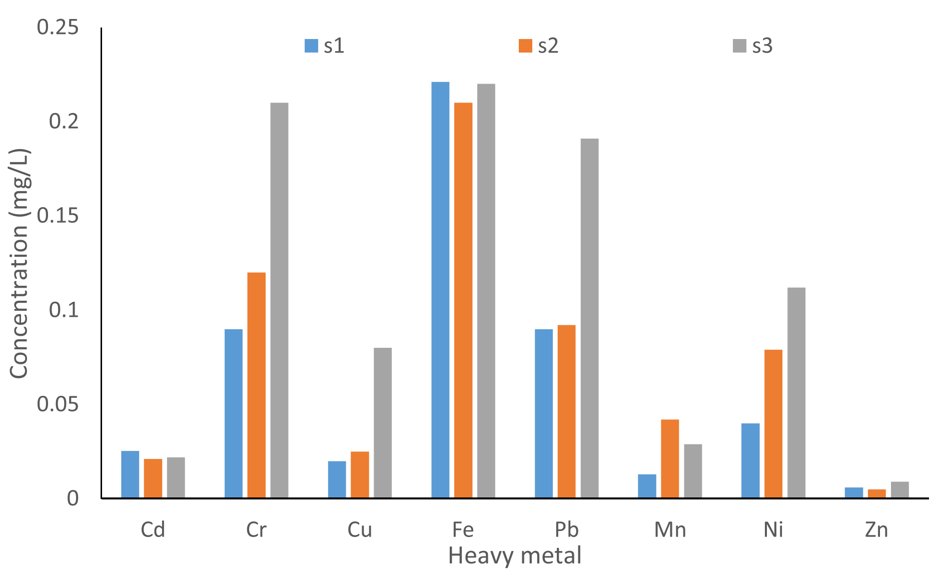

Fig. 6. Concentrations of heavy elements in the study sites during the dry period in July.

which indicates new pollutants. However, S1 shows mixed changes, and S2 shows metal drops. Whereas S3 showed a significant increase in Cr (0.14 mg/L), which is 3 times higher than the WHO and Iraqi standard level of 0.05 mg/L and exceeded the EPA levels of 0.1 mg/L. Also, the concentration of Pb at S3 is very high (0.181 mg/L), which is higher than the Iraqi standard by around 4 times, and 18 times the WHO standards, suggesting a substantial amount of pollutants being added during rains at the southern site. These variations in heavy metal concentrations cause increased ecological risk in high precipitation periods [20]. Meanwhile, S1-S2 appears to show a decrease (especially in Cu, Cd, Mn, Ni), which reflects dilution due to an increase in flow or reduced discharge point impacts. Furthermore, Zn remained low in all three locations, as shown in Fig. 7.

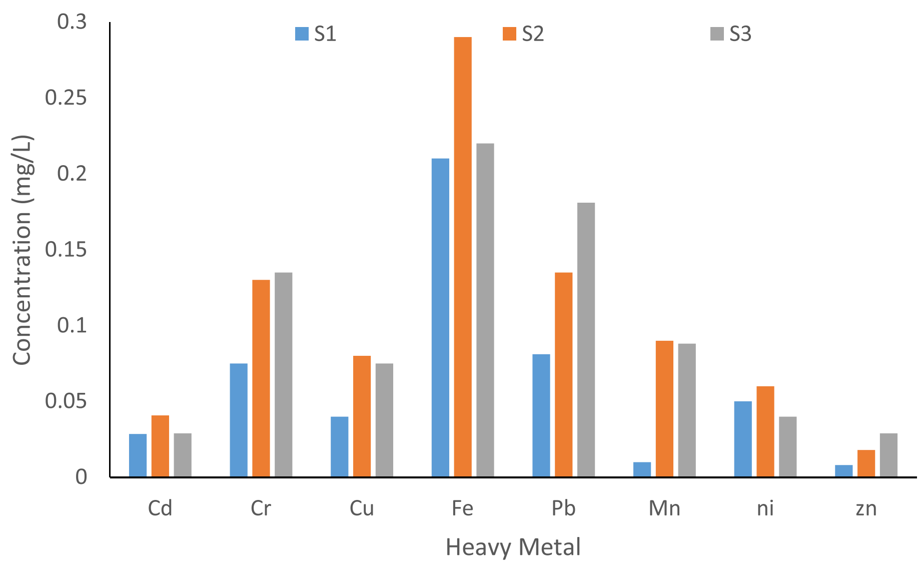

Fig. 7. Concentrations of heavy elements in the study sites during the wet period in November.

