MARSH BULLETIN
EISSN 2957-9848

Marsh Bulletin Volume 21 Issue 1 (April 2026): 14-27

Multi-indix assessment of heavy metal contamination in sediments of Aquatic Environments in southern Iraq

Farah AmerAlsaadi [1], Rafid A. Al-Zabad[2], Idrees A. Al-Bahathy[3]

Department Applied Geology, college of science, university of Babylon. Babylon, Iraq
General Directorate of Education, Basrah, lraq.
Department water resources, College of Engineering, AL-Qasim Green University, Babylon 51031, Iraq

Abstract

This study was conducted to evaluate the sediment quality of the Main Outfall Drain (MOD) River and Al-Sanaf marsh in southern Iraq by measuring (Mn^{+2}, Ni^{+2}, Pb^{+2}, Fe^{+2}, Cr^{+3}, Zn^{+2}, Cd^{+2}, and Cu^{+2}) and application some indices like Contamination factor (Cf), Modified contamination degree (mCd), Metal index (MI) in the sediments. Sediment samples were collected from 3 locations in 2022. The results revealed that the heavy metal concentrations in the MOD and Al-Sanaf Marsh were Fe^{+2} (5324.90 $mg.kg^{-1}$), Mn^{+2} (663.81 $mg.kg^{-1}$), Ni^{+2} (227.41 $mg.kg^{-1}$), Zn^{+2} (153.03 $mg.kg^{-1}$), Pb^{+2} (113.70 $mg.kg^{-1}$), Cu^{+2} (88.68 $mg.kg^{-1}$), Cr^{+3} (18.99 $mg.kg^{-1}$) and Cd^{+2} (14.02 $mg.kg^{-1}$). $Fe^{+2\ has}$ the highest level in sediments. The average Cf values were in sequence: Fe> Cd > Mn> Ni >Pb>Cu> Zn>Cr. The values of the degree of contamination of the heavy metals showed that all the sites had a high degree of contamination, and mCd was over 3. The altered contamination degree (mCd) of Cr and Zn^{+2} was less than 1.5, and that is why the contamination of the sediment is insignificant. On the contrary, Cu^{+2} and Pb had moderate contamination, Ni^{+2} had extreme contamination, and both Mn^{+2} and Cd had an extremely high degree of contamination in the sediments. Fe^{+2} registered a supreme level of pollution. High concentration of Fe^{+2} in the sediments could be related to the extreme weathering and erosion of the parent soil, where most of the Fe^{+2} is obtained and then carried by the streams. The spatial values of modified contamination degree (mCd) for heavy metals revealed that the upper reaches of the MOD (site1 and site2) had the higher metal content in sediments which were located near Al-Nassiriya City, this may be closely related to the concentration of industries near the MOD Basin near the city, in contrast, the site 3 (in Al-Sanaf marsh) was less influential than these sources. According to metal index findings, all selected sites fell into the “threshold of warning” category (MI > 1). The metal content in the aquatic environment in the southern part of Iraq is significantly high, which was related to the more effluents from agricultural, residential, and industrial activities, and it was discharged along the main outfall drain basin. The results provide invaluable information to policy-makers as they allow the development and implementation of evidence-based sustainable management measures that will reduce the likelihood of further trace-metal contamination of the studied location in the future.

Keywards: Heavy metals; water pollution; Contamination factor; Modified contamination degree (mCd); Metal index; southern Iraq

Received 1/2/ 2026 Accepted 4/ 3/2026 Published 1 / 4 /2026

Introduction

Water pollution and sediments of rivers due to heavy metals represent an unfolding universal problem at risk of destruction of the aquatic ecosystems (Han et al., 2024). Heavy metals are a group of enduring pollutants whose persistence in the media and attraction to trophic levels create severe health risks to the human and animal populations (Qin & Tao, 2022). The toxicity of metals is very strong, including nickel, chromium, lead, arsenic, zinc, cadmium, and others (Jomova et al., 2025).

Heavy metal low concentrations can be caused by natural changes, which include weathering of parent rocks and soil matrix, volcanic eruptions, biological emissions, and wind transportation of soil particulates (Masindi & Muedi, 2018). In the last few decades, the type of anthropogenic activities, which include the release of untreated domestic and industrial effluents, agricultural and urban stormwater system runoff, mining processes, and leachate collected by landfills, have increasingly become important contributors of trace metals, as well as other forms of contaminants (Tang et al., 2023).

Sediment composition, suspended sediment composition, and water chemistry control the behavior of metals in natural water environments. Dynamic speciation processes that include dissolution, precipitation, sorption, and complexation occur to the heavy metals in the course of transport, thus affecting their behavior and bioavailability (Batley & Campbell, 2022). The adsorptive sink may be provided by sediments that may hold as much as 30 based on 98 of the total metal that goes into the river system (Mazilamani et al., 2020). Moreover, sediments can also act as probable non-point sources of contamination, since coated metals could be discharged into underlying water at the time of resuspension, alteration of pH or redox, or organic breakdown (Astatkie et al., 2021). These processes increase trace metal bioavailability, as well as may cause damaging effects to aquatic organisms.

The Main Outfall River is also considered as one of the most contaminated rivers in the country because of the release of agricultural and industrial effluents (Khalaf et al., 2025). Globally, sediments are considered to be the final sink of environmental pollutants, thus, their study is an effective method of monitoring heavy metal pollution, anticipating the effects they have on marine and terrestrial ecosystems, estimating environmental safety limits in comparison with local biota, and prescribing suitable remedial actions (Jeong et al., 2022).

