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SPATIAL DISTRIBUTION AND CONTAMINATION OF SPECIFIC HEAVY METALS IN THE SEDIMENT OF BAHR MOUSE, EGYPT

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Abstract

Fifty-seven sediment samples from Bahr Mouse in Sharkiya, Egypt, were analyzed using an atomic absorption spectrophotometer for ten heavy metals. The mean metal concentrations followed the order: Fe > Mn > Zn > Co > Ni > Cr > Pb > Cu > Hg > Cd. Single environmental indices such as the geo-accumulation index (Igeo) and contamination factors (CF) suggested that the sediments in Bahr Mouse are unpolluted (average <1). However, enrichment factors (EF) revealed severe enrichment for Co and moderately severe enrichment for Cd and Pb in some stations. Despite this, integrated indices such as contamination degree (Cdeg) and pollution load index (PLI) indicated an overall absence of heavy metal pollution in the sediments of the study area.

Keywords: Assessment; Bahr Mouse; Contamination; Egypt; Heavy metals; Sediment

1. Introduction

Heavy metals (HMs) are recognized as highly significant environmental contaminants due to their toxicity, persistence, and ability to accumulate in living organisms. These elements can undergo bioaccumulation within the food chain, impacting plants, animals, and ultimately humans **[1,2]**. The Nile Delta, being one of the oldest and densely populated cultivated regions globally, with a population density of ≤ 1,600 inhabitants/km2 **[3]**, faces challenges from agricultural development, industrial activities, and insufficient rural sanitation. These factors contribute significantly to issues such as eutrophication, contamination status, ecological value, and overall environmental conditions in the Nile Delta **[3,4]**.

Both natural and human-induced activities play pivotal roles in the introduction of HMs into the soil. Natural sources, involving weathering and pedogenic processes acting on rock fragments, typically result in relatively low concentrations of HMs **[5,6]**. Conversely, anthropogenic sources, such as commercial fertilizers, liming materials, agrochemicals, and other soil amendments, as well as irrigation water and atmospheric decomposition, are the primary contributors to elevated levels of HMs in soils **[7,8]**.

HMs typically undergo adsorption by soil, initially through rapid reactions occurring within minutes or hours, followed by slower adsorption reactions over days or even years. This process results in the redistribution of HMs into various chemical forms, leading to changes in their bioavailability, mobility, and toxicity **[9-17]**. HMs introduced into the soil through human activities generally exhibit higher mobility compared to those of pedogenic or lithogenic origin. Two key factors contribute to the adverse effects of heavy metals as

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environmental contaminants. Firstly, unlike organic pollutants, biological degradation does not eliminate HMS; instead, they persist. Secondly, HMs tend to accumulate in the bottom sediments of lakes and rivers through adsorption processes involving both organic and inorganic materials **[18,19]**. It's important to note that many HMs, when present in normal concentrations, play essential roles in biochemical processes. However, prolonged exposure to elevated concentrations of HMs poses numerous health risks **[20,21]**.

Baḩr Mouse flows into the eastern Delta of Egypt through Sharkiya Governorate, is a significant watercourse originating as a branch of the Tawfiky diversion directly from the Nile River near Banha city. It traverses the Sharkiya Governorate, forming a substantial canal that extends northward within the Governorate and eventually transforms into a small stream at the end near Awlad Saqr city. Baḩr Mouse holds critical importance as a primary source for agricultural irrigation, drinking water, and is rich in fish wealth for the Sharkiya Governorate.

However, field observations of the Baḩr Mouse region reveal numerous environmental challenges impacting the waterway. These include human waste discharges into the stream, debris from construction along the riverbanks, industrial activities, agricultural runoff, and domestic discharges. Recognizing these concerns, the current study aims to investigate the distribution of HMs and assess pollutants in the bottom sediments and along the banks of Baḩr Mouse. This research is crucial for determining the potential risks that could lead to health problems for humans, animals, and plants over the long term.

2. Material and Methods

2.1. Study area

Baḩr Mouse is a freshwater stream that spans approximately 84 km2 through Sharkiya Governorate in Egypt, situated between 30° 29' 16" N to 31° 12' 56" N and 30° 55' 53" E to 31° 42' 23" E, with a water depth ranging from 1.5 to 4 m. It passes through several cities, including Minia al-kamh, Zagazig, Hehya, Abu Kabir, Al Ibrahimiya, Kafr Saqr, and Awlad Saqr (Fig. 1 and Table 1). Baḩr Mouse holds vital significance for residents of Sharkiya Governorate as it supplies water to numerous drinking water purification stations. The climate in this region is characterized by a warm winter with occasional showers, reaching a minimum temperature of 6.4 °C in January. Summers are hot and arid with moderate humidity, and the highest temperature peaks at 36.7 °C in July. The mean annual precipitation increases northward from 20 to approximately 100 mm, and daily evapotranspiration ranges from 1.5 mm in December to 7.5 mm in July **[22]**.

