Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org

Evaluation of Heavy Metals Pollution in the Sediments of Diyala River Lower Reaches, Eastern Iraq

Younis A. Mijbas[1], Mohammed A. Fayidh[1,*] , Raad M. Nasif [1]

[1] Department of Biology,College of Education for Pure Science Ibn Al-Haitham, University of Baghdad,Baghdad, Iraq.

[*] **Correspondence**: mohammed.a.@ihcoedu.uobaghdad.edu.iq

Received: 9 October 2023

Accepted: 7 January 2024

Published: 30 April 2024

Abstract

Investigating the heavy metals in soil is important to the life of humans and living organisms. Diyala River Lower Reaches was chosen due to the changes in environmental characteristics that took place in recent years. Twelve sediment samples were collected from four different sites. The physical, and chemical properties and the concentrations of nine heavy metals were indicated. The results showed that the average concentrations of arsenic, copper, chromium, cobalt, iron, manganese, nickel, lead, and zinc are 8.5, 45.7, 538.5, 12.2, 5.07, 991.7, 183.5, 16.07, 136.5 ppm, respectively. They reflect contamination with arsenic, chromium, and nickel, while they are free of lead, and zinc contamination, according to the Environmental Protection Agency's (EPA) sediment quality guidelines. The measured contamination indices (the enrichment factor (EF), contamination factor (CF), degree of pollution (Cdeg), geographical accumulation index (Igeo), and pollution load index (PLI)), reflected high contamination factor for arsenic and chromium, and medium for manganese, nickel, lead, and zinc, while low for copper and cobalt. Based on all the results in all sampling sites indicate the presence of heavy element contamination in the sediments of the Diyala River Lower Reaches.

Keywords: Heavy Metals; Sediments; Diyala River; Pollution; Geo-accumulation index.

1. Introduction

Sediments are an integral part of aquatic systems and they play a major role in the hydrological, geomorphological, and ecological performance of basins and estuaries, lakes, reservoirs, and coastal areas (Tundu et al., 2018). In natural and agricultural systems, sediments originate from weathering of rocks, soil erosion, erosion of river banks, as well as landslides and debris flows in most river basins, which are rich in organic matter from a range of sources such as riparian trees and fish (Macklin et al., 2003). Toxic compounds including metals tend to accumulate in the sediments of water bodies through complex physical and chemical adsorption mechanisms that depend on the nature of the sediment matrix and the properties of the adsorbed compounds (Al-Jaberi et al., 2016). The investigation of pollution with heavy elements is one of the important methods in assessing the quality of sediment and the environmental risks resulting from it (Yang et al., 2021).

The physicochemical and geochemical characteristics, organic content, pH, electrical conductivity, and total dissolved salts of sediments in river environments are affected by climate and human activities, (Diab et al., 2014; Bhuyan et al., 2019).

Most of the heavy metals are do not decompose and usually present in the contaminated sediments with weights higher than 5 g/cm, (Gorhe & Paszkowsi, 2006). They can be found naturally in soil or

DOI: 10.46717/igj.57.1D.4ms-2024-4-14

due to human activities and enter the food chain and form complex toxic compounds that lead to a harmful effect on biological functions (Lenart & Wolny-Koladka, 2012). Natural sources include atmospheric emissions from volcanoes, continental dust transport, and weathering of element-rich rocks. It is believed that a large part of the lead, nickel, and iron find their way into the environment due to the combustion of diesel oil and oil spills (Qadoori & Al-Tawash, 2021).

The mechanisms of heavy metals pollution include industrial, agricultural, and municipal discharge of wastewater (Al-Dabbas & Abdullah, 2020).

The Diyala River is one of the main water sources of Iraq. It is one of the most important tributaries of the Tigris River, as the river basin varies widely across the entire drainage basin area or watershed from a semi-arid plain north of Baghdad to a mountainous region in western Iran (Mahmood and Alkhafaji, 2017). The Diyala River meets the Tigris River south of Baghdad and affects the water quality of the Tigris River.

From a geological point of view, a river watershed contains different geological units. It is noted that the Lower Diyala Basin area is mainly covered by modern sediments within the unfolded zone, while the watershed is connected to the Diyala River within heavily cultivated areas, containing many irrigation channels, sewage channels, and wastewater, which contributes to and affects the river's aquatic chemistry (Hamza, 2012).

Many Pollution studies have been conducted on the Diyala River, reflected that the Diyala River is seriously polluted with heavy metals, which indicates the presence of a potential danger, that may affect people’s health (Abdullah, 2013; Issa and Alshatteri, 2021).

The sediments act as a reservoir for pollutants and constitute a potential source to transport them in the water and living organisms. The Diyala River has an important geographical location in Iraq and is exposed to many pollutants from various sources due to the lack of sufficient information on the availability and percentages of pollution in recent years. It was chosen in this study to assess the level of Contamination of its sediments with heavy metals by indicating contamination indices such as the enrichment factor (EF), pollution factor (CF), pollution degree (Cdeg), geographical accumulation index (Igeo), and pollution load index (PLI) (Rahman et al., 2022).

Therefore the current study aimed to evaluate the quality of sediment pollution with heavy metals and its impact on the pollution of the Diyala River Lower Reaches.

2. Materials and Methods

2.1. Study area Description

The sampling sites of the Diyala River Lower Reaches represent the area below the Hamrin Dam up to the connection of the Diyala River (mouth) with the Tigris River. The study area is located between Longitude 44°38'12.9"E and 44°32'20.8"E, and latitudes 33°50'36.1"N and 33°17'01.6"N. It is within the sedimentary plain, and it extends over 1940 km^2 (Al-Musawi, 2018). The sampling sites are Had Maksar, Al-Batool Teaching Hospital, the Iron Bridge- Shafta village, and the Al-Rustamiya Refinarry project.