The indices of sediment pollution, which are Contamination Factor (CF), the modified contamination degree and metal index have been developed to combine several variables of sediment quality into a single measure to determine the extent of anthropogenic inputs of the sediment and the intensity of the anthropogenic contaminants level, these pollution indices are assumed to be a convenient and easy way to assess the degree of anthropogenic pollution of the sediment and the degree of the strength of anthropogenic contaminants in the sediment (Astatkie et al., 2022).

The use of metal pollution indices in research shows that there is an increasing concern of the degradation caused by the elemental contamination. New studies in Iraq are centered on water and sediment quality, particularly in urbanized and industrialized regions, such as the Tigris, Euphrates Rivers, Main Outfall, and marshes (Najam & Wais, 2022; Salman et al., 2023; Khalaf et al., 2025; Al-Bahathy et al., 2024; Al-Janabi et al., 2025; Al-Bahathy & Nashaat, 2025). The majority of these research focuses on sediment metal pollution, research that is not considered adequate in safeguarding the health of aquatic systems. Hence, a sharp necessity to monitor the presence of trace metal pollution in surface water and sediments on a regular basis to aid in the creation of effective water-management practices is present. It is vital to note that the distribution of metals at various stages in freshwater ecosystems is vital in the ecological effects of anthropogenic sources of heavy metals in aquatic environments. Therefore, it is of the utmost importance to learn deeper about the main processes that should take place in the heavy metals in sediments and then determine the health of the entire ecosystem. The aims of the study are aimed at the following: (1) accurately evaluate the accumulation of these metals; and (2) determine the contributions of various sources to the metal content in the river. The results will be used to easily determine the status of river pollution and consequently, come up with holistic strategies for preventing river pollution.

Method and Materials

Study Area

The Main Outfall Drain is an artificial river that the Iraqi administration created with the main purpose of directing agricultural discharges of the middle and southern parts of the country along with the passage of industrial discharges. It stretches about 565km, starting at Al-Saklawiya in Baghdad city in the north and ending at Khor Al-Zubair in the southern part of Iraq. The southern area which is the area of study of the MOD has been further divided into three zones, namely North, Mid, and South with an approximate length of 165 kilometers, which is the length of the Mid sector to the south region of Shatt Al-Basarah (Maktoof et al., 2014). In the area of this research, the position of the two sites (Site 1 and Site 2) is on the Main Outfall Drain, and the third site (Site 3) is in the Al-Sanaf marsh (Table 1 and Figure 1).

Table (1): location of sampling sites

Sites	code	Location	GPS
Site 1	St.1	in the center of Al-Nassiriya city	31°4'50.31"N/ 46°16'4.07"E
Site 2	St.2	22 km from the first site	30°55'52.89"N/ 46°20'35.12"E
Site 3	St.3	at the A-Sanaf Marsh	30°50'27.71"N/ 46°26'45.11"E

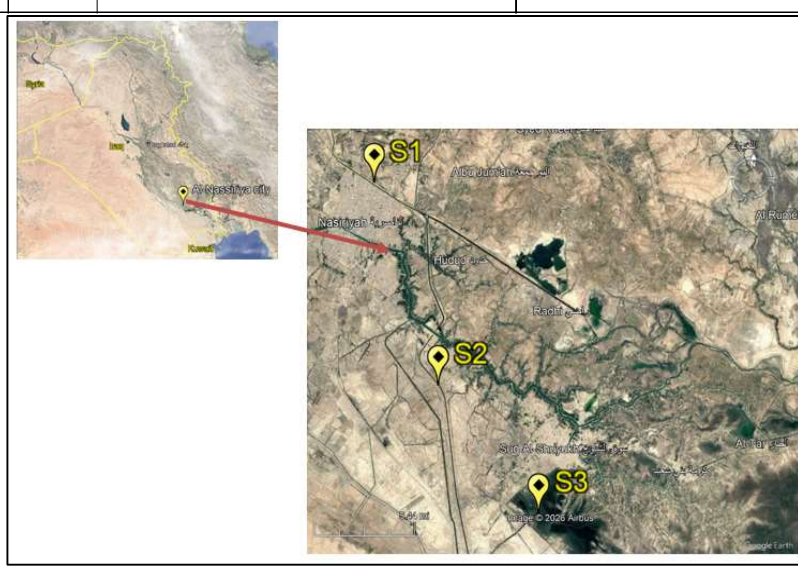

Figure 1: map of the study area (Google Earth Pro, 2026).

Sampling and sample preparation of HEMs

A Van Veen grab sampler was used to collect samples in 2022. The sediments in the laboratory were dry at 105 0 C until they obtained a constant weight, eliminating all the moisture. The sieving with 200 -m mesh was done subsequently to have a homogeneous distribution of the particles. The atomic concentrations of heavy-metals, that is, Mn^{+2}, Ni^{+2}, Pb^{+2}, Fe^{+2}, Cr^{+3}, Zn^{+2}, Cd^{+2}, and Cu^{+2}, were measured on the Shimadzu AAS 6300 atomic absorption spectrophotometer following the Standard Methods (APHA, 2001). The resultant concentrations were compared with the Sediment Quality Guidelines (SQG) (CCME, 2001), as shown in Table 2.

Table (2): The Sediment quality guidelines (ISQG)

Heavy metals ($mg.kg^{-1}$)	Sediment quality guidelines (ISQG)
Manganese (Mn^{+2})	30
Nickel (Ni^{+2})	45
Lead (Pb^{+2})	35
Iron (Fe^{+2})	30
Chromium (Cr^{+3})	30
Zinc (Zn^{+2})	37.3
Cadmium (Cd^{+2})	123
Copper (Cu^{+2})	0.6

Quantification of Pollution

The distribution of heavy metals in sedimentary deposits should also be evaluated to determine the level of environmental pollution. In this research, the contamination factor (CF) was used to evaluate the occurrence and level of heavy metal pollutants. These were used as indices to determine the risky level that could be a possible threat to the biological population in the aquatic life of the study area.