The study area is in the eastern part of the Nile Delta, featuring flat slopes extending northward and eastward, with elevations ranging from 35 m in the south to 0.0 m near Manzala Lake in the north **[23,24]**. It predominantly consists of sedimentary rocks, including fluvio-marine deposits from the Late Pleistocene and old deltaic deposits from the Early Pleistocene. The geological succession is characterized by the Nile silt at the top, followed by old deltaic sands and gravels, underlain by fluvio-marine deposits forming the Quaternary aquifer **[25-27]**.

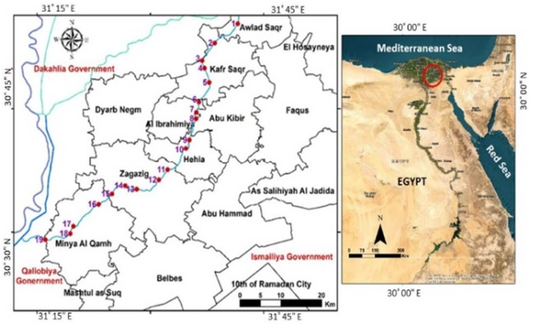


Figure 1: Study area and sampling stations

2.2. Sampling and laboratory work

A total of 57 sediment samples were systematically collected along the course of Baḩr Mouse (Fig. 1), covering 19 stations in December 2022. Each station was subjected to the collection of three samples: two from both sides of the banks below the water level and one from the bottom of the stream. The collection was performed using cylindrical stainless-steel boxes with a depth of approximately 15cm. The precise locations of all sampling stations were determined using Geographic Position System (GPS) instruments, and the study area map was constructed using ArcGIS.

The gathered sediment samples were placed in plastic jars and transported to the laboratory. Subsequently, all samples underwent drying at 80 °C.

For grain size analysis, 100 g from each dried sample was employed, employing a Vibratory Sieve Shaker. Additionally, 2 g from each sediment sample was ground and homogenized using a separate agate mortar. From this powder, 0.2 g was subjected to digestion in an acidic mixture of HF, HNO_3, and $HClO_4$, following the procedure outlined by **[28]**. The digestion solutions were then analyzed for their content of Fe, Mn, Cu, Zn, Pb, Ni, Cd, Co, and Cr using an atomic absorption spectrophotometer (AAS), specifically a Perkin Elmer Model 2380. This instrument was connected to a hydride generation system to measure Hg. The entire analysis was conducted in the central laboratory at the Faculty of Veterinary Medicine, Zagazig University.

In analyzing heavy metals using atomic absorption, various quality assurance and quality control (QA/QC) measures are implemented to guarantee the accuracy and reliability of the results. These measures include instrument calibration, blank analysis to detect contamination, replicate analysis to verify precision, and quality control samples to monitor accuracy and precision. These procedures ensure that the results are accurate, precise, and dependable.

Table 1

The description of the sampling sites along Bahr Mouse

St.	Location		Description
1	Awlad Sakr	Monshaat Nasir Village	Residential area- the presence of a lot of waste on the side of the banks of the watercourse. In addition to the presence of a white brick barn, lime, sand and gravel
2	Kafr Sakr	Hanout Village	Residential area- the presence of rubbish piles near the banks of the river and many plastic bags on the surface of the water and in the bottom sediments.
3		Alhagayzah Village	Agricultural area near the drinking water purification plant.
4		Kafr Alqawasim	Residential and agricultural area- 1.2 km from Singaha drinking water purification plant.
5		Kafr Itman	Residential area- the presence of piles of rubbish, and agricultural waste.
6		Izbat Al Bakakrah	Residential and agricultural area- the site is in front of the car refueling station.
7	Al-Ibrahimeya	Al-Khudariyyah	Agricultural area- In front of the drinking water purification plant.
8		Kofour Negm Village	Agricultural area- the water is loaded with garbage such as bags, bottles and wood, in addition to the presence of waste from demolishing houses next to the river.
9	Hihya	Kafr Abu Hatab	Agricultural area- there is a poultry farm in the area, house demolition waste, and a drainage pipe for a building brick factory.
10		Hihya city	An industrial and residential area - there are factories for building bricks and a store of gravel and sand near the river. There are also house demolition waste, garbage, bags and bottles.
11	Zagazig	Kafr Alhirawy	Residential area - many houses.
12		Izbet Ashabakat	Residential area - there are cafes, a marble workshop, small fishing boats, and large quantities of house demolition waste.
13		Sharwidah	Agricultural area - the surface water is clean, with very large quantities of house demolished waste on the side of the river.
14		Izbet Ashamsi	Residential and agricultural area - there is no garbage in the water, but there are factories for building bricks and landfills for industrial coal.
15		Kafr Al-Jirayah	Residential area - there are large quantities of house demolition waste, stones and rubbish - there is a pickle factory.
16	Menya Alqamh	Kafr Al-Rubaemayah	Residential and agricultural area - piles of house demolitions and soil erosion.
17		Kafr Badawi	Agricultural area- the river water is pure.
18		Kafr Elsaedy	Agricultural area - the river water is pure and there is a brick factory near the river.
19		Alaziziyah	Residential area - the width of the waterway has expanded and the phenomenon of washing dishes by local residents has spread.

