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Heavy Metals in the Bottom Sediments of El Manzala Lagoon, Egypt: Assessment and Correlation with other Mediterranean Aquatic Ecosystems

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Abstract

Recently, an accurate monitoring for coastal lagoons becomes an urgent need to protect them from severe effects of pollution. The present study objects to evaluate the heavy metal pollution in one of the most important coastal lagoons in Egypt, called Manzala Lagoon (ML). The measured concentrations of heavy metals (HMs) reflect that Fe > Zn > Pb > Ni > Cu > Co > Cd. To evaluate the levels of contamination in the studied Lagoon, seven contamination indices are calculated, including contamination factor (Cf), Degree of contamination (Dc), Geo-accumulation index (Igeo), Pollution Load Index (PLI), enrichment factor (Ef), Ecological risk factor (Er) and Potential ecological risk factor (Ri). According to the Cf, the sediments are lowly polluted with Zn, Ni, Co, Cu and Fe, moderately polluted with Pb, and very highly polluted with Cd. The average value of Dc (15.96), indicating a considerable level of contamination. Furthermore, the average values of Ef point to minor enrichment for Ni and Cu, moderate enrichment for Zn and Co, severe enrichment for Pb, and extremely severe enrichment for Cd. The average value of Ri reaches 676.3, suggesting that the sediments have very high risk. Consequently, Cd and Pb are the principal contributors for the ecological risk in ML. Finally, the comparison between the concentrations of heavy metals in the Manzala Lagoon and other Mediterranean is done.

Keywords: Contamination indices; Heavy metals; Manzala Lagoon; Egypt; Mediterranean

Introduction

Because of the harmful consequences on the aquatic environment, pollution of coastal habitats is a global concern. Urbanisation, agricultural waste, industrial sewage, and other human activities can all contribute to pollution (e.g., Zenina, 2009; Tan et al., 2021; El Ouaty et al., 2024). In this context, the northern coastal lagoons of Egypt (El Mariout, Edku, El Burullus, El Manzala, El Bardawil), were exposed to these stresses (e.g., El Nemr, 2003; Masoud et al., 2011; Shalaby et al., 2017; El Baz and Khalil, 2018; El-Amier et al., 2023). Heavy metals like Cd, Hg, Pb, Zn, As, Ni, and Cr are the most dangerous pollutants (e.g., Forstner and Wittmann, 1983; Selvaraj et al., 2004). Temperature, organic matter, pH, salinity, and bottom sediment types are some of the most important determinants of HM levels (e.g., Galanopoulou et al., 2009; Mallick et al., 2016).

It is well known that, the concentrations of metals in sediments are greater than those in water (Singer, 1977).

In relation to the assessment of pollution, many investigations pointed to the importance of evaluating the degree of contamination in different aquatic ecosystems in Africa (e.g., Ennouri et al., 2010; Masoud et al. 2011; Belabed et al., 2013; Abdul et al., 2019), Asia (e.g., Tan et al., 2021), Northern America (Alvarez Zarikian, 2000), Europe (e.g., Ruiz et al., 2004), and Australia (e.g., Roy and Crawford, 1984).

The current development project, that have been carried by the Egyptian government, led to the re-formation of the northern coastal lagoons, where many island, fish farms and aquatic macrophytes were removed. So, the total surface area and the depths of the lagoon increased (e.g., Abd Ellah, 2022). Thus, there is an urgent need to make a continuous assessment for the health of these lagoons during the different stages of the promising Egyptian project. The present study concentrates on assessing the heavy metal pollution in the ML. This investigation may act as a base for future comparative studies on ML after and before the development project. Accordingly, the present study objects (1) to estimate the concentrations of heavy metal in the botttom sediments of ML, (2) to compare these results with those previously recorded from ML and other aquatic ecosystems in the Mediterranean region, and (3) to assess the contamination levels in the studied sites.

Study area

El Manzala Lagoon (ML) represents one of the most largest coastal lagoon in Egypt, locating in the north-eastern part of the Nile Delta. It is placed between latitudes 31°07`N and 31°30`N and longitudes 32°17`E and31°48`E. In addition, it is surrounded by four governorates; Port Said, Damietta, Al Dakahlia and Al Sharkia (Fig. 1). The northern sector of the lagoon is separated from the Mediterranean Sea by a sandbar, which permits the connection to the sea through artificial inlets. Furthermore, the entrance of freshwater to the lagoon is related to three canals (Ratma, Souffra, and Inaniya) in the western side and five drains (Hadous, Faraskour, Bahr El-Bakar, Ramsis and El-Serw) in the southern side. Accordingly, ML becomes a brackish lagoon due to the mixing of freshwater with marine water. Economically, it plays a vital role in the production of high amounts of fish.

Fig.1 location map of El Manzla Lagoon shows sample locations

Many studies the have been done on the pollution in ML (e.g., Badawy and Wahaab, 1997; Abdel-Satar and Genid, 2009; Shalaby et al., 2017; El Baz, 2017; Abdel Gawad, 2018; Redwan and Elhaddad, 2022). In this context, the study of Badawy and Wahaab (1997) concluded that, the level of Cr in the sediments recorded the highest concentration, followed by Zn, Cu, Ni, Pb and Cd. Morover, Abdel-Satar and Genid (2009) arranged the order of heavy metals as follows; Fe (4460 μg/g), Mn (1334 μg/g), Pb (379.4 μg/g), Zn (207.8 μg/g), Ni (108.14 μg/g), Cu (90.99 μg/g), Co (38.8 μg/g), and Cd (10.61 μg/g). In addition, EL-Bady (2016) established that Fe has the highest concentration (1074.55μg/g), followed by Zn (39.53μg/g), Cu (31.21μg/g), Ni (30.83μg/g), Pb (0.077μg/g) and Cd (1.67 μg/g). Goher et al. (2017) concluded that the sediments of ML were moderately polluted with Pb, Zn, Cd and Cu in most stations, but they are lowly contaminated with Fe and Mn. Abdel Gawad (2018) indicated that the concentrations of Fe have the highest concentrations (8342.47 μg/g), followed by Ni (40.73 μg/g), Zn (30.32 μg/g), Cu (26.34 µg/g), Pb (0.244 µg/g) and Cd (0.0264 µg/g). Redwan and Elhaddad (2022) concluded that Fe has the highest concentration (14130 µg/g), followed by Cu, Zn (110 µg/g), Ni (60 µg/g), Pb (20 µg/g) and Cd (1.8 µg/g).

Materials and methods

The current study was done on twenty six sites from ML, Egypt. These sites were chosen based on the degree of proximity to the drains or the Mediterranean Sea. Twenty six samples were collected, in December 2022, using a grab sampler from the bottom sediments of ML. At each site, sample was subdivided into two groups, one for the analysis of grain size and the second for heavy metals (HMs). These samples were saved in ice box and transported to the laboratory. Some ecological parameters (salinity, depth and pH) were recorded during sampling. The environmental and geographical data for each station are shown in Table 1. To investigate the size of the bottom sediments, the standard method of Folk (1974) was applied on 26 sites. According to Liao et al. (2014), the digestion of sediment was done to measure the concentrations of seven metals (Fe, Cu, Zn, Co, Cd, Pb and Ni) in 20 sediment samples. The results of the environmental parameters of the lagoon and the concentrations of HMs were displayed on the distribution maps, using Arc Map. To assess the concentrations of HMs, some pollution indices, such as Cf, Dc, PLI, I_{geo}, Ef, Er, and Ri were calculated. Pearson's correlation coefficient was applied to determine the relationships between the measured metals.