The background concentration, referred to as C background is the concentration of the metal of interest in the sediment before anthropogenic input. According to Hakanson (1980): $CF < 1$ represent low contamination; $1 < CF < 3$ represent moderate contamination; $3 < CF < 6$ represent considerable contamination; and $CF > 6$ represent very high contamination.

Modified contamination degree (mCd)

This index was used to estimate the degree of contamination by the formula derived by Abrahim and Parker (2008).

$$mCd = \sum_{i=1}^{i=n} CF \quad .2$$

where n represents the number of the examined elements, i = ith element, and CF = contamination factor.

For the classification of mCd.

-If mCd less than 1.5 classify from nil to a very low degree of contamination.

-If mCd was between 1.5 and 2, classify a low degree of contamination.

Contamination factor (Cf)

The ratio of the concentration of each metal in the sediment divided by the background concentration of the same metal is termed as the contaminant factor (Cf) based on the equation offered by Hakanson (1980).

$$CF = \frac{\text{Concentration measured for an element x}}{\text{C background}} \quad .1$$

-If mCd was between 2 and 4, classify a moderate degree of contamination.
- If mCd was between 4 and 8, classify a high degree of contamination.
- If mCd was between 8 and 16, classify a very high degree of contamination
- If mCd was between 16 and 32, classify an extremely high degree of contamination.
- If mCd was between mCd and 32, classify an ultra-high degree of contamination.

Metal Index

The index used in calculating the total of all metal quality in each site was computed using Equation 1 (Aljanabi et al., 2022).

$$MI = \sum_{i=1}^{n} \frac{C_i}{(MAC)} \quad .3$$

In this case, Ci is the average concentration of each element, MAC is the maximum permissible concentration by the Canadian sediment quality guidelines (2001), and an MI value above 1 is a warning level (Aljanabi et al., 2022).

Results and Discussion

The mean concentration of the heavy metals in sediments

Figure 2 shows the average contents of different metals in sediments of Mainfall and Al-sanaf marsh, i.e., Fe^{+2} (5324.90 $mg.kg^{-1}$), Mn^{+2} (663.81 $mg.kg^{-1}$), Ni^{+2} (227.41$mg.kg^{-1}$), Zn^{+2} (153.03 $mg.kg^{-1}$), Pb^{+2} (113.70 $mg.kg^{-1}$), Cu^{+2} (88.68 $mg.kg^{-1}$), Cr^{+3} (18.99 $mg.kg^{-1}$), and Cd^{+2} (14.02 $mg.kg^{-1)}$. These values are higher than the ones reported by Al-Asadi and Al-Kafari (2022) of the Euphrates River in the Al-Diwaniyah governorate, Iraq, and those reported by Sojka and Jaskuła (2022) of the river sediments in Poland. On the other hand, the mean of the metals in this study is less than that recorded by Altahaan and Dobslaw (2024) of the Mosul Tigris River in Iraq and Jaskuła and Sojka (2022) of the two largest rivers of Poland. In this regard, one can assume that the key contributors to metals in the examined sites are mainly natural ones, with large anthropogenic input. The high level of Fe in the sediments could be explained by strong weathering and erosion of parent material containing a large part of Fe_2O_3, where the majority of Fe is obtained and carried away through the fluvial system (Kachoueiyan et al., 2024).

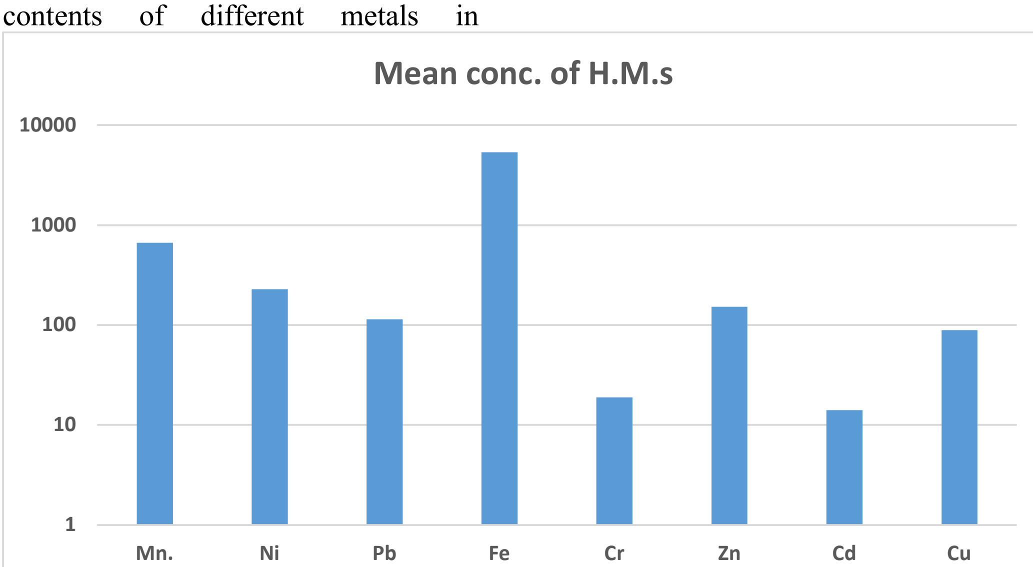

Figure 2: The mean concentrations of some metals in sediments of the study area

Contamination Factor and Modified contamination degree (mCd)

Figure (3) shows the average Cf values, in the following order: Fe> Cd > Mn> Ni >Pb>Cu> Zn>Cr (Figur.3). The degree of contamination of heavy metals revealed that all sites were highly contaminated with cadmium levels surpassing a mark of 3. These findings are in line with the conclusions made by Devanesan et al. (2017) where indicated moderate to high levels of contamination factors. Conversely, Tamanna et al. (2023) discovered that the pollution in the Upper Banar River was low. The indices of contamination factor therefore, can be attributed to the anthropogenic and agricultural processes that are close to the banks of the MOD River and the Al-Sanaf Marsh, which are observed to have increased the indices of contamination factor.