3. Results and discussion

3.1. HMs distribution in sediment

The concentrations of HMs in the sediment samples of Bahr Mouse are detailed in Fig. 2 and supplementary Table S1. Notable variations are observed, with Fe concentrations ranging from 240.3 µg/g at Kafr Itman (Kafr Sakr city) to 723.9 µg/g at Kafr Elsaedy (Menya Alqamh city), averaging 395.7 µg/g. Mn concentrations range from 3.99 µg/g at Hanout Village (Kafr Sakr city) to 8.09 µg/g at Kafr Badawi (Menya Alqamh city), averaging 5.38 µg/g. Cu concentrations vary from 0.34 µg/g at Kafr Alqawasim (Kafr Sakr city) to 1.3 µg/g at Kafr Elsaedy (Menya Alqamh city), with an average of 0.62 µg/g. Cd concentrations range from 0.11 µg/g at Izbet Ashabakat (Zagazig city) to 0.55 µg/g at Kafr Alqawasim (Kafr Sakr city), averaging 0.029 µg/g. Pb concentrations vary from 0.38 µg/g at Izbat Albakakrah (Kafr Sakr city) to 1.71 µg/g at Sharwidah (Zagazig city), averaging 0.93 µg/g. Zn concentrations range from 1.53 µg/g at Izbat Albakakrah (Kafr Sakr city) to 4.5 µg/g at Alaziziyah (Menya Alqamh city), averaging 3.1 µg/g. Ni concentrations vary from 0.65 µg/g at Kafr Abu Hatab (Hihya city) to 3.72 µg/g at Izbat Albakakrah (Kafr Sakr city), averaging 2.32 µg/g. Co concentrations range from 0.73 µg/g at Hihya city to 3.35 µg/g at Kafr Abu Hatab (Hihya city), averaging 2.33 µg/g. Cr concentrations range from 0.05 µg/g at Kafr Abu Hatab (Hihya city) to 3.85 µg/g at Kofour Negm Village (Al-Ibrahimeya), averaging 2.07 µg/g. Hg concentrations vary from 0.19 µg/g at Kafr Ar Rubaemayah (Menya Alqamh city) to 0.44 µg/g at Kafr Alqawasim (Kafr Sakr city), averaging 0.28 µg/g. The highest levels of Cu (0.88 µg/g), Pb (1.18 µg/g), and Cr (2.81 µg/g) are recorded in the sediment of Bahr Mouse in the Al-Ibrahimeya area. Menya Alqamh area records the highest levels of Fe (609.96 µg/g) and Zn (3.67 µg/g). The Awlad Sakr and Kafr Sakr areas record the highest levels of Co (3.26 µg/g), Hg (0.374 µg/g), and Pb (1.18 µg/g), Cr (2.81 µg/g), respectively. Meanwhile, Zagazig area does not record the highest values for any of the studied heavy metals (Fig. 3). Figure 4 illustrates that the average distribution of HMs in the bottom sediment samples of the riverbed does not significantly differ from their distribution in the bank's sediments, indicating a general homogeneity of metal content in the water of the riverbed.

On the other hand, a comparative analysis was conducted between the average concentrations of HMs in the sediments of Bahr Mouse and those in local and international rivers (refer to Table 2). The findings revealed that the recorded levels of Fe (396 µg/g), Pb (0.94 µg/g), and Cd (0.03 µg/g) were higher than those found in the sediments of the Rosetta Nile branch **[29], w**hile all levels of the studied HMs recorded lower values than their counterparts in sediments of Qalubiya drain **[4]**, Terat Ismailiya **[30]**, and Damietta Nile Branch **[31]**. However, it's noteworthy that the study area recorded lower concentrations of all studied HMs compared to sediments from various world rivers, including the Seine River in Paris **[32]**, Uppanar River in India **[33]**, Nakdong River in South Korea **[34]**, and the Euphrates River in Iraq **[35]**. When comparing the levels of HM concentrations in the sediments of Bahr Mouse with the world permissible limits, including the lowest effect level (LEL) and the severe effect level (SEL) according to **[36]**, as well as the recommended maximum limit (RML) and the probable effects level (PEL) according to **[37]**, the values of Bahr Mouse sediments are notably negligible. This suggests that the study area exhibits a very low content of HMs and can be considered almost pristine in terms of environmental contamination.

