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Assessment of the Pollution of some Heavy Metals in the Sediments of the Tigris River in the City of Mosul- Northern Iraq

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ABSTRACT

In this study, the concentrations of heavy metals were studied using atomic absorption spectroscopy of samples from the sediments of the Tigris River within the boundaries of the city of Mosul, northern Iraq, and the environmental parameters of heavy metals were calculated. The results showed that the average concentrations of Co, Cu, Cd, Pb, Zn, and Ni in (ppm) were (8.78, 30.42, 0.179, 12.04, 75.53, and 144.75), respectively, where these results were higher than the international accepted average. It indicates that the main factor in the high concentrations of heavy metals in the environment of the Tigris River in the city of Mosul is the pollution caused by human activities. The results of the environmental treatments for the studied heavy metals showed that the values of the enrichment factor (EF) were moderately contaminated with Cu, Cd, Ni, and Zn and not contaminated with Co and Pb. The value of the contamination factor (CF) for the sediments of the Tigris River in the studied areas showed that the sediments of those areas are moderately polluted with Co, Ni, and Zn metals. The degree of contamination (Cdeg) for the sediments of the study area in general ranges from low - medium pollution, the pollution load index (PLI) average of (1.03) showed that the sediments of the study area were contaminated with heavy metals. Therefore, we conclude that the environment of the Tigris River is polluted with heavy metals, but it is not at the level that causes concern at present.

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INTRODUCTION

Heavy metals are defined as a subgroup of those elements that exhibit metallic properties. They include transition metals, some metals, lanthanides, and actinides, using density as a distinguishing factor (Suciu et al., 2008). Heavy metal pollution has become a global problem, as heavy metals are inorganic pollutants of a non-degradable nature and often accumulate at increasing levels, which leads to or causes harmful biological effects (Jain, 1979). Heavy metals are pollutants capable of causing environmental and health problems in the water, soil, atmosphere, and microorganisms (Navarro et al., 2008). Heavy metals deposited into a river system by natural or anthropogenic sources are dispersed between the aqueous phase and the bed sediments during transportation (Sin et al., 2001). Only a small part of free metal ions remains dissolved in water due to adsorption, hydrolysis, and co-precipitation, whereas many of them are deposited in sediment (Gaur et al., 2005). Sediments are ecologically significant

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components of the aquatic ecosystem, as well as a source of contaminants, and they play a critical role in sustaining the trophic status of any body of water (Singh et al., 1997). Metals become toxic in high concentrations or have a limited biological value and harmful effects even in low concentrations, such as lead, cadmium, nickel, chromium, mercury, and (Bryan, 1971). Perhaps the most important and most dangerous of these metals have a density higher than (5 g/cm^3), the most important of which are mercury, lead, and cadmium. The presence of heavy metals in the environment is often evidence of exposure to pollution (Dahiya, 2022). The concentration of heavy metals depends on the temperature, salinity, pH, and surface area of the organic and mineral materials present in the river. Heavy metals are present in the aquatic environment either in a dissolved state, suspended load, benthic sediments, or within the crystalline structure of the minerals that make up the river sediments. However, measuring their concentrations in water for a long time does not give accurate pollution indicators due to the variation in water expenditures and the instability of pollution sources. Therefore, the focus is on sediments, as the sediment particles whose size is less than (2 microns) contain high concentrations of heavy metals because they contain a high percentage of clay minerals, which has a high adsorption capacity for these minerals in the sedimentation environment (UNESCO, 1983). It is suggested to use GIS to locate appropriate playgrounds because the elements concentration in urban soil may be harmful to children's health (G. Fazeli, 2019). An analysis of the soil's hazardous metal content in 13 parks in metropolitan regions showed that shaded areas had higher quantities of hazardous metals than open areas (Galuškova et al. 2011, G. Fazeli et al, 2019). the primary sources of different metal contents are typically fleet fuels and wastewaters from the residential sector (Möller et al. 2005, Fazeli, et al 2018) .

The Tigris River is one of the important water resources in Iraq; thus, it is imperative to continue studying it, especially from an environmental point of view. The amount of liquid wastes discharged from the city of Mosul and reaching the Tigris River is estimated at 6598 m^3/day, but the total amount that can get into the river of all kinds may reach no less than 400000 m^3/day (Mustafa & Jankeer, 2007). Therefore, this paper aims to characterize the pollution situation in the Tigris River, the city of Mosul - Iraq, by analyzing the concentration of some heavy metals in the river's sediments and evaluating the environmental risks to the local population living near the river.

