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Environmental Assessment of Sediment Quality for the Main Outfall Drain and Al-Sanaf Marsh

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ABSTRACT

This study evaluated the sediment quality of the Main Outfall Drain River in Thi-qar Government by measuring (Mn, Ni, Pb, Fe, Cr, Zn, Cd and Cu) in the sediments. Samples were collected at 4 locations between the summer of 2021 and the winter of 2022, and the results revealed that the heavy metal dominance in the Main Outfall Drain and Al-Sanaf Marsh was in the order of Fe> Mn> Ni> Zn> Cr> Pb>Cu>Cd. Among these sedimentary contaminants, Fe has the highest level in sediments. Two indices were used: sediment quality criteria (QSm) and pollution index (PI). All sites were in the third class of QSm (a possible hazard for aquatic life) because QSm> 0.5. The lowest value is recorded in site 4, and the highest value is located in site 3. The results of PI of Zn and Cu show no effected by pollution to slightly affected in all sites, Cr exhibits the same pattern as Zn and Cu except for site 3 was moderately affected in winter, while Pb caused moderate pollution effect in all sites, except site 2 and site 3 which were slightly affected in winter. Mn, Cd and Fe were seriously affected by pollution in all sites. Pollution index values of most metals (except Fe and Cr) were higher in summer than in winter, probably due to the observed dilution of the metals with anthropogenic origin by rain, leading to lower values in winter. At the same time, Fe and Cr were higher in winter than in summer due to being mostly of terrestrial origin, derived from runoff of the nearby soil by rain. The results show that the sediments of the main outfall drain suffer from large quantities of heavy metals, mainly from site 3, which may be due to receiving industrial effluent, sewage and irrigation water from the governorates through which it passes.

Keywords: pollution indices, sediment quality, river, heavy metal.

INTRODUCTION

Rivers serve a set of functions for humans and the ecosystem, such as water source, ecological habitat, ecotourism and aquaculture (Islam, 2021). The growth of many developing states hinges on industrialization, agriculture, urbanization, and extractive processes. Nevertheless, most of the waste and the chemical compounds discharged to aquatic body are related to these processes, which lead to degrade the water quality of rivers (Emenike et al., 2020). Industrialization and urbanization near river basins have led to more stress on these rivers, indicating deterioration of environmental health (Mishra et al., 2018).

Rivers have been threatened by many sources of contaminants but one of the most hazardous contaminants involves heavy metals in the aquatic environment (Liu et al., 2020). Heavy metals in rivers and other waterbodies are widespread environmental contaminants and due to their bioavailability, toxicity, carcinogenicity, bioaccumulation potentials and non-biodegradability, which are global concerns (Yuan et al., 2020). The elements like cadmium (Cd), lead (Pb), and nickel (Ni) have no biological functions (non-essential metals) and may enter the freshwater through natural processes and anthropogenic activities, these toxicants occur as a result of human activities, especially agricultural, domestic use of these elements and industrial production (Mitra et al., 2022). In turn, the metals (Cu), iron (Fe), chromium (Cr), manganese (Mn), and zinc (Zn) are known as the essential nutrients (Micronutrients) for enzymatic activity in biological systems, but still at high rates these metals can be toxic (Bawa-Allah, 2023). Although concentrations of heavy metals have been recorded in most surface and ground water in Iraq and these metals have a high toxicity risk to aquatic ecosystem health (Ayman & Balsam, 2021; Al-Sulttani, et al., 2022; Nashaat & Al-Bahathy, 2022; Kaizal et al., 2023, Hasham & Ramal, 2022, Al-Bahathy et al., 2023). As the poorly-bound fractions of heavy metals are held in surface sediments by relatively weak forces, it is therefore very important to calculate the quantity of heavy metals in sediments to evaluate the toxicity of heavy metals. Several indices have been used by researchers to assess the environmental contamination in water and sediment from the aquatic environment (Noor, et al., 2022; Al-Janabi, et al, 2019; Maktoof, et al., 2020; Al-Bahathy & Nashaat 2021; Majeed, et al, 2021; Murad et al., 2023). In this study, two pollution indices were used; pollution index (PI) and sediment quality criteria (QSm) and both were considered good mathematical tools to evaluate and measure the natural status of aquatic systems anywhere because they depend on the objective values that allow determining how much the observed values deviate from the objective values (Liu, et al., 2023). PI shows the effect of each metal individually, while MI shows the combined effect of all metals.