Table 1. Coordinates of the studied sites and their measured environmental parameters.

Site no.	Lat. (N)	Long. (E)	Water depth (cm)	pH	Salinity (g/l)	Sand %	Silt %	Clay %
1	31º 21' 41"	31º 56' 11"	400	8.80	10.7	46	45	9
2	31º 21' 19"	31º 58' 01"	300	8.75	10.2	45	47	8
3	31º 21' 15"	31º 59' 20"	250	8.86	11.1	48	45	6
4	31º 21' 15"	32º 1' 09"	125	8.70	11.7	47	46	7
5	31º 20'	32º 2'	90	8.88	10.5	53	38	9
6	31º 18'	32º 6'	85	8.80	10.8	40	43	17
7	31º 17'	32º 6'	150	8.73	7.2	38	42	20
8	31º 17'	32º 2'	410	8.74	10.4	25	45	30
9	31º 19'	32º 1' 09"	450	8.75	10.1	26	43	31
10	31º 20'	31º 58' 01"	500	8.82	9.6	25	43	32
11	31º 20' 5"	31º 56' 11"	210	8.98	9.4	22	44	34
12	31º 18' 46"	31º 55' 56"	200	9.00	7.5	23	42	35
13	31º 19'	31º 57' 27"	250	8.81	9.2	25	45	30
14	31º 17'	32º 2' 29"	300	8.79	10.8	23	44	33
15	31º 16'	32º 7'	200	8.51	4.6	25	35	40
16	31º 13'	32º 7'	160	8.65	5.4	22	33	45
17	31º 14' 30"	32º 5'	100	8.52	5.3	12	38	50
18	31º 14'	32º 3'	150	8.41	4.3	1١	39	50
19	31º 14' 42"	32º 2'	175	8.86	7.1	10	36	51
20	31º 15' 10"	32º 1' 36"	200	8.76	6.9	9	37	54
21	31º 15' 59"	32º 0' 56"	220	8.78	6.9	11	37	52
22	31º 15' 59"	31º 59' 13"	70	8.72	7	9	44	47
23	31º 16'	31º 58' 11"	250	8.88	8.6	10	42	٤٨
24	31º 17'	31º 57' 09"	350	8.84	7.9	12	43	45
25	31º 17'	31º 55' 35"	150	9.00	5	10	44	46
26	31º 18'	31º 54' 10"	170	9.04	5.4	11	46	43

Results

Environmental parameters

The values of depth vary between the different sites, where the maximum depth reaches 5 m at site 10, and the minimum reaches 0.7 m at site 12, with an average of 2.27 m. It is clear that the central and north western parts of the lagoon have the greatest depths (Table 1 and Fig. 2.a). The studied sites display different values of salinity, where the lowest value is 4.3 g/l at site 18 in the southern part, while the highest value is 11.7 g/l at site 4 in the northern part (Table 1), with an average of 8.21 g/l, indicating that the ML is brackish water and increased toward the Mediterranean Sea. In general, the northern sector has higher salinities than the southern sector (Fig. 2.b). Relatively small variations in the values of pH between sites are recorded, where the highest value is 9.04 at site 26 in the western part, and the lowest is 8.51 at site 15 in the eastern part (Table 1 and Fig. 2.c), with an average of 8.78 reflecting that the lagoon is alkaline.

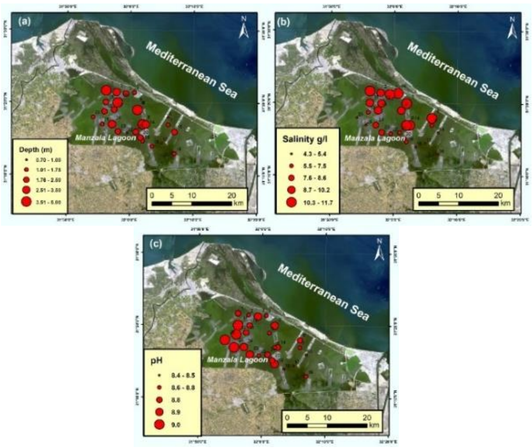

Fig. 2a shows the depth value of different sites at study area. a); fig.2b) shows salinity of different sites at study area; fig.2c) shows pH of different sites at study area.

The substrate of ML consists of a combination of sand, silt and clay (Table 1). The highest portions of sand covered the northern part due to entrance of sea water through the inlets (Fig. 3.a). The percentage of sand changes from 53% (site 5) to 9 % (sites 20 and 22). Also, the percentage of silt increases in the northern and western parts (Fig. 3.b). Generally, the invasion of drains, especially in the southern part, supplies the lagoon with higher portions of clay (Fig. 3.c). The lowest percentage of clay is 6 % (at site 3), while the highest is 52 % (at site 21).

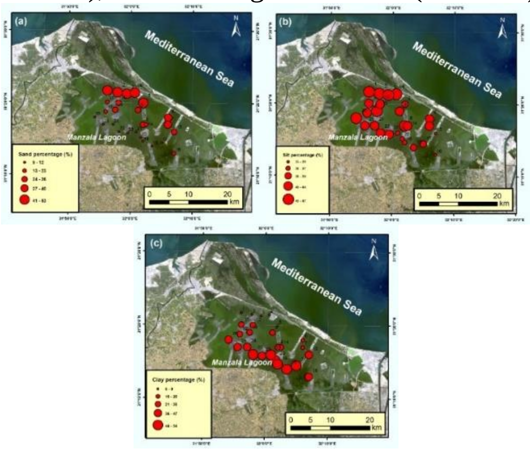

Fig.3a) shows the percentage of sand at different sites of study area.; fig.3b) shows the percentage of silt at different sites of study area; fig.3c) shows the percentage of clay at different sites of study area

Concentrations of HMs in the sediments

Concentrations of Fe, Cu, Zn, Co, Cd, Pb and Ni are clarified in Table 2. For Fe, the maximum value is 43375.81 µg/g at site 12, while the minimum is 1395.58 µg/g at site 22 (Fig. 4.a), with an average of 15223.39 µg/g. For Cu, the highest level is 48.01 µg/g at site 12, while the lowest is 1.07 µg/g at site 25 (Fig. 4.b), with an average of 16.94 µg/g.

For Zn, the maximum level is 188.5 µg/g at site 15, while the minimum is 6.43 µg/g at site 25 (Fig. 4.c), with an average of 67.15 µg/g. For Co, the maximum is 13.64 µg/g at site 17, while the minimum is 2.37 µg/g at site 25, with an average of 8.89 µg/g as shown in Figure 5.a. For Cd, the maximum level is 9.71 µg/g at site 1, while the minimum is 0.19 µg/g at site 2, with an average of 3.88 µg/g (Fig. 5.b). For Pb, the maximum is 117.15 µg/g at site 5, while the minimum is 12.48 µg/g at site 11 (Fig. 5.c), with an average of 20 µg/g. For Ni, the maximum level is 94.51 µg/g at site 23, while the minimum is 10.67 µg/g at site 6 (Fig. 5.d), with an average of 45.6 µg/g.