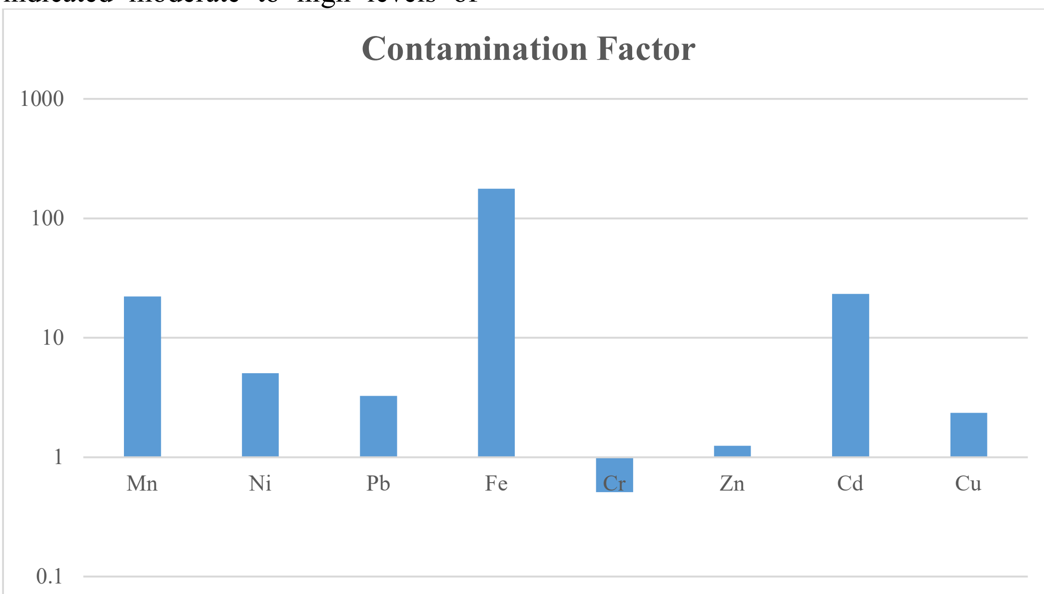

Figure 3: Contamination factor for the heavy metals in the study area

The modified contamination degree (mCd) of chromium (Cr) and zinc (Zn) based on the present study (Figure 4) was below 1.5 which implied that there was no significant contamination of the sediments. There was a moderate level of contamination of copper (Cu) and lead (Pb), high level of contamination of nickel (Ni), and extremely high level of contamination of manganese (Mn) and cadmium (Cd). Fe documented a level of contamination of ultra-high nature. Higher Fe levels in the sediments can be explained by the high rate of weathering and erosion of the parent material, the majority of the Fe is produced in it and later carried in the streams (Kachoueiyan et al., 2024). The mentioned metal content in aquatic environment at the southern part of Iraq is significantly high, which can be related to the more effluents from agriculture, residential and industry activates (Jolly et al., 2023), and that it had discharged along the main outfall basin (Al-Bahathy et al., 2024).

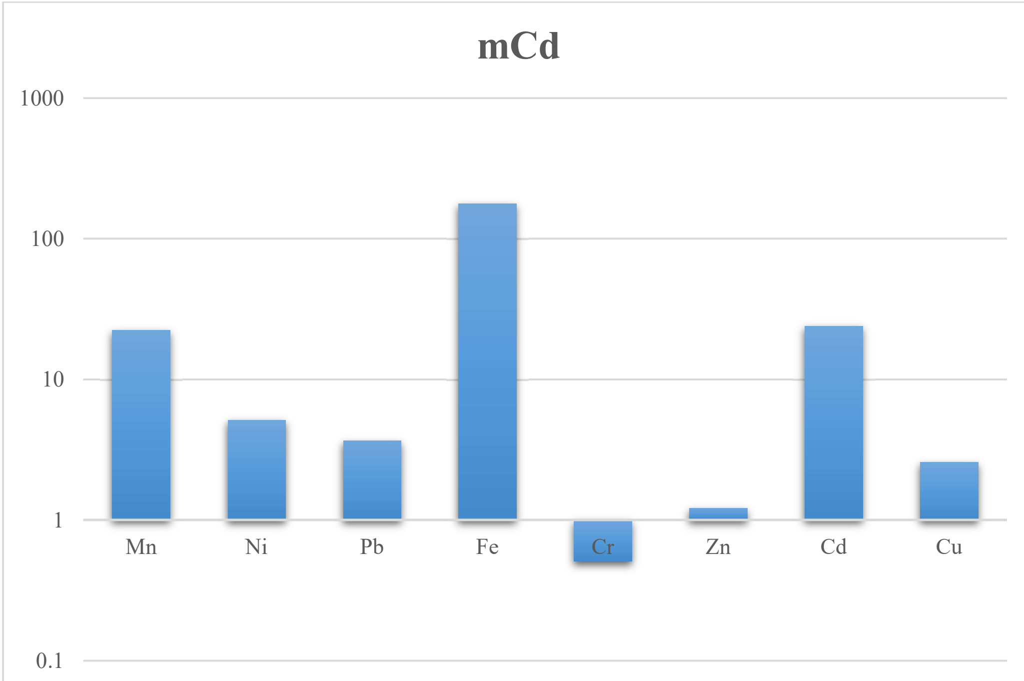

Figure 4: Means of modified contamination degree (mCd) for heavy metals in the study area