Study Area

The Tigris River is one of the most important rivers in Iraq, where it shares with the Euphrates River as the primary source of water suitable for human use, especially drinking water, The length of the Tigris River is about 1850 km, and it originates from the Taros Mountains in eastern Turkey, which is 25 km southeast of the city of Elazık and 30 km from the source of the Euphrates River, Five tributaries flow into the Tigris River from north to south within the Iraqi territories: the Khabur, the Upper Zab, the Lower Zab, the Azim, and Diyala. The Tigris River originates in Turkey and runs for nearly 400 km to reach the city of Mosul in northern Iraq (Rzoska, 1980). The geology of the river consists of sand, clay, and gravel. The city of Mosul is located in the center of the Nineveh Governorate in northern Iraq, within the coordinates of longitude 36°2′ north and latitude 43°7′ east.

MATERIALS AND METHODS

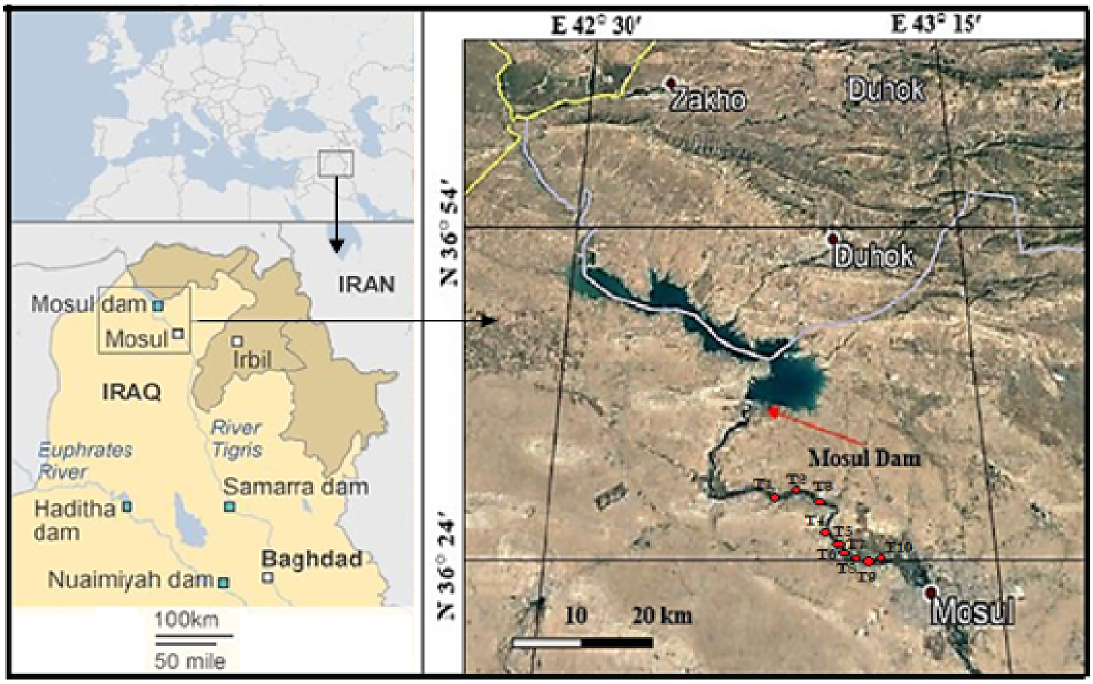
Samples Collection and Preparation

A total of 10 samples were collected from the Tigris river sediment during May 2020 according to the standard protocol. Sediment samples were taken at a depth of 5-7 cm, and three samples of mass of approximately 300 g were collected from each site. Sediment samples were placed in polyethylene bags to avoid confusion between sites. For analysis, grain size fractions smaller than 63 microns were used using sieve (Karbassi et al. 2006). Table 1 and Figure 1 show the

Table 1. The coordinates of the studied sites from the Tigris River in the city of Mosul

Sample ID	Location Name	GPS coordinate	
		Latitudes (N)	Longitudes (E)
TS1	Msheirfeh	36°23′37.38	43°03′54.55
TS2	Al-Kanisat Alraabiea	36°23′47.69	43°04′47.18
TS3	Hawi Al-Kanisa	36°23′34.56	43°06′06.36
TS4	Third Bridge	36°21′39.78	43°06′49.55
TS5	Pashtabiya Castle	36°21′20.17	43°07′20.33
TS6	Fifth Bridge	36°21′09.26	43°07′34.82
TS7	Qleiat	36°20′43.79	43°08′02.10
TS8	Old Bridge	36°20′50.73	43°08′12.67
TS9	Al-Hurriya Bridge	36°20′24.19	43°08′34.69
T10	Dandan	36°20′07.77	43°08′48.93

Fig. 1. The studied sites in the Tigris River within the city of Mosul.



coordinates of the main studied areas in the Tigris River within the city of Mosul.