Contamination indices

To estimate the degree of pollution in the lagoon, some indices could be calculated such as Cf, Dc, I_{geo}, Ef, Er and Ri (Table 3). Average shale (World geochemical background concentration) of Turekian and Wedepohl (1961) is used here.

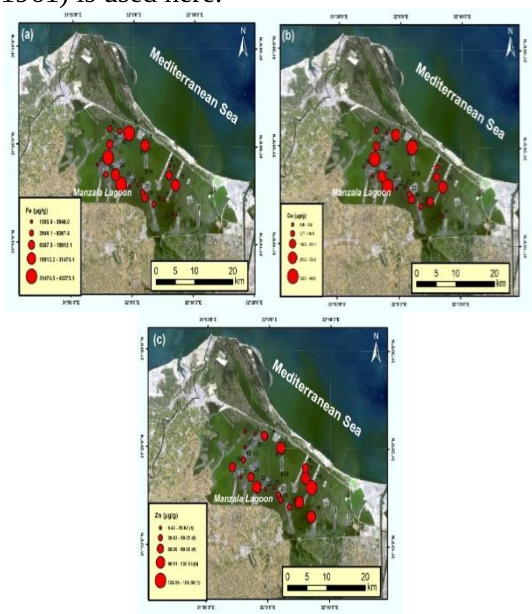

Fig. 4a) concentration of Fe in the studied sites.; fig.4b)concentration of Cu in the studied sites; fig.c) concentration of Zn in the studied sites

Table2. Measured heavy metals (µg/g) in the studied site

Site No.	Fe	Cu	Zn	Co	Cd	Pb	Ni
1	8367.42	10.05	13.69	ND	9.71	58.75	30.5
2	6669.16	ND	10.09	ND	0.19	25.05	ND
3	38620.69	23.84	77.04	ND	1.97	33.1	80
5	25519.93	37.81	124.37	10.94	2.22	117.15	62.47
6	3946	5.83	90.5	ND	ND	45.83	10.67
7	13309.98	14.36	135.55	ND	1.05	45.01	21.19
11	18913.1	21.1	18.14	2.41	0.83	12.48	39.66
12	43375.81	48.01	41.92	9.97	2.22	34.9	93.63
15	26181.82	33.4	188.5	7.98	1.11	62.89	57.51
16	1994.27	2.67	101.24	ND	ND	45.46	ND
17	3382.34	13.34	108.85	13.64	7.65	69.87	35.53
18	5544	7.2	46.4	10.4	7.6	87.2	27.4
19	15106.86	13.88	45.77	11.96	4.63	57.1	45.61
20	7266.73	6.78	50.05	ND	0.92	41.98	12.65
21	2505.95	3.17	20.62	13.01	8.56	58.21	27.12
22	1395.58	1.15	15.4	ND	ND	34.37	ND
23	42290.2	43.33	103.14	6.27	3.33	52.94	94.51
24	31474.45	31.39	76.82	2.37	2.92	42.88	68.61
25	5371.43	1.07	6.43	ND	ND	22.23	ND
26	3232.09	3.63	68.58	ND	7.26	64.57	22.54
Max	**43375.81**	**48.01**	**188.5**	**13.64**	**9.71**	**117.15**	**94.51**
Min	**1395.58**	**1.07**	**6.43**	**2.37**	**0.19**	**12.48**	**10.67**
Average	**15223.39**	**16.94**	**67.15**	**8.89**	**3.88**	**50.59**	**45.6**
Back ground Shale *	**47200**	**45**	**95**	**19**	**0.3**	**20**	**68**

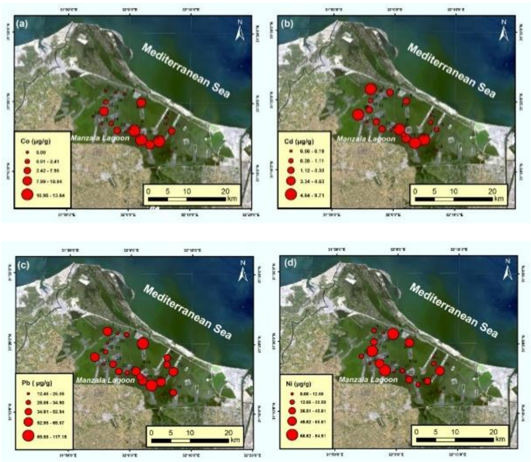

Fig.5a) shows concentration of Co in the studied sites; fig.5b) shows the concentration of Cd in the studied sites; fig 5c) shows concentration of Pb in the studied sites; Fig 5d) shows concentration of Ni in the studied sites.

Contamination factor (Cf)

The levels of contamination is categorized by Hökanson (1980) into the following classes; low Cf (<1), moderate (1≤ Cf < 3), considerable (3≤ Cf < 6), and very high (6≤ Cf). According to the values of Cf, it is clear that the examined bottom sediments of ML, are lowly contaminated with Fe (0.02-0.91) and Co (0.12-0.71) as shown in Table 4. Also, the sediments are lowly contamination with Cu, except for site 12, that is moderately contaminated (1.98). Also, most sites are lowly contamination with Zn, with the exception of sites 5, 7, 15, 16, 17 and 23 that are moderately contaminated. Similarly, most sites are lowly contaminated with Ni, with the exception of sites 3, 12, 23 and 24 that are moderately contaminated. On the contrary, variable values were calculated for Pb, where site 11 is lowly contaminated, sites 1, 2, 3, 6, 7, 12, 16, 19, 20, 21, 22, 23, 24 and 25 are moderately contaminated, whereas sites 5, 15, 17, 26 are considerably contaminated. For Cd, most sites are very highly contaminated; sites 11, 15 and 20 are considerably contaminated, while site 2 is lowly contaminated.

Degree of contamination (Dc)

According to the Dc, values range between 1.31 (site 25) and 48.73 (site 1), with an average of 15.98. Therefore, low degrees are recorded at sites 6, 11, 16, 20, 22 and 25 , moderate values at sites 2, 3, 12, and 15, considerable degrees at sites 5, 19, 23, and 24, and very high values at sites 1, 17, 18, 21, and 26 (Table 4 and Fig. 6.a).

Table 3. Contamination indices applied for the evaluation of metals in ML.