3.4. Dry vs. Wet seasonal trends

By comparing the metals in different seasons, Pb and Cr stand out the most due to their data being high. During the wet season, Cu, Cd, Mn, Ni levels tend to drop due to dilution, and Cr/Mn levels rise at S3, which suggests runoff inputs.

The data recorded for MI values between July and November reveals that the overall contamination still remains significantly high all year round, while some individual sites fluctuated. The peak value was recorded at S3 during the dry season (12.221), whereas at S2 during the wet season showed an increase from 7.048 to 10.217.

The seasonal trend is verified through a paired t-test, which was applied to the data. The outcome of the P-value ($P = 0.77$) when ($P > 0.05$) indicates that the difference between the dry and wet seasons is not statistically significant. This lack of significance is very important because it suggests that the Tigris River is going through a chronic load. The river's "seriously affected" status does not change due to the impact of industrial and sewage discharges. This is because it's so dominant that the seasonal effects of dilution and runoff do not affect the river's "seriously affected" status, which is supported by a study implemented using a multivariate statistical evaluation of the river [21].

3.5. Sources and seasonal influences

The patterns that were shown reflect a combination of municipal sewage discharges, agricultural runoff, and industrial point sources. Sites S1/S2 are located around known industrial zones and wastewater discharge points. This contributes significantly elevated concentrations of Cu, Pb, and Cd during the dry season period because of the increase in anthropogenic discharge into the river and a reduction in volumetric dilution. During the wet season, there is dilution of some pollutants, which is caused by greater river flow. Hence, the large drops in Cu, Cd, Ni at S1–S2.

In contrast, S3 showed spikes (Cr, Mn) Where the rainfall releases pollutants that originate from non-point sources: sewer overflows, which mostly carry heavy metals into the river, in addition to irrigation runoff and eroded soil. Tanning, plating, or textile industries are often associated with Cr; the cause of the increase has come from urban runoff or new discharges downstream [22].

In both seasons, Pb concentration exceeded the higher level not only according to the 1967 Iraqi standard but also the standard level of WHO and EPA. This reflects ongoing inputs from urban waste, batteries, and fuel combustion. It is intensified by low flow in dry periods of time. During dry conditions, the rivers function to dilute the pollutants and decline. These causes contribute to concentration; this gives the explanation of why several metals (especially Pb, Cu, Cd) peaked most at all the sites in July. During the wet period, some metals decrease in levels due to dilution, while other metals' levels rose due to sewage overflow and runoff. For example, the mix of heavy rainfall and urban releases causes different tendencies. Furthermore, metals can be carried in farm runoff and enter the river, which is bound to soil and fertilizers. This occurs in flooded sewers and intense rain events. As a result, dilution is dominating at S1-S2 for some metals, whereas at S3 new input sources dominate.

4. Conclusions

In conclusion, the results showed that site S3 (south Baghdad) had the highest contaminated location with the overall metal oxide (12.221). This peak is because of several heavy metals, such as Pb. Cr, Cd, and Ni) that exceeded the Iraqi river conservation standard and the WHO and EPA. These results highlight the effect of the Za'franiya industrial district on the southern part of the Tigris River even before it connected with the Diyala River. During November at S2 (central Baghdad) showed a great sum of metals declining, which were consistent with dilution. At all site locations, lead (Pb) remained elevated, which in turn exceeded the range of safety limits. Therefore, it reveals chronic pollution. This elevated level not only surpassed the 1967 Iraqi River conservation standard, but also the values of the WHO and EPA. This data suggests that sewage and industrial discharge along the riverbanks are significant contamination sources, while annual rainfall releases additional metals from agricultural runoff. Demonstrating effective pollution control in Baghdad requires addressing both point sources (treating industrial and municipal wastewater) and non-point runoff to maintain and protect the Tigris River, especially during intense storms and periods of low water flow. During dry months, reduced dilution aggravates pollutant concentrations, while rainy periods can mobilize soil-bound metals into streams and rivers. All cited studies highlight the effectiveness and influence of industry, wastewater, and agriculture on river heavy metal pollution.

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Conflict of interest

The authors declare that they have no competing interests.

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