The main goal of this study was to determine the sources of heavy metals in sediments of the Main Outfall Drain and Al-Sanaf Marsh which is one of Southern Marsh in Iraq, in addition to evaluating the toxicity of heavy metals in the sedimentary part of the river.

MATERIAL AND METHODS

Study area

Main Outfall Drain is a river that the Iraqi government created in 1992 and uses primarily to dump agricultural effluents from both sides in the middle and southern regions of Iraq, as well as to discharge industrial waste and transport. It stretches over approximately 565 kilometers from Al-Shaklawiya in Baghdad in the north to Khor Al-Zubair in the south (Maktoof, et al., 2014).

The south sector (study area) of MOD, which is divided into three sectors (North, Mid, and South), stretches for around 165 km from the end of the mid sector to Shatt Al-Basarah in the south. In this sector, the average annual water discharge is 220 m^3/sec. This sector had a new branch built with a 7 km length that fed into the marshes south of Al-Nassiriya city (Maktoof, et al., 2014).

Site 1 (St.1) was situated near Al-Holandee Bridge and on the main carriageway in the center of Al-Nassiriya city (31° 4'27.87"N 46°16'53.88"E). Site 2 (St.2) was 20 km from the first site (30°58'38.14"N 46°20'27.82"E). Site 3 (St.3) was the start of the new branch in (branching area to marshes) (30°47'29.27"N 46°23'27.06"E) and Site 4 (St.4) was at the Al-Sanaf Marsh (30°50'16.03"N 46°26'43.82"E). Iraq has two main seasons, winter and summer; it is characterized by an arid to semi-arid climate with a cold winter and a dry, hot summer, low humidity, as well as low precipitation (Hussein et al., 2019). Recent studies in Iraq classify the Iraqi climate into dry and wet seasons, referring to cold and dry seasons (Al-Ani et al., 2019; Aljanabi et al., 2023; Jabar & Hassan, 2022), so this study covered the dominant seasons (summer and winter) to show the variation in water quality and quantity.

Three samples were taken from each site (mix sample) two from the side and one from the middle, the heavy metals chosen to discover the sediment quality in the studied area are: Mn, Ni, Pb, Fe, Cr, Zn, Cd, Cu. The measured concentration was compared against interim freshwater sediment quality guidelines ISQG for sediment (CCME, 2001) as shown in Table 1.

Indices

Sediment quality criteria

The quality criteria are beneficial as they permit a compelling choice of the sediment toxicity hazard quickly. It depends on the standard values of each factor and the observed values

$$Q_{si} = \frac{C_{mi}}{SQC_i} \quad (1)$$

$$Q_{sm} = \sum Q_{si}/n \quad (2)$$

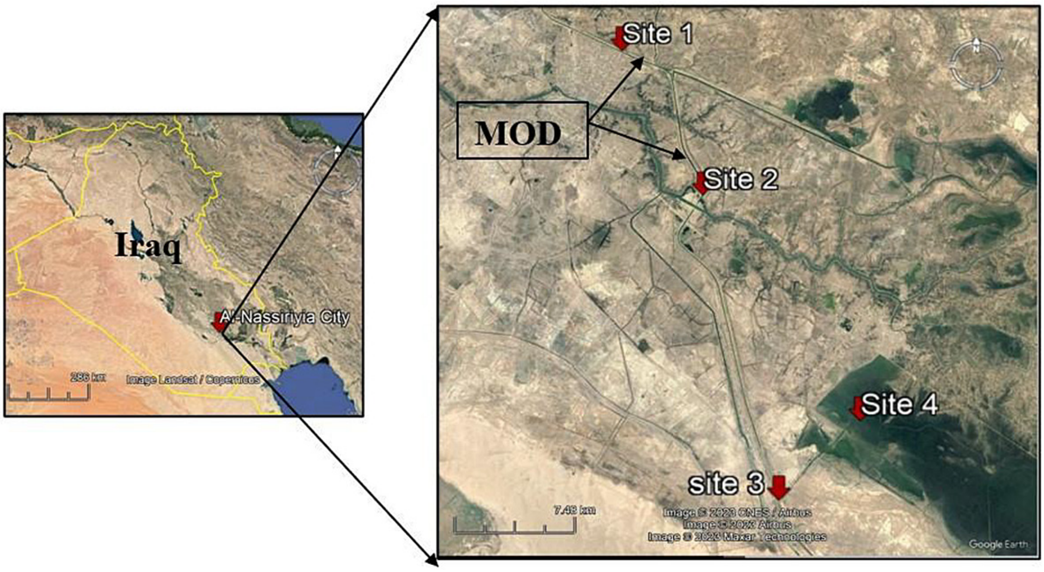

Figure 1. The study area

Table 1. Sediment quality guidelines ISQG (mg/kg)