Contamination indices	Classes
Contamination factor (CF) CF = C_{metal}/ $C_{background\ value}$ Where C_{metal} = metal concentration in polluted sediments $C_{background\ value}$ = background value of the metal.	The contamination factors were divided into four classes by Hakanson (1980): Cf < 1 (low Cf), 1≤ Cf < 3 (moderate Cf), 3≤ Cf < 6 (significant Cf), and 6≤ Cf (extremely high Cf).
Degree of contamination (Dc) The sum of all values of contamination factors.	Four classes of contamination were distinguished by Hakanson (1980): Dc < 7 (low), 7<dc 28 (extremely high).</dc
Pollution Load Index (PLI) PLI= $(Cf1*Cf2*Cf3*\ldots\ldots Cfn)^{1/n}$ Where n is the number of metals and Cf is the Contamination factor.	Tomlinson et al. (1980) distinguished two groups: PLI < 1 (unpolluted); PLI = 1 (minimum pollution); PLI > 1 (polluted).
Geo-accumulation index (Igeo) $I_{geo} = \log_2 (C_n /(1.5 \times B_n))$ Where C_n is the concentration of the element in sediment sample and B_n is the background concentration of the element.	Igeo < 0 (unpolluted), Igeo = 0-1 (unpolluted-moderately polluted), Igeo = 1-2 (moderately polluted), Igeo = 2-3 (moderately-strongly polluted), Igeo = 3-4 (strongly polluted), Igeo = 4-5 (strong to very strongly polluted), and Igeo > 5 (very strong polluted) are the seven grades Müller (1969) made of the geo-accumulation index.
Enrichment factor (Ef) EF = $(M/Fe)_{sample}/(M/Fe)_{crust}$ Where $(M/Fe)_{sample}$ is the ratio of metal and Fe concentrations in the sample, and (M/Fe) crust is the ratio of metal and Fe concentrations in the earth's crust.	EF < 1 (no enrichment), EF < 3 (little enrichment), EF = 3–5 (moderate enrichment), EF = 5–10 (moderately severe enrichment), EF = 10–25 (severe enrichment), EF = 25–50 (very severe enrichment), and EF > 50 (very severe enrichment) are the seven classifications that Birch (2003) identified.
Risk factor (Er) Er=Tr* Cf Where Tr is the toxic-response factor for a given substance, and Cf is the contamination factor.	Hakanson (1980) distinguished the following classes: Er < 40 (low), 40 ≤ Er < 80 (moderate), 80≤ Er < 160 (considerable), 160 ≤ Er < 320 (high), Er ≥ 320 (very high).
Potential ecological risk index (Ri) The sum of all values of risk factors**.**	Hakanson (1980) distinguished the following classes: Ri < 150 (low), 150 < Ri < 300 (moderate), 300 < RI <600 (considerable), Ri > 600 (very high).

Table 4. Calculated Cf, Dc and PLI for the measured metals.

Site	Contamination factor (Cf)							Dc	PLI
	Fe	**Cu**	**Zn**	**Co**	**Cd**	**Pb**	**Ni**		
1	0.17	0.22	0.14	-	32.36	2.93	0.44	48.73	0.79
2	0.14	ND	0.10	-	0.63	1.25	-	12.43	0.33
3	0.81	0.52	0.81	-	6.56	1.65	1.17	11.55	1.28
5	0.54	0.84	1.30	0.57	7.4	5.85	0.91	17.44	1.45
6	0.08	0.12	0.95	-	-	2.29	0.15	3.61	0.32
7	0.28	0.31	1.42	-	3.5	2.25	0.31	8.09	0.82
11	0.40	0.46	0.19	0.12	2.76	0.62	0.58	5.16	0.46
12	0.91	1.06	0.44	0.52	7.4	1.74	1.37	13.47	1.22
15	0.55	0.74	1.98	0.42	3.7	3.14	0.84	11.39	1.18
16	0.04	0.05	1.06	-	-	2.27	-	3.44	0.27
17	0.07	0.29	1.14	0.71	25.5	3.49	0.52	31.02	0.97
18	0.11	0.16	0.48	0.54	25.33	4.36	0.40	31.00	0.80
19	0.32	0.30	0.48	0.62	15.43	2.85	0.67	17.84	0.98
20	0.15	0.15	0.52	-	3.06	2.09	0.18	6.18	0.49
21	0.05	0.07	0.21	0.68	28.53	2.91	0.39	32.86	0.56
22	0.02	0.02	0.16	-	-	1.71	-	1.93	0.12
23	0.89	0.96	1.08	0.33	11.1	2.64	1.38	18.41	1.43
24	0.66	0.69	0.80	0.12	9.73	2.14	1.00	15.18	0.99
25	0.11	0.02	0.06	-	-	1.11	-	1.31	0.29
26	0.06	0.08	0.72	-	24.2	3.22	0.33	28.63	0.68

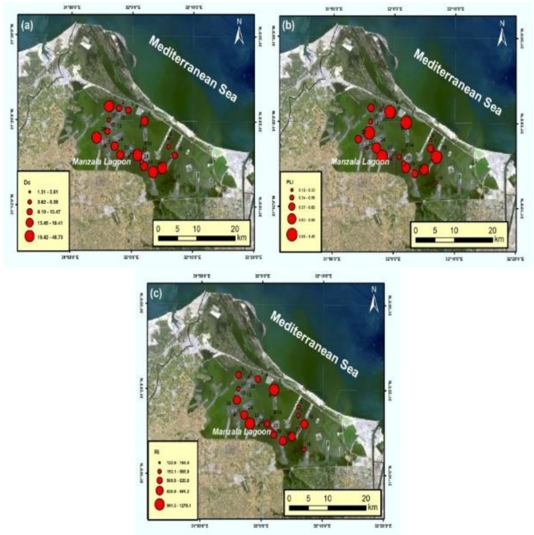

Fig.6a) show Dc for the measured metals, Fig.6b)shows PLI for the measured metals Fig.6c) shows RI for the measured metals .

Pollution Load Index (PLI)

According to Tomlinson et al. (1980), PLI reflects the pollution levels in every sites. The calculated values of PLI range between 0.12 (site 22) and 1.45 (site 5), with an average of 0.77. Most sites are unpolluted (< 1), whereas sites 3, 5, 12, 15 and 23 are polluted (> 1) as shown in (Table 4 and Fig. 6b).

Geo-accumulation index (I_{geo})

The geo-accumulation index of Müller (1969) is followed here. The outputs of I_{geo}, reflect that the bottom sediments of ML are unpolluted with Fe, Cu, Co and Ni, where all values are less than 0. For Cd, site 2 is unpolluted (I_{geo}= -0.374); sites 3, 5, 7, 11, 12, 15, 20, 23 and 24 are unpolluted-moderately polluted (0.26-0.86); while sites 1, 17, 18, 19, 21 and 26 are moderately polluted (1.01 -1.33). It is noted that site 1 is the most polluted with Cd. For Pb, sites 2, 11 and 25 are unpolluted-moderately polluted (0.41-0.83), sites 1, 3, 6, 7, 12, 16, 19, 20, 21, 22, 23, and 24 are moderately polluted (1.10-1.95), sites 15, 17, 18, and 26 are moderately to strongly polluted (2.09-2.90), while site 5 is strongly polluted (3.9) as displayed in Table 5.

Table 5. I_{geo} for the measured metals.