The concentrations of heavy metals under investigation were estimated using atomic absorption spectroscopy. 0.5 g of dry sediment was taken and placed in a glass beaker, and 5 ml of the digestion solution consisted of concentrated sulfuric acid (H_2SO_4), concentrated nitric acid (HNO_3), and concentrated per-chloric acid ($HClO_4$) in a ratio of (1:3:1) was added. The beaker was closed with a glass cover to prevent the evaporation of focused acids. Then the samples were heated on a heater at 90°C for two hours, then diluted by adding deionized distilled water to 25 ml; then, the absorbance of each sample was estimated using a flame atomic absorption spectrometer, and the absorbance was converted into units of concentration (Jackson, 1958).

Certified reference material and duplicate samples were utilized to examine the quality assurance (QA) and quality control (QC) processes. A flame atomic absorption spectrometer

Table 2. Classification of the enrichment factor in sediments (Ustaoglu & Islam, 2020)

Enrichment Factor (EF)	Enrichment Level
EF < 2	Deficiency to minimal enrichment
EF=2-5	Moderate enrichment
EF=5-20	Significant enrichment
EF=20-40	Very high enrichment
EF > 40	Extremely high enrichment

Table 3. Classification of contamination factor in sediments (Ustaoglu & Islam, 2020).

Contamination Degree (Cdeg)	Contamination Level
Cdeg < 8	Low contamination
< 16 Cdeg ≤ 8	Moderate contamination factor
< 32 Cdeg ≤ 16	Important contamination factor
Cdeg ≤ 32	Very high contamination factor

was used to evaluate the bulk metal content of soil samples. Additionally, the non-lithogenous components of metals were extracted using a single step chemical partitioning technique (Hosseini Alhashemi et al. 2011). After filtering via Whatman filter No. 50, the aliquot volume was adjusted to 50 mL. It should be noted that this study underwent QA/QC as indicated for bulk analysis Fazeli, et al 2018).

Metals analysis

The concentration of heavy metals (Co, Cu, Cd, Pb, Zn, and Ni) in the sediment samples under investigation is determined by flame atomic absorption spectrometry (AAS), which consists of the following parts: the radiation source (Acetylene gas), the nuclear cell (Spray or Stove), the appropriate method for selecting wavelength, and the measurement process, as the radiation source generates a narrow emission line suitable for the desired element, but the atomic cell is the location where the sample is inserted and causes atoms for the elements to be measured, and the important part of the process is the isolation of the line. The spectral required from other lines from other radiation sources, the atomic absorption process is characterized by a high degree of selection and the application of an effort difference between (309-400) and a current of (5-20) (Welz & Sperling, 2008).

Assessment of sediment contamination

The environmental assessment of the sediment of the study area was carried out using the following environmental factors and indicators.

Enrichment Factor (EF)

The enrichment factor (EF) is used to assess the volume of environmental pollutants and is often used to determine the anthropogenic pollution of heavy metals in sediments. A reference element that is exceptionally stable in the soil and is devoid of vertical movement and/or degradation events. Additionally, the chosen component should be connected to smaller particles (connected to grain size), and its concentration shouldn't be altered by humans. Table 2 shows the classification of the enrichment factor, and it can be calculated through the relationship (Ustaoglu & Islam, 2020):

Table 4. Classification of the degree of contamination in sediments (Adewoye et al., 2021).

Contamination Degree (Cdeg)	**Contamination Level**
Cdeg < 8	Low contamination
< 16 Cdeg ≤ 8	Moderate contamination factor
< 32 Cdeg ≤ 16	Important contamination factor
Cdeg ≤ 32	Very high contamination factor

$$EF = \frac{(C_i / C_{ref})_{Sample}}{(S_i / S_{ref})_{background}} \quad \textbf{(1)}$$

Where: C_i: The measured concentration of heavy metals in sediment samples.
C_{ref}: The concentration of the reference element in sediment samples.
S_i: the background value of the measured heavy metal.
S_{erf}: The background value of the reference element used.

Contamination Factor (CF)

The contamination factor is a single-element indicator, and this factor is used to describe the extent of soil contamination with heavy metals, and it is the only evidence for this (Ustaoglu & Islam, 2020):

$$CF = \frac{C_{sample}}{C_{background}} \quad (2)$$

Where: S_{ample}: The concentration of the element in samples.
$B_{ackground}$: The concentration of an element in the Earth's crust.