Figure (5) shows the spatial values of modified contamination degree (mCd) for heavy metals at the area sites. This is because the uppermost areas of the MOD site1 and site2 have more metals in the sediments that are located in Al-Nassiriya City and this may be directly linked to the fact that there is a high concentration of industrial activities in the MOD Basin. Historically, refinery, steel, and other related industrial businesses have been in operation in site1 and site2 over a long period, which has resulted in the preponderance of metal inputs, which are industrial and agricultural in nature. In contrast, the site 3 (Al-Sanaf marsh) was less influential than these sources (Al-Bahathy et al.,2024). These findings agree Hussian & Al-Jaberi (2020) who Compared the bed sediment contamination of the southern part, Iraq. While, the study results degree Al-Jaberi et al (2016) who studied heavy metals in sediment quality of Shatt Al-Arab river in southern Iraq. They observed low to moderate contamination degree.

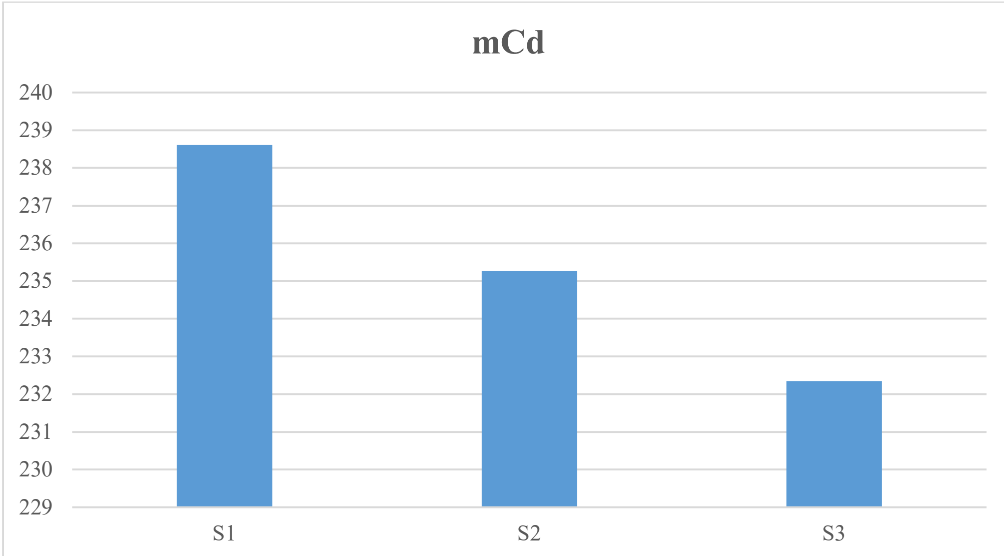

Figure 5: shows the spatial values of modified contamination degree (mCd) for heavy metals in the study area

Metal Index

The values of MI were 238.15, 232.49 and 232.49 in sites 1, 2 and 3, respectively as we shown in Figure (6). Relying on the metal index results, all of the chosen sites were in the category of the threshold of the warning (MI > 1). In the same manner, Aljanabi et al. (2022) indicated that MI values recorded in all sites (5 sites) were above the warning threshold and linked it to human activities widespread in the area. At an international level, Shankar (2019) has found that the quality of the study area in India had a poor trend with the boundaries reaching up to 150.5, which is explained by the urban and agricultural factors.