2.2. Sample Collection and Laboratory Analysis

Twelve sediment samples were collected from the four different sites. Three samples of each site (A, B, and C) were taken using a grab sampler for the period between August 19 and 25, 2023 (Fig. 1, Table 1). The samples (1 kg weight) were kept in tightly closed polyethylene plastic bags, and all the field information was recorded. The samples were transferred to the laboratory within a portable cooling box containing ice bags, to maintain a temperature of 4 °C and analyzed at the University of Baghdad, College of Science, Department of Geology. Sample specification analysis was conducted within two weeks based on APHA, 2017 procedure.

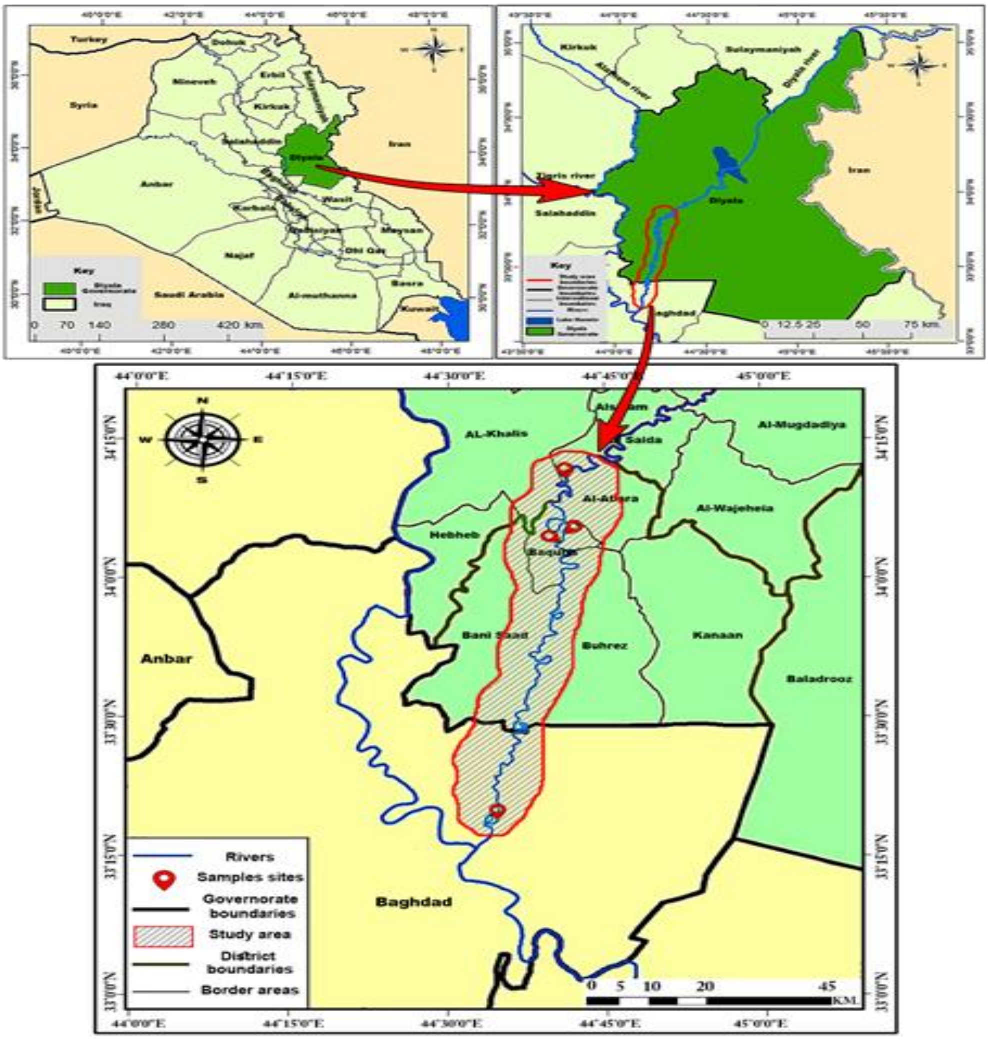

Fig. 1. The location maps of sample sites within Diyala Governorate.

Table 1. Description of the location of the samples with the location codes.

Sample locations	Site description	Longitude-E	Latitude-N
S(A)1	Residential and agricultural	44°38'12.9"E	33°50'36.1"N
S(B)1	(orchards and fields) near fish	44°38'10.2"E	33°50'41.4"N
S(C)1	farming ponds	44°38'15.2"E	33°50'31.2"N
S(A)2	Residential buildings near the	44°37'54.0"E	33°44'50.5"N
S(B)2	waste pumping of Al-Batoul	44°37'54.7"E	33°44'59.8"N
S(C)2	Teaching Hospital	44°37'54.5"E	33°44'44.6"N
S(A)3	Residential and agricultural	44°37'55.2"E	33°44'34.1"N
S(B)3	near the iron bridge, near the	44°37'54.9"E	33°44'40.9"N
S(C)3	pumping of sewage waste	44°37'54.6"E	33°44'28.3"N
S(A)4	Residential near the sewage	44°32'17.9"E	33°17'14.5"N
S(B)4	treatment site of the Rustamiya	44°32'18.2"E	33°17'28.8"N
S(C)4	Third Expansion Project	44°32'20.8"E	33°17'01.6"N

2.3. Physicochemical Analysis

The pH of the study samples was measured on-site using a portable pH device according to the McKeague, 1978 method. The electrical conductivity of the sediment was measured in the laboratory (Richards, 1954). A device was used to measure the proportions of dissolved salts in the sediment in ppm, after preparing aqueous solutions of the samples and mixing them separately with an electric mixer. The organic matter was calculated in sediments in the laboratory according to Carver (1971) method.

The heavy metals concentration and metal oxides are analyzed with high accuracy by applying the X-ray fluorescence technique (XRF). Ten grams of samples were powdered to detect the Fe, Co, Zn, Cu, Ni, and Pb elements by XRF Methods. Powders of the samples were processed in the form of compressed pellets, using a special piston under a pressure of five tons. The results are tabulated in Tables 2 and 3.

Table 2. Physicochemical characteristics of the sediments in the study area.