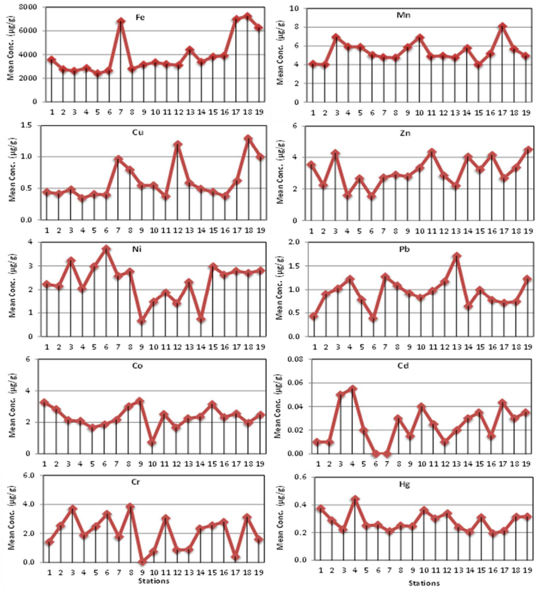


Figure 2: The distribution of the heavy metals in the sediment samples of the Bahr Mouse

3.2. Status of heavy metals contamination

To gauge the pollution levels in the stream sediments of Bahr Mouse, both unilateral and cumulative environmental indicators were assessed, as depicted in Figure 5 and supplementary Table S2. These indicators, widely employed in environmental assessment studies globally **[38,39]**, have proven to be effective tools. The concentrations of heavy metals in the Earth's crust, as outlined by **[40]**, were utilized as background values for this evaluation.

3.2.1 The Geoaccumulation Index (Igeo)

The Igeo is a fundamental environmental indicator employed for assessing pollutants in the soil **[4,41]**. The Igeo is calculated using the equation: $Igeo = Log2\ (M_s\ /\ K\ .\ M_b)$, where M_s is the concentration of the element in the sample, K is the background matrix correction factor due to lithospheric effects and M_b is a concentration of element in the background. Pollution status is classified based on **[42]** criteria into six classes: unpolluted ($Igeo < 0$), uncontaminated to moderately contaminated ($0 \leq Igeo \leq 1$), moderately polluted ($1 < Igeo \leq 2$), moderately to strongly contaminated ($2 < Igeo \leq 3$), heavily contaminated ($3 < Igeo \leq 4$), strongly to very strongly contaminated ($4 < Igeo \leq 5$), and extremely contaminated ($Igeo > 5$). The Igeo results for all HMs in the studied samples were found to be less than 1, indicating that the stream sediments of Bahr Mouse are unpolluted. The highest Igeo values were recorded as follows: -0.44 (Hg), -3.09 (Co), -3.17 (Cd), -4.56 (Pb), -4.78 (Ni), -4.98 (Zn), -5.13 (Cr), -5.70 (Cu), -6.61 (Fe), and -7.30 (Mn). These results collectively suggest an absence of anthropogenic impacts in the study area, as indicated by the Igeo values falling within the unpolluted range.

3.2.2 The Enrichment Factor (EF)

The EF is a crucial environmental parameter that helps identify the source of pollution, whether anthropogenic or natural **[43-44]**. It is calculated using the equation: EF = (Ms / Fes) / (Mb /Feb), where Ms and Fes are the concentration of elements in sample, and Mb and Feb are the concentration of elements in the background. The results indicate that sediment samples are severely enriched with Co (EF = 10-25), moderately severe enriched with Cd and Pb (EF = 5-10), moderately enriched with Ni, Zn, and Cr (EF = 3-5), minorly enriched with Cu (EF = 1-3), and not polluted with Mn (EF < 1). These findings strongly support the anthropogenic origin of the investigated metals, suggesting significant human influence in the observed enrichment patterns.