Degree of Contamination (C_{deg})

It is defined as the sum of the pollution coefficients for all the studied minerals in the sample; and table 4 shows the classifications of the degree of pollution, and the degree of pollution is found through the following equation (Adewoye et al., 2021):

$$C_{deg}=CF_1+CF_2+CF_3+\dots+CF_n \quad (3)$$

$$C_{deg} = \sum CF \quad (4)$$

Where:
n: the number of minerals studied.
CF: Pollution factor

Pollution Load Index (PLI)

The pollution load index PLI is used to measure the extent of mineral pollution in a particular sample site, and the pollution load index is found from the following relationship (Al-Tamimi &Ali, 2018):

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n} \quad (5)$$

Table 5. pollution load index classification (Al-Tamimi &Ali, 2018).

Pollution Load Index	Contamination Level
PLI < 1	There is no heavy elements pollution
PLI > 1	Imply that heavy elements pollution exists

Table 6. Results of heavy metal concentrations for sediment samples for study areas in the unit (ppm).

Sample ID	The concentration of heavy metals (ppm)					
	Co	Cu	Cd	Pb	Zn	Ni
TS1	19.93	40.12	0.721	18.41	69.7	173.11
TS2	14.69	33.50	0.316	12.53	53.04	165.83
TS3	8.01	31.97	0.202	9.02	87.32	171.55
TS4	11.15	35.63	0.165	11.75	133.30	139.70
TS5	7.32	26.90	0.037	10.45	95.08	156.32
TS6	4.53	34.06	0.121	13.11	74.45	131.60
TS7	5.56	23.67	0.062	11.76	112.10	144.51
TS8	3.88	21.93	0.091	13.00	48.03	108.41
TS9	6.06	35.12	0.024	9.82	39.22	143.56
TS10	6.65	21.29	0.059	10.51	42.76	112.91
Average	8.78	30.42	0.179	12.04	75.53	144.75
Min.	3.88	21.29	0.024	9.02	39.22	108.41
Max.	19.93	40.12	0.721	18.41	133.30	173.11

Where:

n: the number of minerals studied.

C_F: Contamination Factor.

RESULTS AND DİSCUSSİON

Heavy metals concentration in sediments

Heavy metals are present in the environment naturally and industrially due to human and industrial activities, as they pollute the environment. Getting rid of heavy metals is difficult as they are long-term elements, and some are toxic to organisms in the ecosystem (Dietterich, 2016). Hence, it may be concluded that occurrence of petrol wells and petrol platform beside study area. There are many reason may be helps to increase the poisons elements as fall out, geochemical nature in this area and industrial waste which enrichment with heavy elements.

The results of heavy metal concentrations for sediment samples are presented in Table 6. The results show that the average concentrations of heavy metals in the sediment samples took the following order in terms of the high concentration: Ni>Zn>Cu>Pb>Co>Cd, respectively.

Heavy metal concentrations in sediment samples were found to be in the following ranges: Co (3.88 - 19.93 ppm), Cu (21.29 - 40.12 ppm), Cd (0.024 - 0.721 ppm), Pb (9.02 - 18.41 ppm), Zn (39.22 – 133.30 ppm), Ni (108.41 – 173.11 ppm).

The increase in the concentration of some heavy metals in the Tigris River environment is due to several natural and human factors that can control this increase, as geological factors can play an essential role in this area, as the content of heavy metals equipped with sediments can be one of these factors as well as the geochemical environment and physical nature of these deposits, as well as the heavy water from residential, agricultural, industrial and agricultural areas that are washed away by rainwater and torrents to the river. The roads of estuaries are one

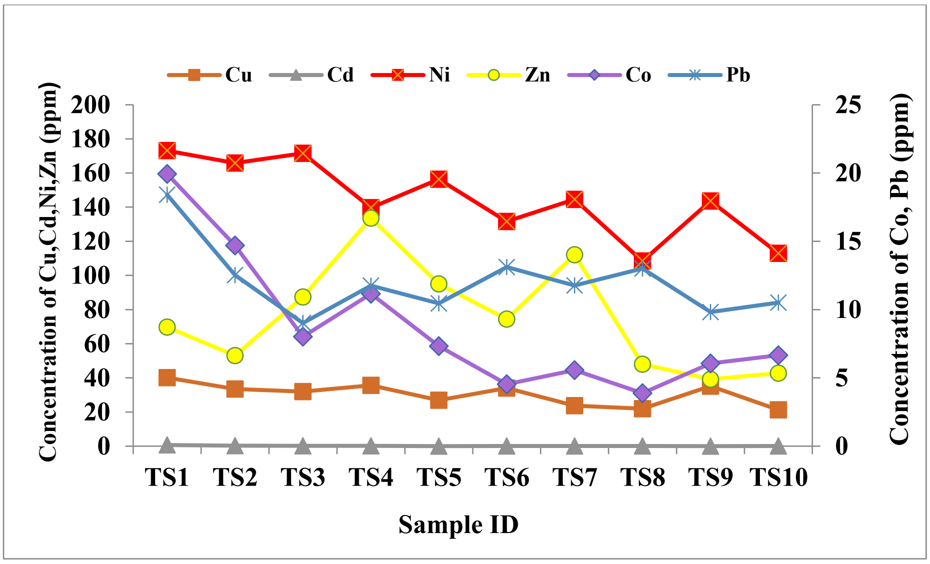


Fig. 2. The values of heavy metals (Co, Cu, Cd, Pb, Zn, and Ni) concentrations in the studied sediment samples.