Mn	Ni	Pb	Fe	Cr	Zn	Cd	Cu
30	45	35	30	37.3	123	0.6	37.7

where: $Q_{Sm} < 0.1$ – toxicity risk is negligible; $0.1 < Q_{Sm} < 0.5$ – the risk is low, but the non-hazardous sediments must be checked; $Q_{Sm} > 0.5$ – risk is non-negligible, and it is a possible hazard for aquatic life.

Pollution index

The pollution index (PI) is a special tool that could be used to evaluate the load of water pollution levels. The concentrations of heavy metals are categorized into 5 classes: 1 (PI <1 demonstrates "no effect", 2) 1<PI<2 is classified as "slightly affected", 3) 2<PI<3 is determined as "moderately affected", 4) 3<PI<5 is classified as "strongly affected" and 5) PI >5 is classified as "seriously affected". PI is based on the following equation (Eq. 1) according to [23].

$$PI = \frac{\sqrt{[\frac{Ci}{Si}]^2_{max} + [\frac{Ci}{Si}]^2_{min}}}{2} \quad (3)$$

where: Ci – refers to the concentration of elements in the sample, Si – refer to national water quality criteria for the metal level.

Statistical analysis

The data was handled using the SPSS (ver. 26) to calculate the descriptive data and Hierarchical.

RESULTS AND DISCUSSION

Heavy metal concentrations in sediment

Table 2 shows that manganese concentration in sediment was the highest in site 2 at the summer season with a mean concentration (148.43 mg/kg), while in winter, the same site (site 1) had the lowest concentration (27.04 mg/kg). Nickel concentration in sediment was highest in site 2 during the summer season with a mean concentration of (60.61 mg/kg). Site 3 had the lowest concentration of nickel (9.24 mg/kg) in summer in the study area. Lead concentration in sediment was highest in site 4 during the summer season with a mean concentration of (38.8 mg/kg). In turn, Site 3 had the lowest concentration of lead (10.05 mg/kg) in summer. Iron concentration in sediment was higher in site 2 during the winter season with a mean concentration (466.58 mg/kg). Site 3 had the lowest concentration of iron (92.83±5383.51 mg/kg) in summer. Chromium concentration in sediment was higher in site 3 during the winter season with a mean concentration of (48.96±97.73 mg/kg). Conversely, site 3 had the lowest concentration of chromium (2.05 mg/kg) in summer. Zinc concentration in sediment was higher in site 3 during the summer season

Table 2. Heavy metal concentrations in sediment samples in mg/kg (mean and standard deviation)

Metals	Site 1		Site 2		Site 3		Site 4	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Mn	67.24±684.7	27.04±639.27	148.43±688.16	46.88±613.19	58.55±650.65	9.36±650.45	87.52±618.58	45.41±550.63
Ni	10.8±231.59	20.3±197.5	60.61±222.41	28.82±180.91	9.24±224.73	13.72±202.18	28.76±228.24	32.44±173.58
Pb	17.16±103.28	19.88±86.06	18.03±114.78	24.91±95.65	10.05±113.38	21.87±94.48	38.8±123.08	26.25±102.56
Fe	106.87±5400.7	448.69±6172.24	209.23±5300.29	466.58±6085.43	92.83±5383.51	461.44±6180.84	149.31±5273.93	327.55±5836.31
Cr	15.05	41.71±84.48	7.16±25.4	44.89±102.7	2.05±13.88	48.96±97.73	5.8±16.53	43.09±90.54
Zn	3.32±136.89	12.64±116.2	42±174.51	22.28±147.44	52.62±137.12	21.81±130.54	19.75±147.71	24.46±108.39
Cd	0.36±14.24	4.6±6.76	0.46±13.84	3.58±8	1.7±14.89	3.84±8.35	2.61±14.01	3.46±8.26
Cu	3.4±91.33	35.16±30.44	10.63±85.93	33.23±28.64	2.16±88.55	34.08±29.52	20.41±88.8	34.3±29.6