Sample locations	Organic matter % (O.M)	Electrical conductivity *mmhos/cm*	pH	TDS Ppm
S(A)1	1.26	0.424	7.5	430
S(B)1	1.77	0.340	7.0	489
S(C)1	1.75	0.399	7.3	460
Average	1.59	0.388	7.2	459
S(A)2	1.45	0.856	7.8	512
S(B)2	1.98	1	7.6	493
S(C)2	1.65	0.855	7.5	418
Average	1.69	0.904	7.6	474
S(A)3	1.48	1.338	7.0	679
S(B)3	1.85	1.415	7.1	707
S(C)3	1.44	1.252	7.2	650
Average	1.59	1.335	7.1	678
S(A)4	1.89	0.907	7.4	522
S(B)4	1.65	0.781	7.3	509
S(C)4	1.57	0.620	7.2	500
Average	1.70	0.769	7.3	510

Table 3. Concentrations of heavy metals in the sediments of the study area.

Sample location	As	Cu	Cr	Co	Fe	Mn	Ni	Pb	Zn
		Ppm			%		Ppm		
S(A)1	9.5	28.6	379	9.6	4.1	1177	118	8.3	75
S(B)1	9.4	48.2	673	12.2	6.1	1108	222	17.7	114
S(C)1	8.4	46.2	982	21	6.0	1081	270	14.5	103
Average	9.1	41	678	14.2	5.4	1122	203	13.5	97
S(A)2	7.7	48.5	1030	21.2	6.2	1093	255	14.1	112
S(B)2	8.3	41.0	244	9.8	4.9	1091	164	13.2	105
S(C)2	9.3	43.8	497	9.7	5.6	959	204	16.5	190
Average	8.4	44.4	590	13.5	5.5	1047	207	14.6	135
S(A)3	6.9	39.7	330	9.4	4.6	807	157	22	132
S(B)3	9.6	44.4	444	10	4.8	820	170	16.7	104
S(C)3	6.7	47.0	385	3.9	4.3	986	137	16.7	273
Average	7.7	43.7	386	7.7	4.5	871	154	18.4	169
S(A)4	10.4	45.2	475	12.6	5.4	932	197	18	118
S(B)4	7.1	71.5	438	9.4	4.1	871	114	18.5	211
S(C)4	9.9	45.1	587	18.2	5.4	979	201	16.9	107
Average	9.1	53.9	500	13.4	4.9	927	170	17.8	145
(Lindsay, 1979)	5	30	100	8	3.8	600	40	10	50

(Wedepohl, 1995)	1.7	25	136	24	4.32	716	56	14.8	65
Haynes et al.,) (2016	1.8	60	102	25	5.63	950	84	14	70

2.4. Evaluation of sediment contamination with heavy metals

2.4.1. Enrichment Factor (EF)

Enrichment factor (EF) is used to assess the deposition intensity and presence of anthropogenic pollutants in river sediments. EF was calculated using the method approved by Sinex and Helz (1981), as follows:

$$EF = (Me/Fe)_{sample} / (Me/Fe)_{background} \quad (1)$$

Where: Me is the heavy metal concentration (ppm), while the Me/Fe background represents the concentration of the heavy element on the reference concentration of iron in the earth's crust. The EF was classified into five grades (Wedepohl, 1995; Pragg and Mohammed, 2018) (Table 4).

Table 4. Classification of sediments depending on the enrichment factor (EF) (Mmolawa et al., 2011)

Enrichment factor (EF)	Enrichment factor (EF) Categories
EF < 2	Deficiency to minimal enrichment
2 ≤ EF < 5	Moderate enrichment
5 ≤ EF < 20	Significant enrichment
20 ≤ EF < 40	Very high enrichment
EF ≥ 40	Extremely high enrichment

2.4.2. Pollution factor (CF) and contamination degree (Cdeg)

The Pollution factor (CF) was determined following an equation according to Hakanson, 1980. Equation 2 was adopted to estimate the level of sediment contamination with minerals (Hakanson, 1980; Al-Dabbas et al., 2018). The level of contamination by metals was established by applying the CF and can be calculated as follows:

$$CF = C_m \text{ Sample} / C_m \text{ Background} \quad (2)$$

C_m Sample is the concentration of particular trace minerals in river sediments, and C_m Background is the value of trace minerals that is equal to the average of the global rocks (Martin and Meybeck, 1979). The degree of pollution represents the total pollution factor for heavy elements according to Hakanson (1980), and is calculated through equation 3:

$$C_{deg} = \sum_i^n CF \quad (3)$$

Where: $\sum_i^n CF$ represents the total pollution factor, (n) represents the number of heavy elements studied. The CF was classified into four grades (Hakanson, 1980) (Table 5).

Table 5. Classification of the level of pollution depends on the pollution factor CF and the degree of pollution C degree (Hakanson, 1980).

CF	C deg	Contamination Level
1 > CF	8 > C deg	Low contamination
3 > CF ≤ 1	16 > C deg ≤ 8	Moderate contamination
6 > CF ≤ 3	32 > C deg ≤ 16	Considerable contamination
6 < CF	32 < C deg	Very high contamination

2.4.3. Geoaccumulation index (I- Geo)

The Geo accumulation (I-geo) index means the assessment of contamination by comparing the levels of heavy metal obtained to a background level (Muller, 1969). Geo-accumulation index (I- geo) was determined by the following equation 4 according to Muller (1969).

$$\mathbf{Igeo = Log2\ (C_m\ Sample\ /\ (1.5 \times C_m\ Background))} \quad (4)$$

Where C_m Sample expresses the measured concentration of the element in the sediment sample and C_m Background is the geochemical background value (World Mean of Surface Rocks) (Martin and Meybeck, 1979). The constant 1.5 was adopted to include the possible variation of background values due to the rock impact. The I- Geo was classified into seven grades (Muller, 1969) (Table 6).

Table 6. Muller's 1969 classification of the index of geographic accumulation (I_{geo}) shows sediment pollution.