of the reasons for the increase in heavy metal concentrations, especially cadmium, where the water of all small and large cities in the Tigris basin is discharged into the river without much treatment, and we do not have accurate information about the quantities of this water or the proportions of cadmium in Iraq.

The average concentrations of heavy metals under investigation were compared with the averages of local and international studies, as it was found that there are values close to the results of the present study as in table (7).

Assessment of Sediment Contamination

The present study has used some of the pollution factors to determine the authentic sources of pollution in the sediments under investigation and then work to distinguish those pollutants resulting from human activity from those from geological sources.

Enrichment Factor (EF)

The enrichment factor (EF) is calculated according to Eq. (1) refers to the assessment of the level of pollution due to human influence; that is, its value determines the volume of contamination with heavy metals (Zn, Pb, Ni, Cd, Cu, Co). The results of the enrichment factor are shown in table (8) and figure 3. The results of the study showed that the extent of the cobalt enrichment factor ranged between (0.29-1.74) with an average of (0.67); the range of lead element was (1.10-2.61) with an average of (1.47), meaning that the sediments of the studied area are not contaminated with cobalt and copper because their averages are less than the minimum, meaning that they are within EF < 2. The range of copper ranged (from 1.45-3.37) with an average of (2.19), cadmium was (0.67-17.58) with an average of (4.08), nickel was (3.41-6.48), and an average of (4.58), Thus, the sediments of the study area are considered moderate enrichment with metals of copper, cadmium, nickel, and zinc, that is, within the range EF = 5-20. The existence of an average enrichment of these minerals may be due to the human resources represented by the releases of industrial and agricultural activities and heavy municipal water wastes.

Contamination Factor (CF)

The contamination factor (CF) is the pollution caused by human influence. The contamination factor (CF) by using eq. (2) was calculated, and table (9) shows the contamination factor (CF)

Table 7. A comparison between the average concentrations of heavy metals (ppm) in the sediments of the study area and its comparison with the averages of other studies and the worldwide average.

Country	**Location**	**The concentration of heavy metals (ppm)**						**Reference**
		Co	**Cu**	**Cd**	**Ni**	**Pb**	**Zn**	
Bangalore	Urban Lakes	47.70	203.50	8.38	97.64	206.0	220.90	(Jumbe & Nardini, 2009)
Korea	Kumho	20.9	125	1.67	97.6	149	298	(Kim et al., 2010)
Iran	Haraz river	9.55	32.1	3.45	43.55	26.35	73.8	(Touraj N., et al., 2010)
Iran	Tehran	11.80	38.54	2.99	56.98	30.95	64.51	(Fazali, G. et al, 2018)
Iran	Urban areas	14.61	42.20	2.74	35.78	41.15	62.93	(Eghbal N. et al, 2019)
Iran	Gorgan Bay	–	18	–	–	11.5	42	(Bastami et al., 2012)
Pakistan	Shah Alam Peshawar	–	0.17-1.48	0.2-0.69		1.01-1.23	1.2-2.0	(Usman et al., 2017)
Nigeria	Lagos Beach	0.001	21.781	0.001	3.206	328.309	14.609	(Samuel et al., 2019)
Cameroon	Ndongn	76.93	94.52	–	147.79	0.00	579.70	(Tchounda et al., 2019)
Iraq, South	Khor-Abdullah	4.17	22	–	99	12	52	(Al-Jaberi & Al-Dabbas, 2014)
Iraq, Babil	Shatt Al-Hilla	28.1	16.09	0.2	15.9	9.17	37.5	(Manea et al., 2019)
Iraq, Maysan	Al-Ma'ail	–	0.631	0.133	0.9	0.844	1.18	(Oadoori &Al-Tawash, 2021)
Iraq, Mosul	Tigris	13.28	35.1	–	183.17	–	126.3	(Mahmood, 2021)
Iraq, Mosul	Tigris	8.78	30.42	0.179	144.75	12.04	75.53	[Present Study, 2021]
Worldwide Average	---	8	30	0.06	40	10	50	(Lindsay, 1979)