with a mean concentration of (52.62±137.12 mg/kg). In turn, site 1 had the lowest concentration of zinc (3.32 mg/kg) in summer in the study area. For cadmium concentration in sediment, site 1 recorded the high and low values during winter and summer (4.6 mg/kg) and (0.36 mg/kg), respectively. Copper concentration in sediment was the highest in site 1 during the winter season, with a mean concentration of (35.16 mg/kg). Site 3 had the lowest concentration of copper (2.16 mg/kg) in summer. Heavy metal dominance in the Main Outfall Drain and Al-Sanaf Marsh was in the order of Fe> Mn> Ni> Zn> Cr> Pb>Cu> Cd. Among these sedimentary contaminants, Fe has the highest level in sediments as a result of industrial wastewater from smelting factories in the study area, this result agreed with Shahmoradi *et al.,* (2020) who studied the Aqyazi River in Iran.

Hierarchical cluster analysis

Cluster analysis (CA) was used to recognize the cluster and measure the distance; objects with low similarity will be sorted into various clusters, whilst objects with high similarity will be clustered in the same cluster (Warsito et al., 2021). In this study, CA was applied to identify distinct classes in the heavy metal data that could illustrate how the river's path through the study area affects the metal concentrations. By using Ward's approach (Squared Euclidean Distance) as a similarity measure, the cluster analysis was performed on the data. The results of cluster analysis for water parameters are illustrated in Figure 2. The first cluster was formed by pairing sites 3 and 4, and the similarity between them was almost the same and may indicate the source of heavy metals is the same. Sites 1 and 2 were paired