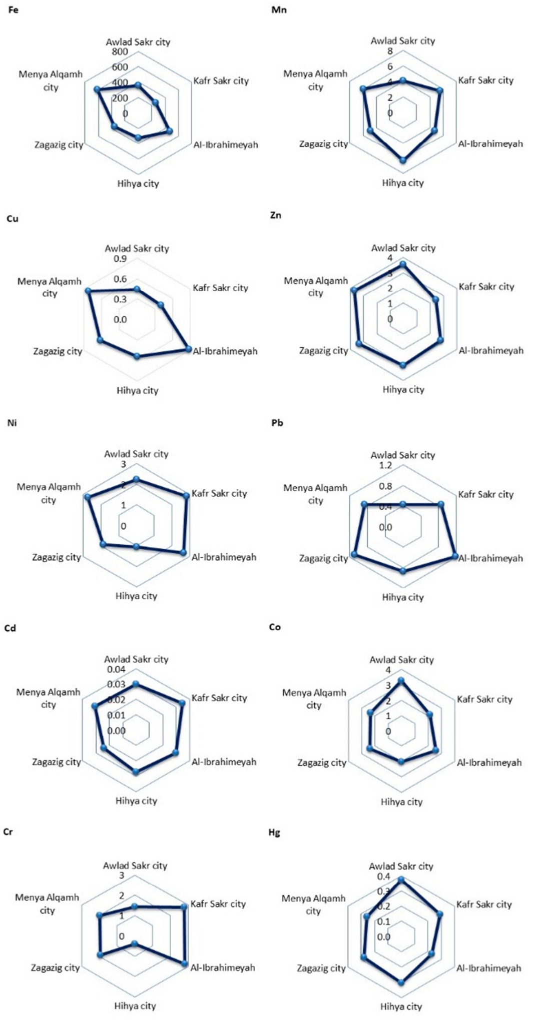


Figure 3: The distribution of the heavy metals in the sediment of the major cities along Bahr Mouse

3.2.3 The Contamination Index (CF)

The CF was employed to evaluate the level of metal contamination in sediment samples **[13, 45]**. It is calculated using the equation: CF = Ms / Mb, where Ms is the concentration of metal in the sample, and Mb is the concentration of element in the background. According to **[46]**, the level of metal contamination is classified into four categories: CF < 1 indicates low contamination; 1 < CF < 3 indicates moderate contamination; 3 < CF < 6 indicates considerable contamination; and CF > 6 indicates very high contamination. The results reveal that the concentrations of all the investigated HMs were less than 1, indicating low contamination in the sediments at each site along Bahr Mouse. The average contamination factor for HMs follows the order: Hg > Co > Cd > Pb > Ni > Zn > Cr > Cu > Mn > Fe.

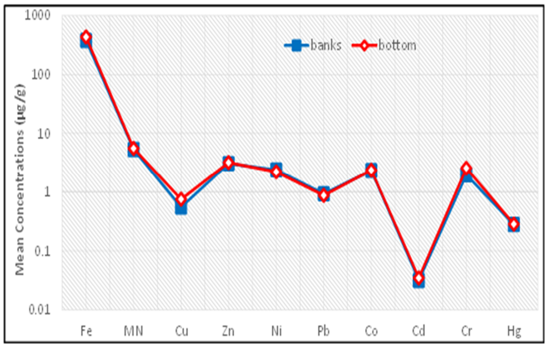


Figure 4: The comparison of the heavy metals in sediment of the bottom and banks samples

3.2.4 The Contamination degree Index (C_{deg})

The Cdeg is an integrated parameter that provides an overall description of the extent of metal contamination in a studied area **[47,48]**. It is derived from the contamination factors using the equation: $Cdeg = \sum_{i=1}^{n} CF$. The integrated contamination of metals across the entire area is classified into four categories based on **[49]**: low degree of contamination (Cdeg < 6), moderate degree of contamination (6 < Cdeg < 12), considerable degree of contamination (12 < Cdeg < 24), and high degree of contamination (Cdeg > 24). The results indicate that the sediments of Bahr Mouse have a low degree of contamination (Cdeg < 6), reflecting a relatively minimal overall impact of metal contaminants in the studied area.