values for the Tigris River sediment samples in the city of Mosul. From the results of table 9, the contamination factor for cobalt was in the range (0.16-0.83), with an average of (0.36); the contamination factor range of cadmium was (0.24-7.21), with an average of (0.170). In comparison, the contamination factor range for the lead was (0.61-1.24), with an average of (0.81). Where the average contamination factor of these three metals falls into the low pollution classification, that is, it falls within CF<1. Thus, the deposits of the studied areas are considered low contamination with cobalt, cadmium, and lead. As for copper, its contamination factor ranged (from 0.85-1.60) with an average of (1.21). The contamination factor ranges for nickel ranged (from 1.93-3.09) with an average of (2.58), while the contamination factor range for zinc was (0.60-1.46) with an average of (1.15). Their average contamination factor for these metals falls within the classification of medium pollution, i.e., $1 < CF < 3$. Thus, the deposits of the studied area are moderately contaminated with copper, nickel, and zinc metals. In general, the contamination coefficient values for the studied heavy metals and the study sediments ranged from low pollution to medium pollution.

Degree of Contamination (C_{deg})

The degree of contamination (C_{deg}) was calculated based on eq. (3). It is listed in the table 10 and shown in Figure 5. They show the degree of contamination of the Tigris river sediments in the

Table 8. Values of the enrichment factor (EF) for the Tigris River sediment samples in the city of Mosul.

Sample ID	Enrichment Factor (EF)					
	Co	Cu	Cd	Ni	Pb	Zn
TS1	1.74	3.37	17.58	6.48	2.61	2.25
TS2	1.01	2.21	6.05	4.88	1.39	1.34
TS3	0.65	2.48	4.55	5.94	1.18	2.60
TS4	0.95	2.92	3.93	5.11	1.63	4.20
TS5	0.47	1.67	0.67	4.35	1.10	2.28
TS6	0.31	2.23	2.30	3.87	1.45	1.87
TS7	0.35	1.45	1.10	3.95	1.22	2.64
TS8	0.29	1.59	1.61	3.53	1.60	1.35
TS9	0.43	2.37	1.93	4.34	1.12	1.02
TS10	0.55	1.68	1.16	3.41	1.41	1.30
Average	0.67	2.19	4.08	4.58	1.47	2.08
Min.	0.29	1.45	0.67	3.41	1.10	1.02
Max.	1.74	3.37	17.58	6.48	2.61	2.60

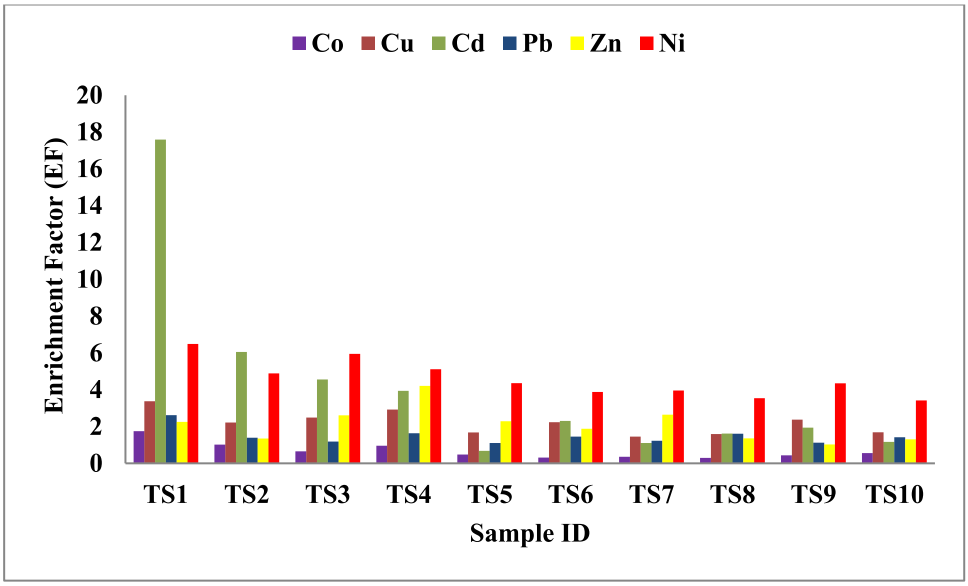


Fig. 3. Changes in the enrichment factor for heavy metals with the locations of the studied samples

city of Mosul. The contamination degree factor is moderate contamination in the sample (TS1) in the third bridge area by about (15.04) because its value is within the range $8 \leq C_{deg} < 16$, and thus this area is moderate pollution, as for the rest of the study areas, they were of low pollution because their values were within Cdeg <8, and the extent of the degree of contamination in the sediments of the study area was about (5.04 - 15.04) with an average of (7.29). Thus, all the sediments of the study area, in general, range from low to medium pollution.