Site	Geoaccumulation index (Igeo)						
	Fe	Cu	Zn	Co	Cd	Pb	Ni
1	-0.92744	-0.82714	-1.01741	-	1.33407	1.958333	-0.5243
2	-1.02596	-	-1.14992	-	-0.37446	0.835	-
3	-0.26321	-0.452	-0.2671	-	0.64124	1.103333	-0.10551
5	-0.44315	-0.2517	-0.0591	-0.41583	0.69314	3.905	-0.21293
6	-1.25388	-1.06364	-0.19717	-	-	1.527667	-0.98044
7	-0.72586	-0.67215	-0.02172	-	0.36797	1.500333	-0.68247
11	-0.57327	-0.50502	-0.89518	-1.07283	0.26586	0.416	-0.41025
12	-0.21279	-0.14797	-0.53139	-0.45615	0.69314	1.163333	-0.03719
15	-0.43203	-0.30556	0.121496	-0.55284	0.39211	2.096333	-0.24886
16	-1.55025	-1.40279	-0.14846	-	-	1.515333	-
17	-1.32082	-0.70415	-0.11699	-0.32003	1.23049	2.329	-0.458
18	-1.10621	-0.97197	-0.4873	-0.43781	1.22761	2.906667	-0.57085
19	-0.67086	-0.68691	-0.49323	-0.37711	1.01238	1.903333	-0.34954
20	-0.98869	-0.99807	-0.45441	-	0.31055	1.399333	-0.90651
21	-1.45106	-1.32824	-0.83953	-0.34057	1.27921	1.940333	-0.57531
22	-1.70528	-1.76861	-0.96629	-	-	1.145667	-
23	-0.22379	-0.19252	-0.14039	-0.65758	0.86922	1.764667	-0.03312
24	-0.35208	-0.33251	-0.26834	-1.0801	0.81217	1.429333	-0.17221
25	-1.11994	-1.79992	-1.3456	-	-	0.741	-
26	-1.34055	-1.2694	-0.31762	-	1.20774	2.152333	-0.65565

Enrichment factor (Ef)

To detect the anthropogenic origin of metals, Ef was is as introduced by Birch (2003). For Cu, site 17 is moderately enriched, sites 3, 19, 20, 22, and 25 have no enrichment; while the other sites have minor enrichment (Table 6). For Zn, sites 1, 2, 3, 11, 12, and 25 have no enrichment, sites 5, 19, 23, and 24 have minor enrichment, sites 15, 18, and 21 have moderate Ef, sites 7 and 22 are moderately severe enrichment, while sites 6, 17, and 26 have severe Ef. For Co, sites 11, 12, 15, 23, and 24 have no enrichment, sites 5 and 19 have minor Ef, site 18 had moderate Ef, while sites 17and 21 have severe Ef. For Cd, sites 1, 17, 18, 21, and 26 have extremely severe enrichment, site 19 has very severe enrichment, sites 5, 7, 20, 23, and 24 have severe Ef, sites 2, 3, 11, 12, and 15 have moderately severe Ef. For Pb, sites 3, 11, 12, 23 have minor enrichment, site 24 has moderate Ef, sites 2, 7, 15, 19, 25 have moderately severe Ef, sites 1, 5, and 20 has severe Ef, sites 6, 17, 18, and 26 has very severe Ef, while sites 16 and 22 have extremely severe Ef. For Ni, sites 1, 3, 5, 6, 7, 11, 12, 15, 19, 20, 23, and 24 have minor Ef, sites 18 and 26 have moderate Ef, while sites 17and 21 have moderately severe Ef.

Table 6. Calculated Ef for the measured metals.

Site	Enrichment factor (Ef)					
	Cu	**Zn**	**Co**	**Cd**	**Pb**	**Ni**
1	1.25	0.81	-	182.57	16.57	2.53
2	-	0.75	-	4.48	8.86	-
3	0.64	0.99	-	8.02	2.02	1.43
5	1.55	2.42	1.06	13.68	10.83	1.69
6	1.54	11.39	-	-	27.40	1.87
7	1.13	5.059	-	12.41	7.98	1.10
11	1.17	0.47	0.31	6.90	1.55	1.45
12	1.16	0.48	0.57	8.05	1.89	1.49
15	1.33	3.57	0.75	6.67	5.66	1.52
16	1.40	25.22	-	-	53.79	-
17	4.13	15.98	10.01	355.84	48.75	7.29
18	1.36	4.158	4.66	215.68	37.11	3.43
19	0.96	1.50	1.96	48.22	8.92	2.09
20	0.97	3.42	-	19.91	13.63	1.20
21	1.32	4.08	12.89	537.43	54.81	7.51
22	0.86	5.48	-	-	58.1215	-
23	1.07	1.21	0.36	12.38	2.95	1.55
24	1.04	1.21	0.18	14.59	3.21	1.51
25	0.20	0.59	-	-	9.76	-
26	1.17	10.54	-	353.40	47.14	4.84

Ecological risk factor (Er) and Potential ecological risk factor (Ri)

To detect the toxicity of the studied HMs, Er is calculated based on Hakanson (1980). The toxic response factors of Cd, Ni, Pb, Cu, and Zn are 30, 5, 5, 5, and 1 respectively (Hakanson, 1980). For Cu, sites 6, 16, 18, 21, 22, 25 and 26 have low levels of toxicity, sites 1, 7, 17 and 19 have moderate levels, sites 3, 11 and 24 have considerable levels, sites 5, 12, 15 and 23 have high levels (Table 7). For Zn, sites 1, 11, 22, and 25 have low levels, sites 3, 12, 18, 19, 20, 24, and 26 have moderate levels, sites 5, 7, 16, 17, and 23 have considerable levels, while site 15 have high level. For Cd, sites 2, 7, 11, 15, and 20 have low levels, sites 3, 5 and 12 have moderate levels, sites 19, 23 24 have considerable levels, while sites 1, 17, 18, 21, and 26 have high levels. For Pb, site 11 has moderate levels, sites 2 and 25 has considerable levels, sites 1, 3, 6, 7, 12, 15, 16, 19, 20, 21, 22, 23, and 24 have high levels, while sites 5, 17, 18, and 26 have very high levels. It is noted that site 5 was the highest value of Er. According to Hakanson (1980), Ri is identified as the sum of all of risk factors. These values range between 122.93 (site 25) and 1278.12 (site 5), with an average of 676.30. Sites 2 and 25 have low Ri, site 22 has moderate Ri, sites 6, 7, 11, 16, and 20 have considerable Ri, while sites 1, 3, 5, 12, 15, 17, 18, 19, 21, 23, 24, and 26 have very high Ri (Fig. 6 c).

Table 7. Calculated Er and Ri for the measured metals.

Site	Ecological risk factor (ER)					Potential ecological risk index (Ri)
	Cu	**Zn**	**Cd**	**Pb**	**Ni**	
1	50.25	13.69	291.3	293.75	152.5	801.49
2	-	10.09	5.7	125.25	-	141.04
3	119.2	77.04	59.1	165.5	400	820.84
5	189.05	124.37	66.6	585.75	312.35	1278.12
6	29.15	90.5	-	229.15	53.35	402.15
7	71.8	135.55	31.5	225.05	105.95	569.85
11	105.5	18.14	24.9	62.4	198.3	409.24
12	240.05	41.92	66.6	174.5	468.15	991.22
15	167	188.5	33.3	314.45	287.55	990.8
16	13.35	101.24	-	227.3	-	341.89
17	66.7	108.85	229.5	349.35	177.65	932.05
18	36	46.4	228	436	137	883.4
19	69.4	45.77	138.9	285.5	228.05	767.62
20	33.9	50.05	27.6	209.9	63.25	384.7
21	15.85	20.62	256.8	291.05	135.6	719.92
22	5.75	15.4	-	171.85	-	193
23	216.65	103.14	99.9	264.7	472.55	1156.94
24	156.95	76.82	87.6	214.4	343.05	878.82
25	5.35	6.43	-	111.15	-	122.93
26	18.15	68.58	217.8	322.85	112.7	740.08

Discussion

This investigation tries to assess the levels of pollution in the bottom sediments of ML after the dredging process that carried out by the Egyptian government. Moreover, the detection of the ecological risks that resulted from the contaminated sediments is another target. Furthermore, the measurements of some ecological parameters are essential to realize the quality of any aquatic environment.