I_{geo} Value	Class	Sediment Quality
≤ 0	0	Unpolluted
0 – 1	1	From unpolluted to moderately polluted
1 – 2	2	Moderately polluted
2 – 3	3	From moderately to strongly polluted
3 – 4	4	Strongly polluted
4 – 5	5	From strongly to extremely polluted
> 6	6	Extremely

2.4.4. Pollution load index (PLI)

The PLI provides a simple but comparative means for assessing a site's quality. The pollution load index (PLI) was determined following equation 5 according to Thomilson et al. (1980), where (PLI) is expressed as follows:

$$\mathbf{PLI = (\ CF_1 \times CF_2 \times .....\ CF_n\ )^{1/n}} \quad (5)$$

Where (CF) represents the pollution factor and (n) represents the number of the studied elements. The value of the total pollution load, if it is greater than one, indicates a gradual deterioration in the sediment quality and its contamination with heavy elements, but if it is less than one, it indicates that there is no pollution with heavy elements (Tomlinson et al., 1980).

3. Results and Discussion

3.1. Physicochemical characteristics and Concentration of Heavy metals

The results of the physical and chemical properties (pH, organic matter, electrical conductivity, and total dissolved salts) showed that there are differences in their values in the sediments of the study area (Table 2). Such variations result from weathering and erosion of rocks and soil of the river basin or have been transferred to the riverbed by humans or Water (Al-Kinani & Al-Mukhtar, 2014).

Heavy metal concentrations in the sediments were evaluated by comparison with the other research findings (USEPA,1977; Lindsay, 1979; Wedepohl,1995; Haynes et al., 2016) (Table 3).

The results showed that there was a variation in the concentrations of heavy metals, which included arsenic, copper, chromium, cobalt, iron, manganese, nickel, lead, and zinc, in sediment samples of the study area and summarized in Table 3.

- Arsenic

The results indicate that the average concentration of arsenic reached between 6.7 and 10.4 ppm, which is higher than its average in the Earth's crust and its global average, according to Lindsay (1979; Wedepohl (1995); Haynes et al. (2016). The reason for enriching the sediments of the study sites with arsenic is due to the alkalinity of the pH. Agricultural activities are a source of arsenic pollution through the use of pesticides and chemical fertilizers. Industrial and traffic activities also play an important role in increasing the concentration of arsenic in the sediments of the region.

- Copper

The copper concentration rate reached between 28.6 to 71.5 ppm, which is higher than its rate in the earth's crust and its global average, as human activities and the use of fertilizers and pesticides on agricultural lands, as well as its emission from the movement of vehicles and means of transportation, cause an increase in Its concentration in sediments (Wojciechowska et al., 2019).

- Chromium

The concentration rate of chromium element ranged between 244 to 1030 ppm, and it was higher than its rate in the earth's crust and its global average. The increase in its concentration is attributed to traffic activities as well as industrial activities and the use of pesticides and chemical fertilizers in industrial lands (Li et al., 2020).

- Cobalt

The average concentration of cobalt was between 3.9 and 21.2 ppm, which is lower than the average concentration in the Earth's crust and higher than its global average, according to Lindsay (1979). The increase in its concentration is attributed to industrial activities near the river.

- Iron

The rate of iron concentration ranged between 4.1% to 6.2%, which is higher than the global average and lower than the rate of its presence in the Earth's crust. This is due to the corrosion of pipes or tanks, which causes an increase in the concentration of iron when it accumulates for periods.

- Manganese

The concentration rate of manganese ranged between 807 and 1177 ppm, which is higher than the rate of its presence in the earth's crust and the global rate. This is attributed to industrial activities and vehicular traffic, as well as the friction between vehicle tires and the surface of the earth, which is one of the important sources of contamination (Kolawole et al., 2018).

- Nickel

The concentration of nickel ranged between 114 and 270 ppm and was higher than its average presence in the earth's crust and its global average. This is attributed to industrial and traffic activities and agricultural activities represented by pesticides and chemical fertilizers in agricultural lands, which play an important role in the nickel contamination of sediments.

- Lead

The lead concentration ranged between 8.3 and 22 ppm and was higher than its average presence in the earth's crust and its global average. This is attributed to the corrosion of pipes and industrial activities, as well as traffic activities, vehicle movement, and the resulting smoke, as they have a role in the emission of lead through the combustion of fuel and also in activities. Crops play an important role in increasing the concentration of lead, leading to contamination of sediments with this element.

- Zinc

The concentration of zinc reached between 75 and 273 ppm and was higher than its average presence in the earth's crust and its global average. This is attributed to human activities and population density, which have a major role in environmental pollution, as well as the corrosion of pipes lining the water and sewage networks. Also, industrial and agricultural activities, are represented by fertilizers and pesticides in agricultural areas (Wojciechowska et al., 2019).

The results showed that the concentrations of heavy metals in sediment samples are higher than the natural levels of their presence in the Earth's crust and also higher than their global rates according to Lindsay (1979); Wedepohl (1995); Haynes et al. (2016) (Table 3). In general, the high availability of heavy elements can be attributed to the geological nature of the sample sites and the sources of pollution added to the riverbed, whether industrial, agricultural, human, domestic or municipal wastewater, hospital sewage, and also the various means of transportation that pass through. These pollutants and heavy elements in sediments are explained by their presence in high concentrations (Sarkar et al., 2004). These results are consistent with the results of the study by Al-Sarraj et al. (2019).