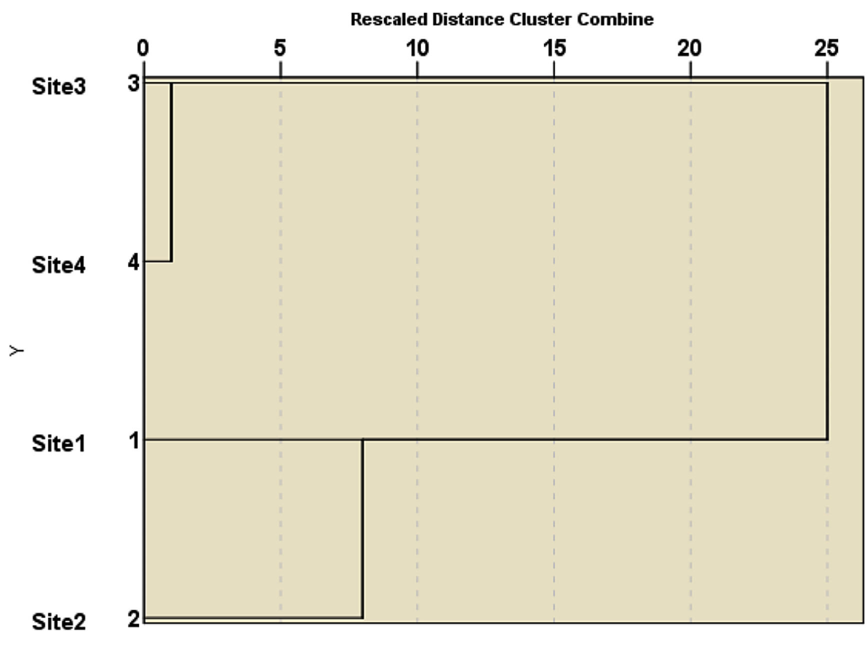

Figure 2. Dendrogram of sampling sites for all period study

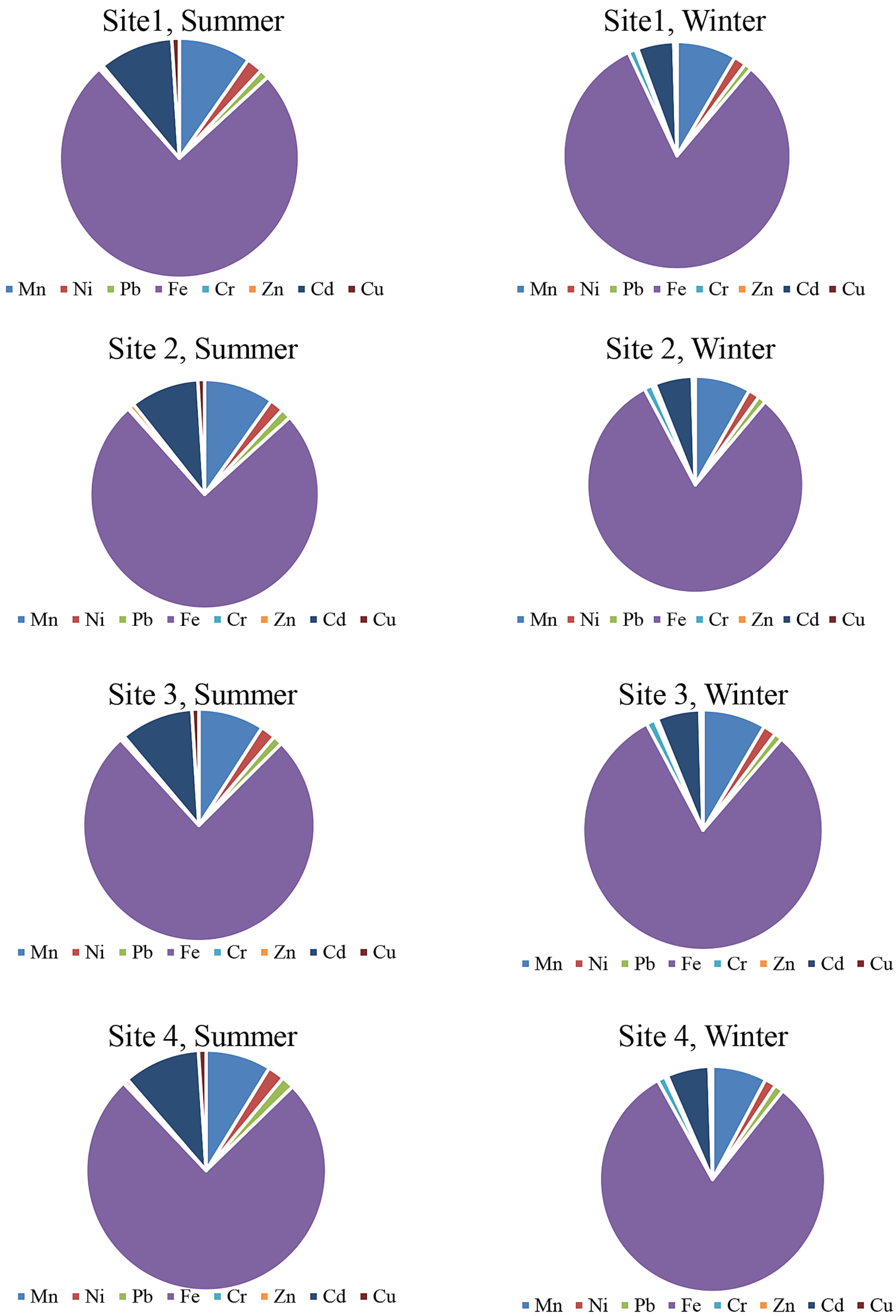

Figure 3. Pollution index of heavy metals in the study area

after a distance from the first cluster and formed the second cluster, which also indicates the exact source of heavy metals, but with some differences which relate to the nature of these two sites located inside of the city, the same conclusion was applied for the first cluster that includes site 3 and 4, where site 3 represented the branching area to marshes and site 4 was the marsh itself. The first cluster (sites 1 and 2) was separated from the second cluster (sites 3 and 4); this means that there is a clear difference in the source of heavy in the studied area and that the water entering the river from the center of the

Al-Nassiriya city is affected in varying degrees by the activity of the city, including the discharge of Agricultural and Industrial runoff or urban city sewage (Maktoof et al., 2020).

Pollution indices

Table 3 shows the mean quality in sediment (QSm) of the Main Outfall Drain for the four sites in summer were 29.70, 29.28, 29.62, and 28.92, respectively. Conversely, in winter, the mean values were 31.08, 30.93, 31.58 and 29.61, respectively. All sites were in the third class of QSm (a possible hazard for aquatic life) because QSm> 0.5. The lowest value is recorded in site 4 and the highest value is located in site 3. Another index was used to determine the degree of pollution by heavy metal in the sediment of the Main Outfall Drain; the results of PI in Table 4 indicate that the sediment results of Zn and Cu show no effects by pollution to slightly affected in all sites, Cr exhibits same pattern to Zn and Cu except site 3 which was moderately effected at winter, while Pb caused moderate effect in all sites except site 2 and site 3 were slightly affected at winter. Pollution in all sites was seriously affected by Mn, Cd and Fe (Figure 3). The results from PI depend on individual calculations for heavy metals. PI ratings are divided into five classes, which is highly useful for identifying the environmental components that are the most curial heavy (Maktoof et al., 2020). The pollution index values of most metals (except Fe and Cr) were higher in summer than in winter, probably due to the observed dilution of the metals with anthropogenic origin by rain leading to lower values in winter (Dibofori-Orji, et al., 2019). Similarly, Reyes-Marquez et al., (2022) recorded higher values in summer when studying the Gulf of Mexico. In contrast, Sugumaran, et al., (2022) observed lower values of pollution in summer compared with winter in the study of the Kelantan River, Malaysia.