The measured concentrations of HMs indicate that the average levels of the metals are arranged as: Fe > Zn > Pb > Ni > Cu > Co > Cd. It is noted that, Fe fluctuates in a wide range in the sediments of ML, representing the highest concentration than any other metal. Similarly, Zn, Pb and Ni have wide range of variations between different sites. Pb, Zn and Cd are toxic elements and they have dangerous effects on marine fauna (Zahran et al., 2015). Pb possesses higher concentrations due to different sources, including phosphate fertilizers, paint factories, and gas factories (e.g., Hamed et al., 2013; Redwan and Elhaddad, 2022). The excessive usage of phosphate fertilizers and pesticides in agriculture may be the reason for increasing the levels of Cd (Redwan and Elhaddad, 2022). Moreover, the sources of Cu and Ni may be related to the discharges of agricultural drains in the southern side and industrial wastes in the eastern side (industrial region in Port Said).

The comparison between the concentrations of the measured HMs and those of the back ground Shale (Turekian and Wedepohl, 1961) is discussed here as follows.
The measured concentrations of Fe and Co in all the studied sites are lower than those of the back ground Shale. For Cu, all sites have lower values, except site 12 (in the south-western part) has higher value. For Zn, most sites have lower values, with the exception of sites 5, 7, 15, 16, 17 and 23 that have higher values. For Cd, most sites have higher values. For Pb, all sites have higher values, with the exception of site 11(western part) has lower value. For Ni, most sites have lower values, with the exception of sites 3, 12, 23 and 24 have higher values.

The present distribution patterns of the HMs in the lagoon are disturbed, due to the dredging processes that led to the accumulation of polluted sediments in many sites in the lagoon. Therefore, these polluted sediment may be easily transported to different uncontaminated parts, resulting in high levels of pollution. Consequently, the concentrations of the examined metals have no significant trends.

To detect the relationship between the heavy metals, Pearson's correlation was applied on heavy metals. The resulting correlation matrix is shown in (Table 8). The values are considered significant if p-value ≤ 0.05, moderate significant ≤ 0.01, and highly significant ≤ 0.001. According to Suresh et al. (2011), the significant positive correlation between heavy metals reflects their common sources, and the same behavior during the transport. It is noted that, Fe has strong positive correlation with Cu (0.92) and Ni (0.93), indicating the same geochemical behavior (Figs. 7.a, 7.b). Also Cu has a strong positive correlation with Ni (0.93) as shown in Figure 7.c. Also, Pb has a moderate positive correlation with Co (0.58) and a significant positive correlation with Cd (0.49) as presented in Figure 7.d. Moreover, Cd has a significant positive correlation with Co (0.49). Pb is signified as an indicator of anthropogenic source. Consequently, Cd, Co and Zn may have the same origin. On the other side, Fe and Cu have no significant relationship with Cd and Pb.

It is necessary to compare the current results with the former results on ML (Table 9), to determine the state of the lagoon after the development processes that carried out by the Egyptian government. The previous studies reflected that the southern side is more polluted than the northern side (e.g., Abdel-Satar and Genid, 2009; El Baz, 2017; Elmorsi et al., 2017; Abdel Gawad, 2018; Redwan and Elhaddad, 2022).

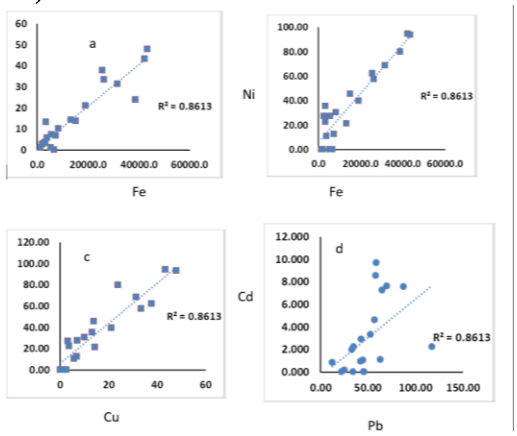

Fig 7 shows Pearson's correlation on heavy metals;

(Figs. 7.a, 7.b) Fe has strong positive correlation with Cu (0.92) and Ni (0.93); Figure 7.c) Cu has a strong positive correlation with Ni (0.93); Figure 7.d) Pb has a moderate positive correlation with Co (0.58) and a significant

In this context, the current concentration of Fe (15223.39) is higher than those of the previous studies of Abdel-Satar and Genid (2009), El Baz (2017) and Elmorsi et al., (2017). For Zn (67.15 µg/g), it is lower than that of Redwan and Elhaddad (2022), but it is higher than those of EL-Bady (2016) and Abdel Gawad (2018). For Cu (16.94 µg/g), it is lower than those of the above-mentioned studies. For

positive correlation with Cd (0.49).

Pb (50.59) and Cd (3.88), they are higher than those of Abdel Gawad (2018) and Redwan and Elhaddad (2022), but they are lower than those of Abdel-Satar & Genid (2009). Also, the unexpected lower concentrations of HMs in some southern sites of the lagoon may be due to the removal of huge amounts of bottom sediments.

Table 8. Pearson's correlation coefficients (r) between the measured heavy metals in in bottom sediments of ML.

	Fe	Cu	Zn	Co	Cd	Pb	Ni
Fe	1						
Cu	0.92***	1					
Zn	0.30	0.45*	1				
Co	0.18	0.38	0.19	1			
Cd	-0.17	-0.08	-0.15	0.47*	1		
Pb	-0.03	0.19	0.45*	0.58**	0.49*	1	
Ni	0.93***	0.93***	0.33	0.43	0.13	0.19	1

*, **, *** significant correlation at P ≤ 0.05, moderate significant ≤ 0.01, and highly significant ≤ 0.001

Table 9. Comparison between the analyzed heavy metals (µg/g) in Manzala Lagoon and those measured in other localities.