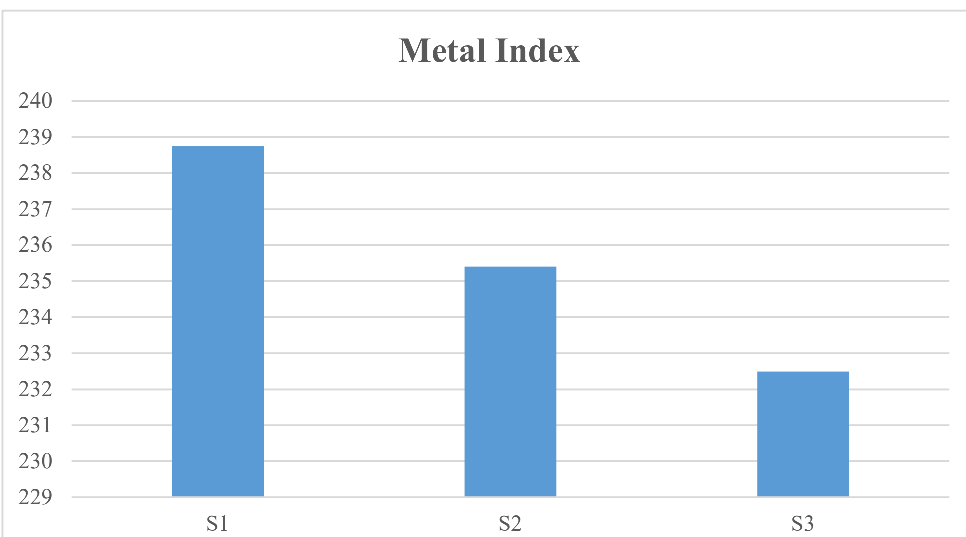

Figure 6: The metal index for heavy metals in the study area

Hierarchical Cluster Analysis HCA

Using Ward's hierarchical cluster analysis to compare the three sites based on the concentrations of heavy metal under this study (Mn^{+2}, Ni^{+2}, Pb^{+2}, Fe^{+2}, Cr^{+3}, Zn^{+2}, Cd^{+2}, and Cu^{+2}), the dendrogram between the sites showed that the two closest sites to each other were site 2 and site 3 because they merged first at the smallest distance (approximately 80.28 according to the Euclidean distance), while site 1 was the most different because it only joined them at a higher distance (figure 7). This means that the overall chemical fingerprint (across the eight metals) at site 2 and site 3 is more homogeneous than either of them with site 1. The important observation here is that the correlations between sites across metals were almost perfect (~1.0), This indicates that the metals move in the same direction between sites (i.e., the order of the metals and their pattern of increase and decrease are similar), and that what distinguishes the cluster in Ward is often the difference in overall concentration (magnitude) rather than a difference in ‘shape’ or ‘direction’; This is a common pattern in heavy metal contamination data, where geochemical signatures are similar (e.g., Fe and Mn dominance as geological/granular background) but intensity varies due to differences in exposure or proximity to anthropogenic sources (Putman et al., 2022). From an environmental interpretation perspective, the similarity between site 2 and site 3 could indicate a similarity in source or conditions (e.g., sediment type, runoff nature, or the same industrial/traffic impact), while the distinctiveness of site 1 suggests an additional factor or a higher/lower loading level that affects the combined mineral group, including elements commonly found in human sources such as Pb, Cd, Cu, Zn, Ni, and Cr, compared to elements that are often more ‘background’ such as Fe and Mn (Öncü et al., 2025). Scientifically, this use of Ward-Euclidean distance in clustering pollution sites is consistent with what is widely published in studies assessing heavy metal contamination of soil/sediment using HCA to show that sites typically cluster into ‘source groups’ or ‘contamination severity clusters,’ with the common methodological caveat in the literature that the presence of outliers or large differences in measures may make the clustering sensitive to the overall level. Therefore, many papers recommend standardization (z-score) or logarithmic transformation prior to HCA to reduce the dominance of metals with higher values and improve the interpretation of proximity as compositional similarity rather than simply differences in magnitude Chang et al., 2025; Frenzel, 2023; Gâf-Deac et al., 2022). However, the central result remains clear: site 2 and site 3 behave as a single, closely clustered group, and site 1 is more differentiated across the eight minerals mentioned.

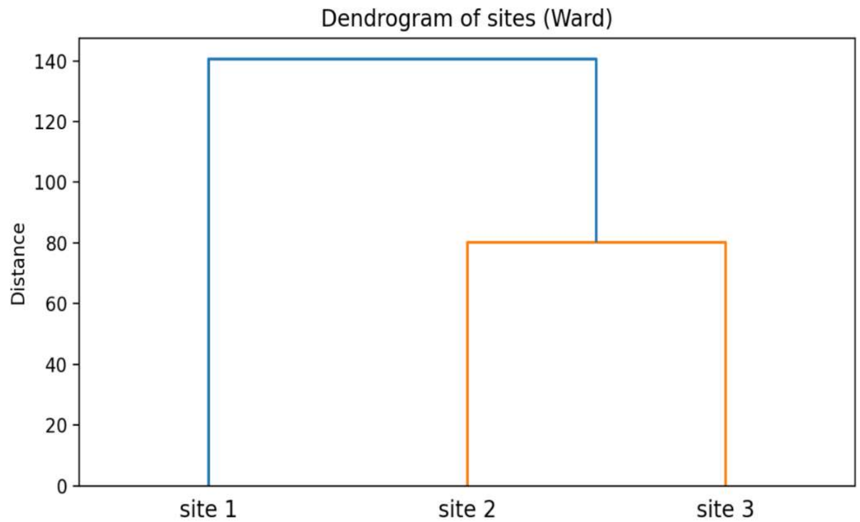

Figure 7: Dendrogram of the studied Sites.

Conclusions

Overall, the results of the analyses revealed that sediments samples within the MOD river (site1& site2) and Al-Sanaf marsh (site3) were polluted**.** The average Cf values were according the following sequence: Fe> Cd > Mn> Ni >Pb>Cu> Zn>Cr. The degree of contamination values determined by the heavy metals showed that all sites contained high degree of contamination with cadmium value being higher than three. The adjusted values of mCd of chromium and zinc were lower than 1.5, which showed that there was no significant contamination of sediment. On the other hand, moderate contamination was found in copper and lead and high level of contamination in nickel and a very high level of contamination in manganese and cadmium in sediments. Iron registered an exceptionally high level of contamination. The high levels of iron can be linked to excessive weathering and erosion of parent soil where most of the iron is obtained and carried away by streams. The spatial values of modified contamination degree (mCd) for heavy metals at the area sites. The upper reaches of the MOD (site1 and site2) had the higher metal content in sediments which were located near Al-Nassiriya City This could be strongly connected to the fact that industries are concentrated near the MOD Basin. Site 3 (in the Al-Sanaf Marsh) on the contrary showed a smaller impact on these sources. Based on the results of metal index, all the chosen sites were characterized as the threshold of warning (M >1) because of the impact of urban and agricultural activities. The metals content in aquatic environment at the southern part of Iraq is significantly high, which was related to the more effluents from agricultural, residential and industrial activates and that it had discharged along the main outfall drain basin.

References

Hakanson L (1980) An ecological risk index for ĂqƵĂƟc ĐŽůůƵƟŽn control: a sedimentological approach. Water Res 14: 975-100 1.

Abrahim, G. M. S., & Parker, R. J. (2008). Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environmental monitoring and assessment, 136(1), 227-238.