Table 2

Comparison between heavy metal levels in the sediments of Bahr Mouse with the local and the international rivers

Location	Fe	Mn	Cu	Zn	Ni	Pb	Co	Cd	Cr	References
Bahr Mouse	3957	5.38	0.62	3.10	2.32	0.94	2.33	0.03	2.07	Present work
Qalubiya drain, Egypt	3052	168.63	76.22	183.90	87.64	62.14	49.01	0.81	86.68	[4]
Rosetta Nile Branch, Egypt	285	34	0.76	4.75	NA	0.17	NA	0.02	NA	[29]
Terat Ismailiya, Egypt	NA	194.8	32.6	117.8	32.1	31.8	29.4	0.23	NA	[30]
Damietta Nile Branch, Egypt	15321	623	28	55	18.9	6.2	NA	0.5	NA	[31]
Seine River, Paris	NA	NA	33	0.6	NA	41	NA	153	NA	[32]
Uppanar River, India	NA	NA	6.52	6.93	NA	6.6	NA	0.41	NA	[33]
Nakdong River, South Korea	NA	NA	6.41	16.77	NA	4.7	NA	0.11	NA	[34]
Euphrates River, Iraq	2250	228.2	18.91	48	67.1	22.6	28.16	1.87	NA	[35]
Average values recorded in shale	47200	850	45	95	68	20	19	0.3	100	[40]
Average values in the earth's crust	NA	NA	25	70	20	15	10	NA	155	[57]
Lowest effect level (LEL)	20000	460	16	120	16	31	NA	NA	26	[36]
Severe effect level (SEL)	40000	1100	110	820	75	250	NA	NA	110	
Recommended maximum limit (RML)	5000	2000	100	300	50	100	100	3	50	[37]

Not available

3.2.5 The pollution load index (PLI)

The PLI was employed to assess the integrated pollution status of HMs at the sampling sites **[50]**. It is calculated using the equation: PLI = $(CF_1 \times CF_2 \times CF_3 \times \ldots\ldots CF_n)^{1/n}$, where CF is the contamination factor of each element, and n is the number of metals. The level of metal contamination is classified into four categories: (PLI ≤ 1) is unpolluted; (1 < PLI < 3) is moderately polluted; (3 < PLI < 5) is highly polluted; and (PLI > 5) is extremely polluted **[51]**. The results indicate that (PLI < 1). Therefore, it can be concluded that there is no heavy metal pollution in the sediments of Bahr Mouse, as the Pollution Load Index falls within the unpolluted category.

3.3. Estimation the pollution sources

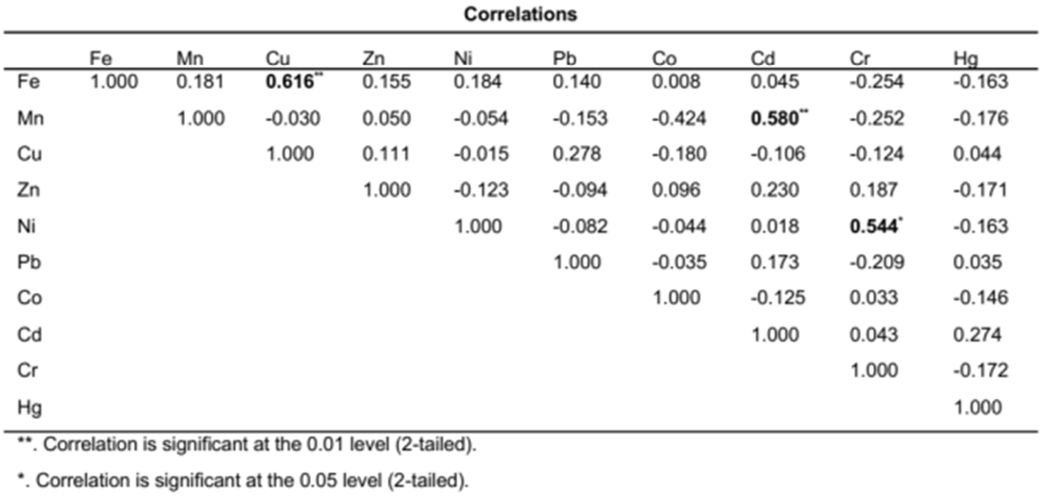
In the total study area, hierarchical cluster analysis (HCA-R mode, Fig. 6a) grouped HMs into four clusters: the first cluster contains Fe-Cu combined with Pb. The second cluster consists of Mn-Cd combined with Zn, while the third cluster contains Ni-Cr combined with Co, and the last cluster contains Hg. This implies the presence of several sources for heavy metals in the studied area [52,53].

On the other hand, HCA-Q mode (Fig. 6b) classified the studied sites into four groups: the first group includes 7 sites (7-18-19, 13-17, 1-15); the second group includes 5 sites (2-6, 11-16, 14); the third group includes 4 sites (10-12, 4, 9); and the last group includes 3 sites (3-5, 6).

The correlation coefficient (Table 3) revealed a positive relation between Cu-Fe (r = 0.616**), Cd-Mn (r = 0.580**), and Cr-Ni (r = 0.544**). These results indicate that these pairs of HMs share a common origin **[40, 53]** Additionally, the principal component analysis (Table 4) classified the variables into five components. The first components include Fe, Mn, and Cu, while the second component includes Fe and Cu. The third component includes Ni and Cr, while the fourth component includes Ni and the fifth consists only of Cd. These results suggest that the elements in each component may have originated from similar natural and anthropogenic sources, especially the first and second components due to the presence of Fe in them **[54-57]**.