Locality	Mn	Fe	Cu	Zn	Cd	Ni	Pb	Cr	Reference
Manzala Lagoon, Egypt	1334	4460	90.99	207.8	10.61	108.14	379.4	-	Abdel-Satar and Genid, 2009
	725.55	1074.55	31.21	39.53	1.67	30.83	0.077	40.95	EL-Bady, 2016
	38.1488	8342.47	26.34	30.32	0.0264	40.73	0.244	-	Abdel Gawad, 2018
	880	14130	110	110	1.8	60	20	-	Redwan and Elhaddad, 2022
	-	15223.39	16.94	67.15	3.88	45.6	50.59	-	Present study
Burullus Lagoon, Egypt	948	17550	30	50	0.2	40	30	-	Melegy et al., 2019
Bardawil, Lagoon, Egypt	352.57	2092.7	46.01	52.93	15.79	30.29	29.8	42.09	EL-Bady , 2016
Mariout Lagoon, Egypt	585	19340	91	139	0.7	40	59	-	EL-Bady, 2020
Mediterranean Coast, Egypt	381	13256	8.46	22.19	0.22	25.93	13.17	82.74	Soliman et al., 2015a
Red Sea Coast, Egypt	136.3	7094.4	25.4	24	1.05	11.5	8.55	18.3	El-Kahawy et al., 2021
Mediterranean Coast, Libya	28.6	571.4	15.4	20.1	8.3	22.2	36.6	18.7	Soliman et al., 2015b
Tarut Island, Arabian Gulf , Saudi Arabia	75.2	3447	5.8	17.6	0.7	-	58.7	27.1	Youssef et al., 2015
Homa Lagoon, Turkey		16500-28300	9-24	38-88	0.5-0.8	-	6-30	92-220	Tas and Sunlu, 2013
Gulf of Izmir, Turkey	522.43	-	22.38	99.87	0.03	108.12	48.37	109.56	Bergin et al., 2006
Sidi Moussa lagoon, Morocco		-	30.4	49.8	-	29.1	-	96.9	Maanan et al., 2004
Oubeira Lagoon, Algeria		13436.25	23.51	89.95	0.038	101.75	21.21	102.75	Belabed et al., 2011
Tunis Lagoon, Tunisia		41727.19	27.28	148.52	1.51	71.81	102.22	99.84	Abidi et al., 2022

Risk assessment of HMs

The average values of Cf are arranged as follows: Cd (12.95208) > Pb (2.529925) > Zn (0.706895) > Ni (0.680461) > Co (0.468158) > Cu (0.37662) > Fe (0.322529). These values indicate that the sediments are lowly polluted with Zn, Ni, Co, Cu and Fe; moderately polluted with Pb; while they are very highly polluted with Cd. The average value of Dc reaches 15.96, indicating a considerable level of contamination. According to PLI, most sites are unpolluted, whereas sites 3, 5, 12, 15, and 23 are polluted. Concerning the values of I_{geo}, the bottom sediments of ML are unpolluted with Fe, Cu, Co and Ni. On the contrary, all sites are polluted with Pb. For Cd, most sites are polluted and the highest value reaches 1.33 in site 1. The average values of Er are arranged as follows: Pb (252.99) > Ni (228) > Cd (116.56) > Cu (84.73) > Zn (67.15). Furthermore, the average values of enrichment factor indicate minor enrichment for Cu (1.28); moderate enrichment for Zn (4.96) and Co (3.28); extremely severe enrichment for Cd (112.51); a moderate Ef for Pb (21.05) and minor Ef for Ni (2.66). Consequently, Cd and Pb are the principal contributors for the ecological risk in ML. According to Ungureanu et al. (2016), Pb and Cd originate chiefly from anthropogenic activities. These results indicate a high Er for Pb and Ni; a considerable Er for Cd and Cu; whereas Zn has a moderate Er. Moreover, the average value of Ri (676.30), suggesting that the bottom sediments of ML have very high risk, due to the higher levels of Cd and Pb.

Comparison between the measured HMs and those from other aquatic ecosystems

The concentrations of the measured HMs are correlated with those documented from other sites inside Egypt (Table 9 and Fig. 8) and outside Egypt (Figure 9), including Libya, Tunisia, Algeria, Morocco, Saudi Arabia and Turkey (Table 9).

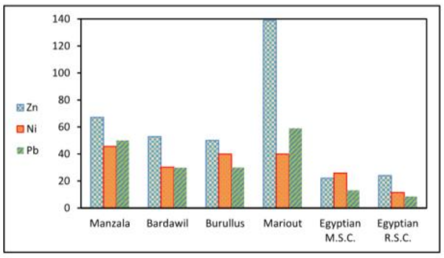

Fig 8 shows the concentrations of the measured HMs which correlated with those documented from other sites inside Egypt

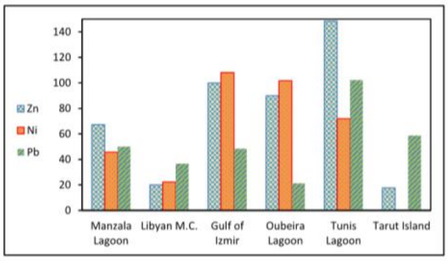

Fig 9 shows the concentrations of the measured HMs which correlated with those documented from other sites outside Egypt

Egypt

Many studies have been carried out on the evaluation of HMs in the surface sediments of the Egyptian lagoons and coasts, including Burullus Lagoon (e.g., Masoud et al., 2011; El Baz and Khalil, 2018; Melegy et al., 2019), Bardawil, Lagoon, Mariout Lagoon (e.g., EL-Bady, 2016), Edku Lagoon (e.g., Badr-ElDin et al., 2022), the Mediterranean Coast (Soliman et al., 2015a), and the Red Sea Coast (El-Kahawy et al., 2021). In Burullus Lagoon, Masoud et al. (2011) and El Baz and Khalil (2018) pointed to the higher concentrations of Cd. In Edku Lagoon, the investigation of Badr-ElDin et al. (2022) suggested that, Cd and Pb have severe effects on the aquatic biota. According to El-Bady (2016), the highest degrees of contamination were recorded in the Bardawil Lagoon, whereas the Burullus Lagoon had the lowest values. The study of Soliman et al. (2015a) on the surface sediments of the Egyptian Mediterranean coast, indicated that Fe has the greatest concentration followed by Mn, Cr, Ni, Zn, Pb, Cu and Cd. Moreover, El-Kahawy et al. (2021) examine the concentrations of metals in the sediments of the Red Sea Coast, and concluded that the order of metals were Fe > Mn > Cu > Zn > Cr > Ni > Pb > Cd.

Libya

Also, Soliman et al. (2015b) recorded higher levels of Pb (36.6 μg/g), Ni (22.2 μg/g), Cr (18.7) and Cd (8.3 μg/g) from the sediments of the Mediterranean Coast of Libya. They concluded that, the sediments were polluted with Cd. Also, Omar et al. (2021) investigated the metal pollution in the surface sediments along the northeastern coast of Libya and indicated that the metals were arranged as Al > Fe > Mn > Zn > Cu > Pb > Cd. They concluded that the concentrations of metals have lower values than those of the background, with the exception of Cd, that has higher values in some sites.

Tunisia

Fe has the highest content (41727.19 μg/g), followed by Zn (148.52 μg/g), Pb (102.22 μg/g), Cr (99.84 μg/g), Ni (71.81 μg/g), Cu (27.28 μg/g), and Cd (1.51 μg/g), according to a study by Abidi et al. (2022) in the bottom sediments of the South Lagoon of Tunis.

Algeria

Belabed et al. (2011) showed that the sediments of Oubeira lagoon display the following levels HMS: Fe (13436.25 µg/g), Cr (102.75 µg/g), Ni (101.75 µg/g), Zn (89.95 µg/g), Pb (21.21 µg/g) and Cd (0.038 µg/g).

Morocco

Also, many investigations have been carried out on the assessment of HMs in the bottom sediments of different Moroccan ecosystems (Maanan et al., 2004; Ben bouih et al., 2005; Tnoumi et al., 2022). The study of Tnoumi et al. (2022), on the sediments of Khnifiss Lagoon recorded minor enrichments with Ni and Cd.