3.2. Correlation between the Concentration of Heavy Metals and the Physicochemical Properties

Correlation is conducted by applying Pearson's method (negative or positive) between the concentration rates of heavy elements of the four sites samples and between the degrees of pH, electrical conductivity, organic matter, and total dissolved salts (Table 7). It is noted that these factors affected to different degrees the percentage of heavy elements in the sediments of the region. It was found that there is a negative correlation between the pH value and the concentrations of each of the elements (arsenic, chromium, cobalt, iron, manganese, and nickel), offset by a positive correlation between pH and the concentration of lead and zinc. There is also a positive correlation between the organic content and the concentration of the copper element, and there is a negative correlation between the value of the total dissolved salts and the concentration of the elements (arsenic, chromium, cobalt, iron, manganese, and nickel). The results revealed that there is a positive correlation between the value of the total dissolved salts and the concentration of the elements lead and zinc, as well as a positive correlation between the value of the electrical conductivity and the concentration of the elements iron and nickel (Table 7). Such results are consistent with the study of Kim et al. (2006). It indicates that the physicochemical properties of sediments have common sources and are one of the important factors that describe the heavy metal content of sediments.

Table 7. Pearson correlation coefficient between the rate of heavy metal concentrations and the physicochemical properties of the sediments in the study area

Elements	OM	pH	EC	TDS
As	0.329	- 0.915	0.161	- 0.826
Cu	0.742	0.071	0.132	- 0.031
Cr	0.040	- 0.904	0.395	- 0.915
Co	0.475	- 0.885	0.557	- 0.990
Fe	0.275	- 0.720	0.697	- 0.915
Mn	- 0.077	- 0.829	0.376	- 0.841
Ni	0.184	- 0.695	0.660	- 0.874
Pb	0.097	0.748	- 0.419	0.794
Zn	0.144	0.947	- 0.155	0.831

3.3. The correlation of the heavy elements concentrations

It was found that there is a positive correlation between the concentration of arsenic with chromium and cobalt and a negative with zinc. There is a positive correlation between the concentration of chromium and cobalt, iron, manganese, and nickel, while a negative relationship between lead and zinc. Also, a positive relationship between the concentration of cobalt and iron, manganese, and nickel exists. The negative relationship between lead and zinc, with a positive relationship between manganese and nickel found (Table 8).

According to Suresh et al. (2011), the high positive correlation between heavy elements with each other indicates that they have a common origin, either from natural or anthropogenic sources. There is also evidence of sites contaminated by agricultural and industrial activities with mutual dependence. It also indicates that they have similar fixed or non-point sources of pollution, while the weak connection between the elements shows that these elements are not controlled by a single element, but rather by a group of geochemical support (Singh et al., 2015).

Table 8. Pearson correlation coefficient for heavy elements in sediments in the study area of th Diyala River

	As	Cu	Cr	Co	Fe	Mn	Ni	Pb	Zn
As	1.000								
Cu	0.337	1.000							
Cr	0.706	-0.348	1.000						
Co	0.887	0.152	0.871	1.000					
Fe	0.543	-0.302	0.928	0.850	1.000				
Mn	0.570	-0.507	0.983	0.774	0.925	1.000			
Ni	0.480	-0.400	0.928	0.798	0.994	0.943	1.000		
Pb	-0.462	0.582	-0.954	-0.713	-0.930	-0.991	-0.957	1.000	
Zn	-0.738	0.380	-0.968	-0.799	-0.806	-0.950	-0.813	0.903	1.000

On the other hand, it was found that the rates of heavy element concentrations underwent changes according to the locations and the nature of the area, and this is consistent with the findings of Hassan et al. (2008) (Fig. 2). Applying the enrichment factor equation to all samples, it was found that the enrichment value of sediments in the study area with arsenic, and chromium at rates 5.31 and 5.64, respectively, but the enrichment value was medium for a nickel 2.36 and zinc 2.23.

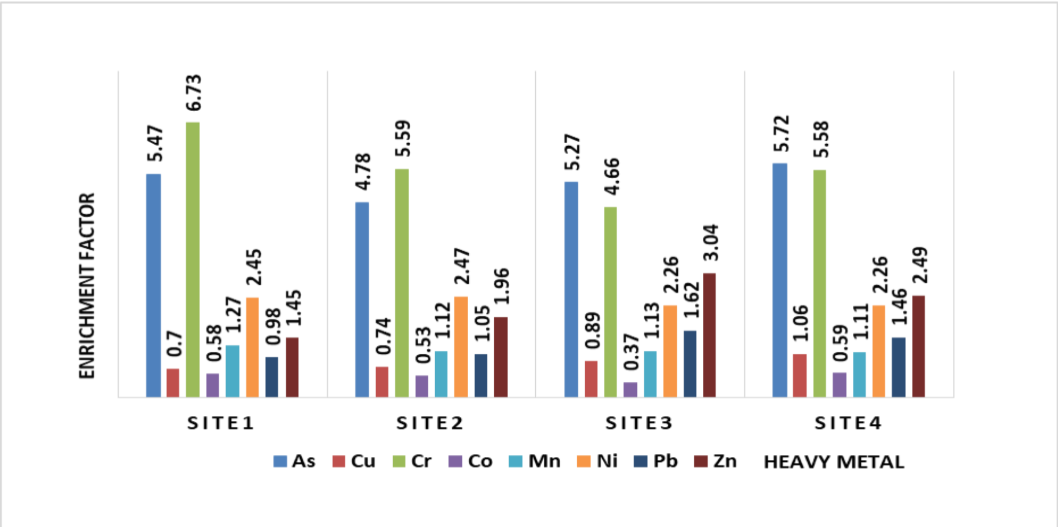

Fig. 2. Enrichment factor for heavy elements in the sediments of the study area

The results of EF were reduced to the minimum for copper, cobalt, manganese, and lead, as they reached 0.84, 0.51, 1.15, and 1.27, respectively. Considering the sediment uncontaminated with these heavy elements, this is consistent with a study by Issa et al. (2020).

Zhang and Liu (2002) confirmed that if the value of the enrichment factor is between 0.5 and 1.5, it indicates that the heavy elements are caused by natural sources. But if the value of the enrichment factor is greater than 1.5, it is caused by human sources.

Accordingly, the high concentration of arsenic, chromium, and medium nickel and zinc for all sites in the study area indicates that it is from anthropogenic sources that may be caused by agricultural and industrial activities (such as the use of pesticides and chemical fertilizers), as well as waste from industrial areas that flow into the Diyala River. The low enrichment factor of copper, cobalt, manganese, and lead in all study sites indicates that they are from natural sources (Agyarko et al., 2014).