Pollution Load Index (PLI)

This indicator expresses the state of soil or sediment pollution in a particular site, known as the geometric mean of the pollutants studied. According to the definition, the pollution load index (PLI) visualizes the pollution situation at a particular site.

Table 9. Shows the contamination factor (CF) values of the Tigris River sediment samples in Mosul city.

Sample ID	**Contamination Factor (CF)**					
	Co	**Cu**	**Cd**	**Ni**	**Pb**	**Zn**
TS1	0.83	1.60	7.21	3.09	1.24	1.07
TS2	0.61	1.34	3.16	2.96	0.84	0.82
TS3	0.33	1.28	2.02	3.06	0.61	1.34
TS4	0.46	1.42	1.65	2.49	0.79	2.05
TS5	0.31	1.07	0.37	2.79	0.70	1.46
TS6	0.19	1.36	1.21	2.35	0.88	1.14
TS7	0.23	0.95	0.62	2.58	0.79	1.72
TS8	0.16	0.88	0.91	1.93	0.87	0.74
TS9	0.25	1.40	0.24	2.56	0.66	0.60
TS10	0.28	0.85	0.59	2.01	0.71	0.65
Average	0.36	1.21	0.170	2.58	0.81	1.15
Min.	0.16	0.85	0.24	1.93	0.61	0.60
Max.	0.83	1.60	7.21	3.09	1.24	1.46

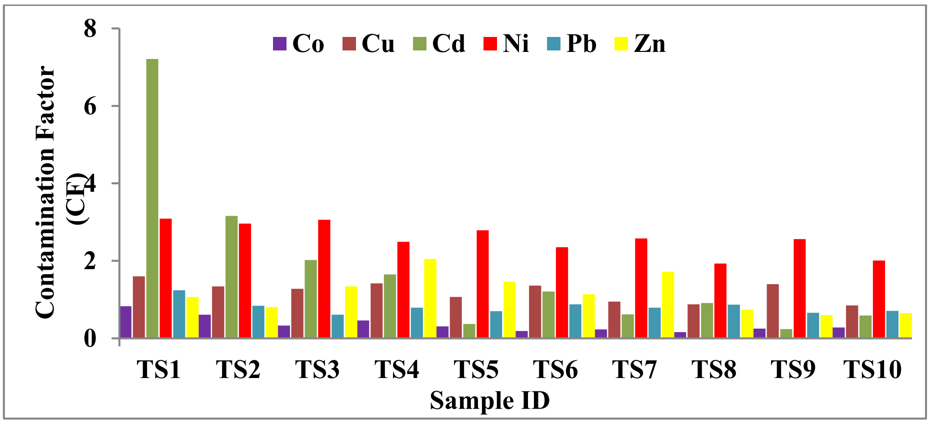


Fig. 4. Shows the change of pollution factor values for heavy metals with the locations of the studied sediment samples.

Table 10. Shows the values of the degree of contamination (Cdeg) for the sediment samples of the study area.

Degree of Contamination	
Sample ID	**Cdeg**
TS1	15.04
TS2	9.72
TS3	8.64
TS4	8.86
TS5	6.70
TS6	7.13
TS7	6.89
TS8	5.49
TS9	5.71
TS10	5.04
Average	7.92
Min.	5.04
Max.	15.04

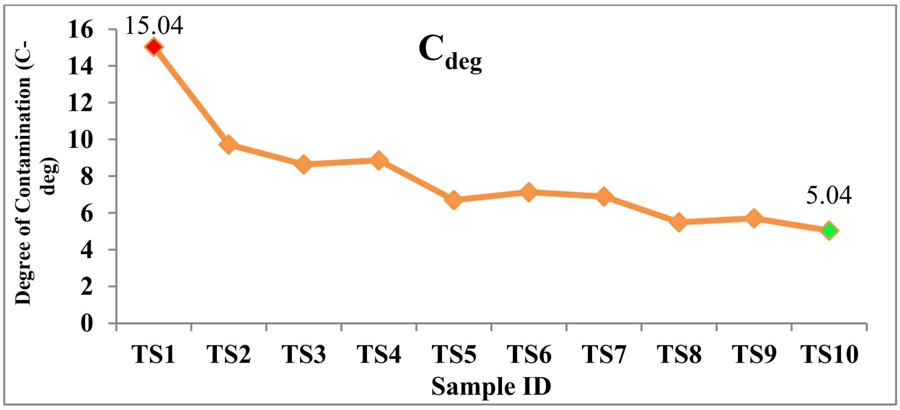


Fig. 5. The change in the values of the degree of contamination with heavy metals with the locations of the studied sediment samples.