Table 3

Correlation coefficient for the studied HMs in studied sediment samples



Correlations

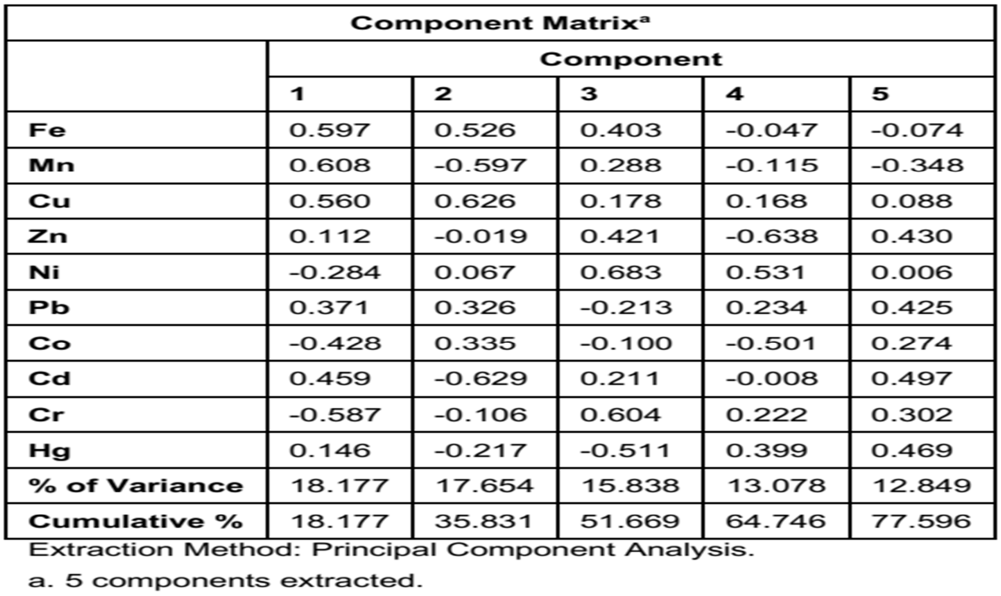
	Fe	Mn	Cu	Zn	Ni	Pb	Co	Cd	Cr	Hg
Fe	1.000	0.181	**0.616********	0.155	0.184	0.140	0.008	0.045	-0.254	-0.163
Mn		1.000	-0.030	0.050	-0.054	-0.153	-0.424	**0.580****	-0.252	-0.176
Cu			1.000	0.111	-0.015	0.278	-0.180	-0.106	-0.124	0.044
Zn				1.000	-0.123	-0.094	0.096	0.230	0.187	-0.171
Ni					1.000	-0.082	-0.044	0.018	**0.544***	-0.163
Pb						1.000	-0.035	0.173	-0.209	0.035
Co							1.000	-0.125	0.033	-0.146
Cd								1.000	0.043	0.274
Cr									1.000	-0.172
Hg										1.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4

The Principal Component Analysis for the studied HMs in sediment samples



Component Matrix[a]

	Component				
	1	2	3	4	5
Fe	0.597	0.526	0.403	-0.047	-0.074
Mn	0.608	-0.597	0.288	-0.115	-0.348
Cu	0.560	0.626	0.178	0.168	0.088
Zn	0.112	-0.019	0.421	-0.638	0.430
Ni	-0.284	0.067	0.683	0.531	0.006
Pb	0.371	0.326	-0.213	0.234	0.425
Co	-0.428	0.335	-0.100	-0.501	0.274
Cd	0.459	-0.629	0.211	-0.008	0.497
Cr	-0.587	-0.106	0.604	0.222	0.302
Hg	0.146	-0.217	-0.511	0.399	0.469
% of Variance	18.177	17.654	15.838	13.078	12.849
Cumulative %	18.177	35.831	51.669	64.746	77.596

Extraction Method: Principal Component Analysis.

a. 5 components extracted.