Through the application of the Contamination Factor (CF), it was found that the highest average concentration rate was for arsenic 5.1 and chromium 6.6, which indicates high contamination (Fig. 3). The average rate for manganese (1.1), nickel (2.5), lead (1.3) and zinc (2.4) indicates an average level of contamination with those elements and low level of pollution for copper (0.8) and cobalt (0.6) (Fig. 3).

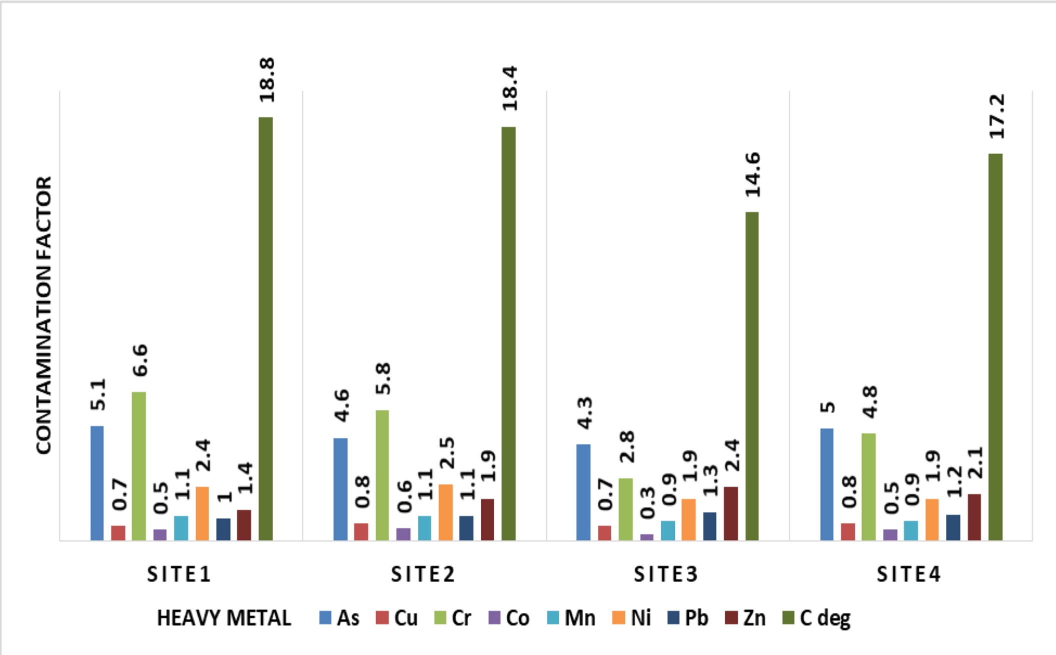

Fig. 3. Average of contamination factor and contamination degree Cdeg of heavy elements in the sediments samples in the different location study.

The degree of pollution of all sediment samples reflects that they are at a high level of pollution, due to agricultural activities such as the use of pesticides, fertilizers, industrial activities, waste of industrial areas that flow into the Diyala River and traffic near the river, (Shen et al., 2019).

Through the application of the geographical accumulation index (Table 9), it was found that the sediments of the Diyala River were not contaminated with the elements under study (copper, cobalt, manganese, nickel, lead, and zinc). Medium contamination with arsenic at a rate of 1.65 and chromium at 1.68 is indicated. Such results are consistent with the study of Agyarko et al. (2014) and Al-Ali (2019), while they are not consistent with the findings of Al-Dabbas et al. (2017).

By applying the pollution load index PLI, it was found that the value of the index was greater than one, indicating the presence of heavy element contamination in the sediment of the study area (Tomlinson et al., 1980) (Table 9).

Table 9. Geographical accumulation index of heavy elements in the sediments of the study area.

Sample locations	Geographical Accumulation Index (I_{geo})								(PLI)*
	As	**Cu**	**Cr**	**Co**	**Mn**	**Ni**	**Pb**	**Zn**	
S(A)1	1.81	- 1.65	1.31	- 1.97	- 0.28	- 0.09	- 1.34	- 0.49	1.2
S(B)1	1.80	- 0.90	2.14	- 1.62	- 0.36	0.82	- 0.25	0.12	1.7
S(C)1	1.64	- 0.96	2.68	- 0.84	- 0.40	0.1	- 0.53	- 0.03	1.9
Average	1.75	- 1.17	2.04	- 1.47	- 0.34	0.61	- 0.70	- 0.13	1.6
S(A)2	1.51	- 0.89	2.75	- 0.82	- 0.38	1.02	- 0.57	0.09	1.9
S(B)2	1.62	- 1.13	0.67	- 1.94	- 0.39	0.38	- 0.67	0	1.3
S(C)2	1.78	- 1.04	1.7	- 1.95	- 0.57	0.7	- 0.35	0.86	1.6
Average	1.63	- 1.02	1.70	- 1.57	- 0.44	0.7	- 0.53	0.31	1.6
S(A)3	1.35	- 1.18	1.11	- 2	- 0.82	0.32	0.07	0.33	1.4
S(B)3	1.83	- 1.02	1.54	- 1.91	- 0.8	0.43	- 0.33	- 0.01	1.2
S(C)3	1.31	- 0.94	1.33	- 3.27	- 0.53	0.12	- 0.33	1.38	1.4
Average	1.49	- 1.04	1.32	- 2.39	0.71	0.29	- 0.19	0.56	1.3
S(A)4	1.95	- 0.99	1.63	- 1.57	- 0.61	0.64	- 0.22	0.17	1.5
S(B)4	1.39	- 0.33	1.52	- 2	- 0.71	- 0.14	- 0.18	1.01	1.5
S(C)4	1.87	- 1	1.94	- 1.04	- 0.54	0.67	- 0.31	0.03	1.7
Average	1.73	- 0.77	1.69	- 1.53	- 0.62	0.39	- 0.23	0.40	1.5

* PLI > 1 Pollution with heavy elements

* PLI < 1 No Pollution with heavy elements (Tomlinson et al.,1980).