Agwu, E.J., Odanwu, S.E., Ezewudo, B.I., Odo, G.E., Nzei, J.I., Iheanacho, S.C., and Islam, M. S. 2023. Assessment of water quality status using heavy metal pollution indices: A case from Eha-Amufu catchment area of Ebonyi River, Nigeria. Acta Ecol. Sin. 43(6), 989-1000 https://doi. org/10.1016/j.chnaes.2023.02.003

Al-Asadi, S. A., & Al-Kafari, H. M. (2022). Levels and sources of heavy metals pollution in the water and sediments of Al-Diwaniyah River, Iraq. *Sustainable Water Resources Management*, *8*(4), 101.

Al-Bahathy, I. A., Al-Janabi, Z. Z., Al-Hassany, J. S., Majeed, O. S., & Naje, A. S. (2024). Environmental Assessment of Sediment Quality for the Main Outfall Drain and Al-Sanaf Marsh. *Ecological Engineering & Environmental Technology*, *25*.

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. *The Iraqi Geological Journal*, 88-97.

Aljanabi, Z.Z., Hassan, F.M. and Al-Obaidy, A.H.M.J. 2022. Heavy metals pollution profiles in Tigris River within Baghdad city. In IOP Conference Series: Earth and Environmental Science (Vol. 1088, No. 1, p. 012008). IOP Publishing

Altahaan, Z., & Dobslaw, D. (2024). Assessment of the impact of war on concentrations of pollutants and heavy metals and their seasonal variations in water and sediments of the Tigris River in Mosul/Iraq. Environments, 11(1), 10.

APHA; WWA and WEF "Standard methods for examination of water and wastewater," 21st Edition, American Public Health Association, Washington, D.C., 2005.

Astatkie, H., Ambelu, A., & Mengistie, E. (2021). Contamination of stream sediment with heavy metals in the Awetu Watershed of Southwestern Ethiopia. Frontiers in Earth Science, 9, 658737.

Astatkie, H., Ambelu, A., & Mengistie, E. (2021). Contamination of stream sediment with heavy metals in the Awetu Watershed of Southwestern Ethiopia. *Frontiers in Earth Science*, *9*, 658737.

Batley, G. E., & Campbell, P. G. (2022). Metal contaminants of emerging concern in aquatic systems. Environmental Chemistry, 19(1), 23-40.

CCME. (2001). Canadian sediment quality guidelines for the protection of aquatic Life. Canadian Council of Ministers of the Environment, Winnipeg. Publication No. 1299.

Chang, X., Zhang, M., Chen, L., Zhang, S., Ren, W., & Zhang, X. (2025). Application of Clustering Methods in Multivariate Data-Based Prospecting Prediction. Minerals, 15(7), 760. https://doi.org/10.3390/min15070760

CCME, C. (2001). Canadian sediment quality guidelines for the protection of aquatic life. *Canadian Council of Ministers of the Environment*.

Devanesan, E., Gandhi, M. S., Selvapandiyan, M., Senthilkumar, G., & Ravisankar, R. (2017). Heavy metal and potential ecological risk assessment in sedimentscollected from Poombuhar to Karaikal Coast of Tamilnadu using Energy dispersive X-ray fluorescence (EDXRF) technique. *Beni-Suef University journal of basic and applied sciences*, *6*(3), 285-292.

Edet, A.E. and Offiong, O.E. 2002. Evaluation of Water Quality Pollution Indices for Heavy Metal

Contamination Monitoring. A Study Case from Akpabuyo-Odukpani Area, Lower Cross River Basin (Southeastern Nigeria). Geomicrobiol. J., 57, 295-304. https://doi.org/10.1023/ b:gejo.0000007250.92458.de

Frenzel, M. (2023). Making sense of mineral trace-element data–How to avoid common pitfalls in statistical analysis and interpretation. Ore Geology Reviews, 159, 105566. https://doi.org/10.1016/j.oregeorev. 2023.105566

Gâf-Deac, I. I., Jaradat, M., Bran, F., Crețu, R. F., Moise, D., Platagea Gombos, S., & Breaz, T. O. (2022). Similarities and Proximity Symmetries for Decisions of Complex Valuation of Mining Resources in Anthropically Affected Areas. Sustainability, 14(16), 10012. https://doi.org/10.3390/su141610012

Han, X., Wu, H., Li, Q., Cai, W., & Hu, S. (2024). Assessment of heavy metal accumulation and potential risks in surface sediment of estuary area: A case study of Dagu river. *Marine environmental research*, *196*, 106416.

Hussian, M. L., & Al-Jaberi, M. H. (2020). Comparison the bed sediment contamination of the southern part of euphrates river with Shatt Al-Arab, Iraq. *The Iraqi Geological Journal*, 68-89.

Jaskuła, J., & Sojka, M. (2022). Assessment of spatial distribution of sediment contamination with heavy metals in the two biggest rivers in Poland. *Catena*, *211*, 105959.

Jeong, I., Ryu, Y., Nam, S. Y., Lee, I. C., & Kim, K. (2022). Physicochemical effects of calcium on suppression of coastal sediment resuspension. Marine Pollution Bulletin, 184, 114206.

Jolly, Y. N., Rakib, M. R. J., Kumar, R., Islam, A. R. M. T., Rabby, A., Mamun, K. M., ... & Idris, A. M. (2023). Deciphering the source of heavy metals in industrially affected river sediment of Shitalakshya river, Bangladesh, and potential ecological and health implications. *Journal of Hazardous Materials Advances*, *10*, 100268.

Jomova, K., Alomar, S. Y., Nepovimova, E., Kuca, K., & Valko, M. (2025). Heavy metals: toxicity and human health effects. Archives of toxicology, 99(1), 153-209.