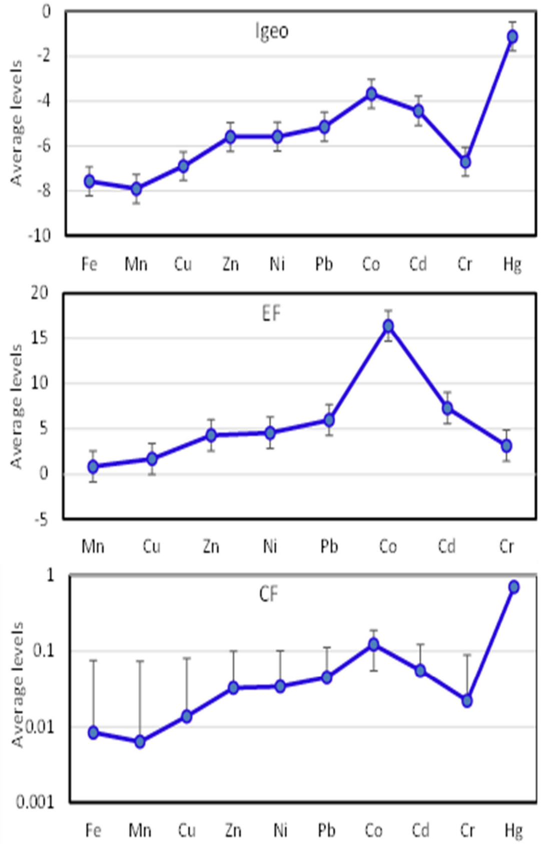


Figure 5: Environmental indicators data the stream sediments of the Bahr Mouse

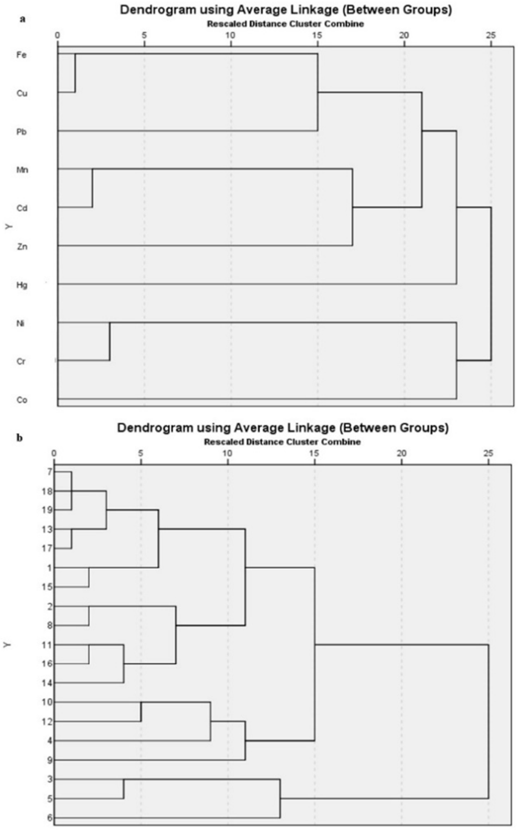


Figure 6: Hierarchical cluster analysis (HCA-R and HCA-Q modes).

4. Conclusions

The findings of the study highlight specific concentrations and enrichment levels of HMs in different sites along Bahr Mouse. Specifically, the sediment in Al-Ibrahimeya area recorded the highest levels of Cr (3.85 µg/g), while Menya Alqamh area showed the highest concentrations of Fe (723.9 µg/g), Mn (8.09 µg/g), Cu (1.3 µg/g), and Zn (4.5 µg/g). Kafr Sakr areas registered the highest levels of Cd (0.55 µg/g), Ni (3.72 µg/g), and Hg (0.44 µg/g). Simultaneously, Zagazig area exhibited the highest levels of Pb (1.71 µg/g), and Hihya area had the highest level of Co (3.35 µg/g). Igeo results for all HMs indicated values below 1, signifying that the stream sediments of Bahr Mouse are unpolluted. The Igeo results suggest an absence of anthropogenic impacts in the study area. EF results revealed severe enrichment with Co (EF = 10-25), moderate to severe enrichment with Cd and Pb (EF = 5-10), moderate enrichment with Ni, Zn, and Cr (EF = 3-5), minor enrichment with Cu (EF = 1-3), and no pollution with Mn (EF < 1). These findings support the notion of human origin for the investigated metals. CF results indicated that all investigated HMs were less than 1, indicating low contamination in the sediments at each site along Bahr Mouse. Cdeg results indicated a low degree of contamination (Cdeg < 6) in the sediments of Bahr Mouse, reflecting a relatively minimal overall impact of metal contaminants in the studied area. PLI results were below 1, suggesting no heavy metal pollution in the sediments of Bahr Mouse. The comprehensive assessment based on various indices and factors consistently indicates low contamination and negligible pollution of HMs in the sediments of Bahr Mouse, affirming the overall environmental health of the study area.

5. Conflicts of interest

There are no conflicts to declare.

6. Formatting of funding sources

This research did not receive any funding.

7. References

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