4. Conclusions

The concentrations of arsenic, copper, chromium, cobalt, iron, manganese, nickel, lead, and zinc were estimated at four sites within the lower reaches of the Diyala River. Correlation analysis of mean concentrations showed positive correlations between arsenic, chromium, cobalt, iron, nickel, manganese, lead, and zinc, indicating that these heavy elements have buyer sources. The enrichment factor (EF), pollution factor (CF), geographical accumulation index (Igeo), and pollution load index (PLI) were applied to assess pollution. The results reflect high contamination with arsenic to medium contamination with copper, chromium, and nickel. All sites were not contaminated with lead. By applying the degree of pollution, it was found that the sediment is at a high level of pollution due to agricultural activities such as the use of pesticides, fertilizers, industrial activities, waste from industrial areas that flow into the Diyala River, and traffic near the river. The pollution load index shows that the value of the indicator was greater than one, and this indicates the presence of heavy element pollution in the sediments of the Diyala River. Considering all the evaluation criteria, arsenic and chromium are responsible for large contamination by heavy elements.

References

Abdullah, E.J., 2013. Evaluation of surface water quality indices for heavy metals of Diyala River-Iraq. Journal of Natural Sciences Research, 3(8), 63–70.

Agyarko, K., Dartey, E., Kuffour, R., Sarkodie, P., 2014. Assessment of trace elements levels in sediment and water in some artisanal and small-scale mining (ASM) localities in Ghana. Current World Environment Journal, 9(1), 7–16.

Al-Ali, I.A., 2019. Assessing sediment pollution by applying some geochemical indices for Al-Wind River Banks/ east of Iraq. Iraqi Journal of Science, 60(8), 1711–1719.

Al-Dabbas, M.A., Abdullah, M.A., 2020. Assessment of soil pollution in the Ishaqi project area- Salah Al-Dean governorate, Iraq. Iraqi Journal of Science, 61(2), 382–388.

Al-Dabbas, M.A., Maiws, S.O., Kadhim, W.H., 2017. Evaluate the groundwater suitability for irrigation in Dujaila area – Wasit Governorate – middle of Iraq. Iraqi Geological Journal, 50(1), 76–89.

Al-Dabbas, M., Mahdi, K., Al-Khafaji. R., Obayes, K., 2018. Heavy metals characteristics of settled particles of street dust from Diwaniyah City- Qadisiyah Governorate – Southern Iraq, IOP Conf. Series: Journal of Physics: Conf. Series 1003 (2018), 012023.

Al-Jaberi, M.H., Al-Dabbas, M. A., Al-Khafaji, R., 2016. Assessment of heavy metals contamination and sediment quality in Shatt al-Arab River, S Iraq. Iraqi Geological Journal, 39–49(1), 88–97.

Al-Kinani, D.M.A.H., Al-Mukhtar, I.A.A., 2014. Organic content in the sediments of Tigris and Diyala Rivers, South of Baghdad, and its relationship with some environmental factors, benthic invertebrates groups and values of diversity indices. Baghdad Journal of Science. 11(3), 1354-1360.

Al-Musawi, N., 2018. Evaluation water quality of Diyala River in Iraq using Bhargava method. MATEC Web of Conferences, 162(1), 05001.

Al-Sarraj, E.S., Janker, M.H., Al-Rawi, S.M., 2019. Estimation of the Concentrations of some Heavy Metals in Water and Sediments of Tigris River in Mosul City. Al-Rafidain Science Journal, 28(1),1-10.

APHA, 2017. American Public Health Association. Standard methods for the examination of water and wastewater. 23rd ed.

Bhuyan, M.S., Bakar, M.A., Rashed-Un-Nabi, M., Senapathi, V., Chung, S.Y., Islam, M.S., 2019. Monitoring and assessment of heavy metal contamination in surface water and sediment of the Old Brahmaputra River, Bangladesh. Applied Water Science, 9 (5),1-13.

Carver, R. E., 1971. Procedure in Sedimentary Petrology, John Wiley and sons Inc, NewYork, 653.

Diab, W., Toufaily, J., Villieras, F., Koubayssi, B., Mortada, H., Lakis, H., Hamieh, T. 2014. Study of physicochemical properties of colloidal sediments of Litani River in Lebanon. Physics Procedia, 55(1), 251–258.

Göhre, V., Paszkowski, U., 2006. Contribution of the arbuscular mycorrhizal symbiosis to heavy metal phytoremediation. Planta, 223(6), 1115–1122.

Hakanson, L., 1980. An ecological risk index for aquatic pollution control.a sedimentological approach. Water Research, 14(8), 975–1001.

Hamza N.H., 2012. Evaluation Of Water Quality Of Diyala River For Irrigation Purposes. Diyala Journal of Engineering Sciences, 5(2), 82–98.

Hassan, W.F., Al-Badran, B.N.A., Faraj, M.A., 2008. The Geochemical Distribution Of Trace Metals In Shatt Al-Arab River Sediments. Mesopotamian Journal of Marine Science. 23(2),419-436.

Haynes, W.M., Lide, D.R., Bruno, T.J., 2016. CRC handbook of chemistry and physics (97th ed.). Boca Raton, Florida, CRC Press.

Issa, H.M., and Alshatteri, A.H., 2021. Impacts of wastewater discharge from Kalar city on Diyala-Sirwan River water quality, Iraq: Pollution evaluation, health risks of heavy metals contamination. Applied Water Science, 11(4), 1–13.

Issa, M.J., Muslim, R.I., and Al- Obaidi, B.S., 2020. Evaluation of some trace elements pollution in sediments of the Tigris River in Wasit Governorate, Iraq. Baghdad Science Journal, 17(1),9 –22.

Kim, Y, Oh, M., Bang, S., Park, J. 2006. Monitoring Heavy Metal Transport in aquifer based on electrical property measurements. Journal of ASTM International, 3(6), 13330.