In turn, Fe and Cr were higher in winter than in summer, and may return to their mostly terrestrial origin, derived from runoff of the nearby soil by rain (El-Sorogy, et al., 2020) Generally, according to Tables 1, 2 and 3, the sediment of the main outfall drain suffers from the presence of large quantities of contaminants, mainly from site 3, which makes it an unhealthy environment for aquatic life because the sediment is always considered as the sink for a pollutant and can be released from sediment any time by the effect of physic-chemical and hydrological factors, and the origin of these pollutants may be from industrial effluent (texture, melting, oil and food factories near the drain) and sewage from governorates through which it passes. Some of the farms surrounding the drain are irrigated with polluted water, and the sediments of its

Table 3. Sediment quality criteria of heavy metals for the study area (QSm)

Site 1 (QSm)		Site 2 (QSm)		Site 3 (QSm)		Site 4 (QSm)	
Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
29.70	31.08	29.28	30.93	29.62	31.58	28.92	29.61
Possible hazard for aquatic life	Possible hazard for aquatic life	Possible hazard for aquatic life	Possible hazard for aquatic life	Possible hazard for aquatic life	Possible hazard for aquatic life	Possible hazard for aquatic life	Possible hazard for aquatic life

Table 4. The pollution index of heavy metals for the study area

Metals	Site 1 (PI)		Site 2 (PI)		Site 3 (PI)		Site 4 (PI)	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Mn	16.44	15.16	16.31	14.55	15.35	15.33	14.33	13.14
Ni	3.71	3.13	3.29	2.99	3.52	3.15	3.67	2.71
Pb	2.13	1.77	2.44	2.05	2.27	1.95	2.80	2.19
Fe	127.01	146.57	124.37	142.84	127.33	146.15	122.73	137.25
Cr	0.28	1.87	0.49	2.13	0.26	2.11	0.32	1.93
Zn	0.78	0.66	1.11	0.91	0.82	0.78	0.85	0.65
Cd	16.88	9.21	16.06	9.83	17.08	10.35	16.81	10.19
Cu	1.719	0.82	1.58	0.81	1.65	0.78	1.68	0.83

banks are also used for fertilization (Nour et al., 2021). These site-specific high values measured in the main outfall drain are similar to the high values derived by Maktoof, et al. (2020) and Ikwu River in Nigeria by Anyanwu et al. (2022).

CONCLUSIONS

Iraq has experienced water scarcity for the past 20 years, which has caused worse water quality for the Tigris and Euphrates rivers. As an outcome, this study showed that the sediment quality in the considered area was low. The results give suitable information about the possible factor that may influence the quality status of sediments for the studied water body. Heavy metal dominance in the Main Outfall Drain and Al-Sanaf Marsh was in the order of Fe> Mn> Ni> Zn> Cr> Pb> Cu> Cd. Among these sedimentary contaminants, Fe has the highest level in sediments as a result of industrial wastewater from smelting factories in the study area. All sites were in the third class of QSm (a possible hazard for aquatic life) because QSm> 0.5. The lowest value is recorded in site 4 and the highest value is located in site 3. The results of PI of Zn and Cu show no effect by pollution to slightly affected in all sites, Cr exhibits the same pattern as Zn and Cu, except for site 3 which was moderately affected in winter, while Pb caused a moderate effect in all sites except site 2 and site 3 which were slightly affected in winter. Mn, Cd and Fe were seriously affected by pollution in all sites. Analytical results revealed pollution index values of most metals (except Fe and Cr) were higher in summer than in winter probably due to observed dilution of the metals with anthropogenic origin by rain leading to lower values in winter. In turn, Fe and Cr were higher in winter than in summer because of their mainly terrestrial origin, which was produced from rainwater that ran off onto the surrounding soil. The findings demonstrate that the main outfall drain is generally adversely affected by the presence of higher levels of heavy metals. particularly site 3 as a result of receiving industrial effluent, sewage and irrigation water from several governorates through which it passes.

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