Kachoueiyan, F., Alipour Atmianlu, P., Rajabi, A., Ustaoğlu, F., & Karbassi, A. (2024). Contamination source, health and ecological risk assessment of hazardous elements in the sediment of the Shahid Rajaee reservoir. *Frontiers in Environmental Science*, *12*, 1493547.

Kantun, W., & Sutapa, I. W. (2023, January). Detecting bioaccumulation of heavy metal in yellowfin tuna (Thunnus albacares Bonnaterre, 1788) in Southwest Pacific Waters, Indonesia. In AIP Conference Proceedings (Vol. 2588, No. 1, p. 020004). AIP Publishing LLC.

Khalaf, H. H., Sayl, K. N., & Abdulhameed, I. M. (2025, March). Spatially distributed model for water quality in main outfall drain (MOD) in Iraq. In *AIP Conference Proceedings* (Vol. 3303, No. 1, p. 120002). AIP Publishing LLC.

Maktoof, A. A., ALKhafaji, B. Y., & Al-janabi, Z. Z. (2014). Evaluation of total hydrocarbons levels and traces metals in water and sediment from main outfall drain in Al-Nassiriya City/Southern Iraq. *Natural Resources*, *5*(13), 795-803.

Masindi, V., & Muedi, K. L. (2018). Environmental contamination by heavy metals. *Heavy metals*, *10*(4), 115-133.

Mazilamani, L. S., Annammala, K. V., Nainar, A., & Najib, M. Z. M. (2020). Trace element concentrations in fine sediment and linkages to non-point pollution source: Lower Johor river basin. In *IOP conference series: materials science and engineering* (Vol. 736, No. 7, p. 072005). IOP Publishing.

Müller G (1969) Index of geoaccumulation in sediments of the Rhine River. Geojournal 2:108–118.

Najam, L. A., & Wais, T. Y. (2022). Radiological hazard assessment of radionuclides in sediment samples of Tigris river in Mosul city, Iraq. *Arab Journal of Nuclear Sciences and Applications*, *55*(1), 45-52.

Öncü T, Yazman MM, Ustaoğlu F, Hristova E, Yüksel B. Source dynamics and environmental risk of street dust as a vector of human exposure to potentially toxic elements in Istanbul, Türkiye. Scientific Reports. 2025 Aug 20;15(1):30550. https://doi.org/10.1038/s41598-025-11472-2

Prasanna, M. V., Praveena, S. M., Chidambaram, S., Nagarajan, R., & Elayaraja, A. (2012). Evaluation of water quality pollution indices for heavy metal contamination monitoring: a case study from Curtin Lake, Miri City, East Malaysia. *Environmental Earth Sciences*, *67*(7), 1987-2001.

Putman AL, Jones DK, Blakowski MA, DiViesti D, Hynek SA, Fernandez DP, Mendoza D. Industrial particulate pollution and historical land use contribute metals of concern to dust deposited in neighborhoods along the Wasatch Front, UT, USA. GeoHealth. 2022 Nov;6(11):e2022GH000671.

Qin, Y., & Tao, Y. (2022). Pollution status of heavy metals and metalloids in Chinese lakes: Distribution, bioaccumulation and risk assessment. Ecotoxicology and environmental safety, 248, 114293.

Sahoo, B.P., and Sahu, H.B. 2022. Assessment of metal pollution in surface water using pollution indices and multivariate statistics: a case study of Talcher coalfield area, India. Appl. Water Sci., 12(9), 223. https://doi.org/10.1007/s13201-022-01743-y

Salman, J. M., Kaizal, A. F., & Kot, P. (2023). Evaluation of some heavy metals, their fate and transportation in water, sediment, and some biota within AL-Musayyib River, Babylon Governorate, Iraq. *Baghdad Science Journal*, *20*(2), 25.

Shankar, B.S.A. 2019. critical assay of heavy metal pollution index for the groundwaters of Peenya Industrial Area, Bangalore, India. Environ Monit Assess., 191(5), 289. https://doi.org/10.1007/ s10661-019-7453-9

Sojka, M., & Jaskuła, J. (2022). Heavy metals in river sediments: contamination, toxicity, and source identification—a case study from Poland. *International Journal of Environmental Research and Public Health*, *19*(17), 10502.

Tang, R., Cai, B., Wang, H., Huang, X., Song, X., Han, Z., ... & Fan, Z. (2023). Human activities contributing to the accumulation of high-risk trace metal (loid) s in soils of China's five major urban agglomerations. *Science of the Total Environment*, *905*, 167218.

Al-Janabi, Z. Z., Al-Bahathy, I. A., Al-Hassany, J. S., Al-Ani, R. R., Naje, A. S., & Maktoof, A. A. (2025). Environmental Impact of Al-Dalmaj Marsh Discharge Canal on the Main Outfall Drain River in the Eastern part of Al-Qadisiya City and Predicting the IQ-WQI with Sensitivity Analysis Using

BLR. *Nature Environment & Pollution Technology*, *24*(1).

Al-Bahathy, I., & Nashaat, M. (2025). Impacts of Hindiya Barrage on the Microcrustacean Cladocera Along Euphrates River. *Egyptian Journal of Aquatic Biology and Fisheries*, *29*(3), 501-517.

Al-Bahathy, I. A., Al-Janabi, Z. Z., Taha, R. A., & Adel, M. M. (2024). Biodiversity of Cladocera and Water Quality for Euphrates River in the Eastern of Al-Qadisiyah Governorate, Iraq. *Egyptian Journal of Aquatic Biology & Fisheries*, *28*(1).