Kolawole, T.O., Olatunji, A.S., Jimoh, M.T., Fajemila, O.T., 2018. Heavy metal contamination and ecological risk assessment in soils and sediments of an industrial area in Southwestern Nigeria. Journal of Health and Pollution, 8(19), 180906.

Lenart, A., Wolny-Koładka, K. 2012. The effect of heavy metal concentration and soil ph on the abundance of selected microbial groups within ArcelorMittal Poland Steelworks in Cracow. Bulletin of Environmental Contamination and Toxicology, 90(1), 85–90.

Li, Y., Zhou, H., Gao, B., Xu, D., 2020. Improved enrichment factor model for correcting and predicting the evaluation of heavy metals in sediments. Science of The Total Environment, 755, 142437.

Lindsay, W.L. 1979: Chemical equiliberia of soils. John Wiley and Sons.

Macklin, M.G., Brewer, P.A., Balteanu, D., Coulthard, T.J., Driga, B., Howard, A.J., Zaharia, S., 2003. The long term fate and environmental significance of Contaminant Metals released by the January and March 2000 mining tailings dam failures in Maramureş County, upper Tisa Basin, Romania. Applied Geochemistry, 18(2), 241–257.

Mahmood, R.,Alkhafaji, N., 2017. Distribution of Heavy Metals in Parts of Diyala River (Basin), Iraq. International Journal of Science and Research (IJSR), 6(12), 879-884.

Martin, J., Meybeck, M., 1979. Elemental mass-balance of material carried by major world rivers. Marine Chemistry, 7(3),173-206.

McKeague, J.A., 1978. Manual on Soil Sampling and Methods of Analysis. 2nd Edition, Canadian Society of Soil Science, Ottawa.

Mmolawa, K., Likuku, A., Gaboutloeloe, G. 2011. Assessment of Heavy Metal Pollution in Soils along Roadside Areas in Botswana. African Journal of Environmental Science and Technology, 5(1), 186-196.

Muller, G. 1969. Index of Geoaccumulation in Sediments of the Rhine River. GeoJournal, 2, 108-118.

Pragg, C., Mohammed, F.K., 2018. Pollution Status, ecological risk assessment and source identification of heavy metals in road dust from an industrial estate in Trinidad, West Indies. Chemistry and Ecology, 34(7), 624–639.

Qadoori, A. H., Al-Tawash, B. S. 2021. Assessment of some heavy metals in water and sediments using bio-concentration method of Al-Ma'ail River in al-Kahla'a district, Maysan, southern Iraq. Iraqi Geological Journal, 54(1D), 82-92.

Rahman, M.S., Ahmed, Z., Seefat, S.M., Alam, R., Islam, A.R., Choudhury, T.R., Idris, A.M., 2022. Assessment of heavy metal contamination in sediment at the newly established Tannery Industrial Estate in Bangladesh: A case study. Environmental Chemistry and Ecotoxicology, 4(1), 1–12.

Richards, L.A., 1954. Diagnosis and Improvement of Saline Alkali Soils. Agriculture, Handbook 60. US Department of Agriculture, Washington DC.

Sarkar, S.K., Frančišković-Bilinski, S., Bhattacharya, A., Saha, M., Bilinski, H., 2004. Levels of elements in the surficial estuarine sediments of the Hugli River, northeast India and their environmental implications. Environment international, 30(8), 1089-1098.

Shen, F., Mao, L., Sun, R., Du, J., Tan, Z., Ding, M., 2019. Contamination Evaluation and Source Identification of Heavy Metals in the Sediments from the Lishui River Watershed, Southern China. International Journal of Environmental Research and Public Health, 16(3),1-14.

Sinex, S., Helz, G., 1981. Regional geochemistry of trace elements in Chesapeake Bay sediments. Environmental Geology, 3(6), 315-323.

Singh, S.K., Srivastava, P.K., Singh, D., Han, D., Gautam, S.K., Pandey, A.C., 2015. Modeling groundwater quality over a humid subtropical region using numerical indices, Earth observation datasets, and X-ray diffraction technique: A case study of allahabad district, India. Environmental Geochemistry and Health, 37(1), 157–180.

Suresh, G., Ramasamy, V., Meenakshisundaram, V., Venkatachalapathy, R., Ponnu-samy V., 2011. Influence of mineralogical and heavy metal composition on natural radionuclide contents in the river sediments. Applied Radiation and Isotopes, 69, 1466–1474

Tomlinson, D.L., Wilson, J.G., Harris, C.R., Jeffrey, D.W., 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgoländer Meeresuntersuchungen, 33(1), 566–575.

Tundu, C., Tumbare, M.J., Kileshye Onema, J.M., 2018. Sedimentation and its impacts/effects on river system and reservoir water quality: Case study of Mazowe catchment, Zimbabwe. Proceedings of the International Association of Hydrological Sciences, 377(1), 57–66.

United States Environmental Protection Agency (USEPA) 1977 Guidelines for the Pollutional Classification of Great Lake Harbor Sediments. Region 5, USEPA, Chicago, IL.

Wedepohl, H. 1995. The composition of the continental crust. Geochimicaet Cosmochimica Acta, 59(7), 1217–1239.

Wojciechowska, E., Nawrot, N., Walkusz-Miotk, J., Matej-Łukowicz, K, Pazdro, K. 2019. Heavy Metals in Sediments of Urban Streams: Contamination and Health Risk Assessment of Influencing Factors. Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Poland. Sustainability, 11(563), 14.

Yang, W., Cao, Z., Zhang, H., Lang, Y. 2021. A national wide evaluation of heavy metals pollution in surface sediments from different marginal seas along China mainland. Regional Studies in Marine Science, 42(1), 101637.

Zhang, J., Liu, C.L. 2002.Riverine composition and estuarine geochemistry of particulate metals in China—weathering features, anthropogenic impact and chemical fluxes. Estuarine, coastal and shelf science, Elsevier Science Ltd., 54(6), 1051-1070.