Table 11. Values of the Pollution Load Index (PLI) for the Tigris River sediment samples in Mosul.

Pollution Load Index	
Sample ID	PLI
TS1	1.84
TS2	1.32
TS3	1.13
TS4	1.28
TS5	0.83
TS6	0.95
TS7	0.88
TS8	0.73
TS9	0.66
TS10	0.71
Average	1.03
Min.	0.66
Max.	1.84

Table 11 shows the values of the pollution load index calculated according to the eq. for the sediment samples, as it showed that the importance of the pollution load index in the samples (TS4, TS3, TS2, TS1) amounted to (1.28, 1.13, 1.32, 1.84), respectively. Whereas, these results suggest that the sediments of these areas are contaminated with heavy metals because values PLI > 1. The reason is due to human activities, such as the presence of gravel and sand extraction plants, the discharge of sewage, and the disposal of the factory and home waste, among others.

As for the samples (TS10, TS9, TS8, TS7, TS6, TS5) in the sediments of the Tigris River for the studied areas, the values of the pollution load index reached (0.71, 0.66, 0.73, 0.88, 0.95, 0.83), respectively. The sediments of these areas are not contaminated with heavy metals because the PLI values are <1. As for the average pollution load index in the sediments of the Tigris River in the studied areas, it reached (1.03) with a range of (0.66-1.84). Thus, the sediments of these areas are contaminated with heavy metals. Figure 6 shows the change in the pollution index values of the pollution load index in the sediments of the Tigris River in the city of Mosul, according to the difference in the locations of the samples. Table 11 shows the values of the pollution load index (PLI) for the Tigris River sediment samples in the city of Mosul.

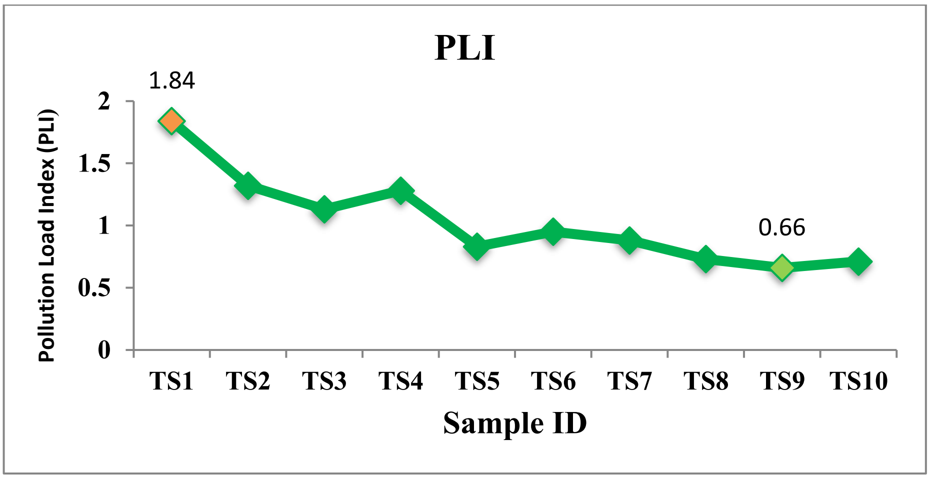


Fig. 6. The change in the values of the pollution load index of heavy metals with the locations of the studied sediment samples.

CONCLUSİONS

Heavy metal concentrations in some studied areas were higher than the maximum allowed globally. Human activities play the dominant role in the high and low concentrations of heavy metals, which was evident through the variation in the concentrations of these metals from one site to another. The results showed that the concentrations of heavy metals studied were in the following order: Ni>Zn>Cu>Pb>Co>Cd. The results of pollution treatments EF, CF, Cdeg, and PLI indicated that it was due to human activity.

In light of the results obtained, the authors recommend the following:

1. Industrial plants and commercial activities must be required to treat their wastes at the production site before putting them in the river.
2. Monitoring the flow of sewage, agricultural drainage, and urban waste, setting environmental control over the concentrations of toxic heavy metals contained in the river, and taking possible treatments by the competent authorities.
3. Treatment at the source or central treatment of wastewater in an efficient manner allows it to be dumped into the river after conforming to the Iraqi environmental conditions.

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DECLARATIONS

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Raw data were generated at the University of Mosul large-scale facility. Derived data supporting the findings of this study are available from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Rana Hesham Mahmmod, Laith A. Najam, Taha Yaseen Wais and Howaida Mansour. all authors commented on previous versions of the manuscript and approved the final manuscript.

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