Saudi Arabia

In the Arabian Gulf, Saudi Arabia, Youssef et al. (2015) recorded higher values of Pb (58.7 µg/g) from the surface sediments of Tarut Island.

Turkey

The geochemical analysis of Bergin et al. (2006) for the HMs in the surface sediments of the Gulf of Izmir, reflected that Mn had the highest levels followed by Cr, Ni, Zn, Pb, Cu, Cd. They observed high values for Cr (109.56 µg/g), Ni (108.12 µg/g), Zn (99.87 µg/g) and Pb (48.37 µg/g). Moreover, Tas and Sunlu (2013), indicated that the concentrations of Fe in the Homa lagoon ranged from 16500-28300 µg/g, Cr (92-220 µg/g), Zn (38-88 µg/g), Cu (9-24 µg/g), Pb (6-30 µg/g) and Cd (0.5-0.8 µg/g).

From the above-mentioned studies, it is clear that the current levels of Fe in ML is higher than those recorded in Burullus (Melegy et al., 2019), Egyptian Mediterranean Coast (Soliman et al., 2015a), Egyptian Red Sea (El-Kahawy et al., 2021), Libyan Mediterranean Coast (Soliman et al., 2015b), Oubeira Lagoon, Algeria (Belabed et al., 2011); Tarut Island, Arabian Gulf, Saudi Arabia (Youssef et al., 2015) and Gulf of Izmir, Turkey (Bergin et al., 2006), but it is lower than those recorded in Mariout (EL-Bady, 2016) and the South Lagoon of Tunis, Tunisia (Abidi et al., 2022).

For Cu, It is lower than those recorded in the Burullus (Melegy et al., 2019), Bardawil (EL-Bady, 2016), Egyptian Red Sea (El-Kahawy et al., 2021), Gulf of Izmir, Turkey (Bergin et al., 2006), Sidi Moussa lagoon, Morocco (Maanan et al., 2004), Oubeira lagoon, Algeria (Belabed et al., 2011), Tunis Lagoon, Tunisia (Abidi et al., 2022), but it is higher than those of the Egyptian Mediterranean Coast (Soliman et al., 2015a), Libyan Mediterranean Coast (Soliman et al., 2015b), Tarut Island, Arabian Gulf, Saudi Arabia (Youssef et al., 2015) and Homa Lagoon, Turkey (Tas & Sunlu, 2013).

For Zn, It is lower than those recorded in Mariout (EL-Bady, 2016), Gulf of Izmir, Turkey (Bergin et al., 2006), Oubeira lagoon, Algeria (Belabed et al., 2011) and Tunis Lagoon, Tunisia (Abidi et al., 2022), but it is higher than those in Burullus (Melegy et al., 2019), Egyptian Red Sea (El-Kahawy et al., 2021),Sidi Moussa lagoon, Morocco (Maanan et al., 2004), Egyptian Mediterranean Coast (Soliman et al., 2015a); Libyan Mediterranean Coast (Soliman et al., 2015b), Tarut Island, Arabian Gulf, Saudi Arabia (Youssef et al., 2015) and Homa Lagoon, Turkey (Tas and Sunlu, 2013).

For Cd, it is higher than those recorded in all the above sites, with the exception of Bardawil (EL-Bady, 2016) and Libyan Mediterranean Coast (Soliman et al., 2015b). For Ni, it is higher than those recorded in all the above environments, with the exception of Gulf of Izmir, Turkey (Bergin et al., 2006) and Oubeira lagoon, Algeria (Belabed et al., 2011). For Pb, it is higher than those recorded in all the above ecosytems, with the exception of Mariout Lagoon (EL-Bady, 2016).

Conclusions

The continuous monitoring for pollution is very essential for saving the health of ML. Based on the geochemical analysis of HMs in the bottom sediments of ML, the metals are arranged as: Fe > Zn > Pb > Ni > Cu > Co > Cd. Compared with many other aquatic ecosystems in Egypt, ML possesses higher concentrations of Fe, Pb, Cd, Zn and Ni. On the contrary, it displays lower levels of HMs compared with north African Lagoons. This study tries to assess the levels of pollution depending on the contamination indices. The findings of Cf reflect that the sediments have high contamination with Cd, moderate contamination with Pb, and lowly contamination with Zn, Ni, Co, Cu and Fe. The values of I_{geo} indicated that the sediments are unpolluted with Fe, Cu, Co and Ni; unpolluted-moderately polluted with Cd; and moderately to strongly polluted with Pb. Moreover, the average values of enrichment factor indicate minor enrichment for Ni, Cu, moderate enrichment for Zn, Co, severe enrichment for Pb and extremely severe enrichment for Cd. The results of risk factors reflect a higher risk for Pb and Ni; a considerable risk for Cd and Cu; whereas Zn displays a moderate risk. The average value of Ri (676.30) suggest that sediments have very high risk. Thus, Cd and Pb are the principal contributors for the ecological risk in ML.

Data availability

All data generated or analyzed during this study are included in this published article.

Declarations

The authors declare no competing interests.

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الملخص العربي

عنوان البحث: المعادن الثقيلة في الرواسب السفلية لبحيرة المنزلة، مصر: تقييم وربط مع النظم البيئية المائية الأخرى في البحر الأبيض المتوسط

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في الآونة الأخيرة، أصبح الرصد الدقيق للبحيرات الساحلية ضرورة ملحة لحمايتها من الآثار الخطيرة للتلوث. تهدف هذه الدراسة إلى تقييم تلوث المعادن الثقيلة في إحدى أهم البحيرات الساحلية في مصر، وهي بحيرة المنزلة (ML). تُظهر تركيزات المعادن الثقيلة المقاسة أن Fe > Zn > Pb > Ni > Cu > Co > Cd. لتقييم مستويات التلوث في البحيرة المدروسة، تم حساب سبعة مؤشرات تلوث، تشمل عامل التلوث (Cf)، ودرجة التلوث (Dc)، ومؤشر التراكم الجغرافي (Igeo)، ومؤشر حمل التلوث (PLI)، وعامل الإثراء (Ef)، وعامل الخطر البيئي (Er)، وعامل الخطر البيئي المحتمل (Ri). وفقًا لـ Cf، فإن الرواسب ملوثة بدرجة منخفضة بالزنك والنيكل والكوبالت والنحاس والحديد، وملوثة بدرجة متوسطة بالرصاص، وملوثة بدرجة عالية جدًا بالكادميوم. يبلغ متوسط قيمة Dc (١٥,٩٦)، مما يشير إلى مستوى تلوث كبير. علاوة على ذلك، تشير متوسط قيم Ef إلى إثراء طفيف للنيكل والنحاس، وإثراء متوسط للزنك والكوبالت، وإثراء شديد للرصاص، وإثراء شديد للغاية للكادميوم. يصل متوسط قيمة Ri إلى ٦٧٦,٣، مما يشير إلى أن الرواسب ذات مخاطر عالية جدًا. وبالتالي، فإن الكادميوم والرصاص هما المساهمان الرئيسيان في المخاطر البيئية في ML. وأخيرًا، تمت مقارنة تركيزات المعادن الثقيلة في بحيرة المنزلة وغيرها من بحيرات البحر الأبيض المتوسط.