Research Article

Assessment of potentially toxic elements in water and sediments in the drainage network of Lake Mariout, Egypt

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Abstract

The present work investigated the distribution and assessment of potentially toxic elements (PTEs) in the water and surface sediments of both Qalaa and Umum Drains. The water samples were taken from eighteen sampling sites covering the downstream part of the two drains before reaching Lake Mariout Main Basin (LMMB) and Lake Mariout Fishery Basin (LMFB) during the summer period. The samples collected were analyzed for Cu, Cd, Zn, Co, Ni, Mn, Fe and Al. Pollution loading index (PLI), enrichment factor (EF), contamination factor (C_F), Geo accumulation index (I_{geo}) and sediment quality guidelines (SQGs) were calculated as a criterion of possible contamination. Qalaa Drain is characterized by a low pH value of 6.93 compared to the other waters in the studied areas. The lowest Cl was always recorded in the water of Qalaa Drain with an average of 0.65 g Cl/L. The water of Umum Drain, LMMB and LMFB are continually aerated with O_2 concentration, compared to the Qalaa drain, which constantly carries H_2S. The outcomes revealed that the concentrations of the dissolved metals are at suitable levels according to U.S. Environmental Protection Agency (USEPA). Fe and Al are the two abundant metals in the sediment of the four studied areas. The order of abundance of the metals in the sediments of the present study areas was Fe > Al > Zn > Mn > Cu > Ni > Co > Cd. For the sediments, only cadmium and zinc concentrations in all sites during the study period exceeded the average shale rock concentration. According to the examined indices, the level of contamination in Qalaa Drain ranges from considerable to extremely high. Additionally, the four examined regions have higher Cu and Zn contents than SQGs.

Article Highlights

- Base line of the PTEs pollution for the Lake Mariout drainage network.
- Pollution indices analysis of water and sediment of Lake Mariout.
- Ecotoxilogical and background concentrations of PTEs in sediments.

Keywords Surface sediments · Agricultural drainage waters · PTEs · Pollution loading index · Lake Mariout · Egypt

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1 Introduction

PTEs are considered a major anthropogenic contaminant in coastal and marine environments worldwide [1]. They pose a serious threat to human health, living organisms and natural ecosystems because of their toxicity, persistence and bio-accumulation characteristics [2]. Many PTEs are known to be toxic or carcinogenic to humans [3]. PTEs can contribute to the degradation of marine ecosystems by reducing species diversity and abundance and accumulating metals in living organisms and food chains [4]. Anthropogenically, PTEs can be introduced to coastal and marine environments through various sources, including industries, wastewaters and domestic effluents [3]. PTEs in marine sediments originate from geogenic (physical and chemical weathering of parent rocks) and anthropogenic sources [5]. With rapid industrialization, urbanization, and associated activities like agriculture, domestic and mining waste disposal constitute the major anthropogenic inputs. These unusual activities affect the natural environment and ecosystem i.e. water, sediment, and organisms [6]. Pollutants and their relationship with anthropogenic activities are used in understanding pollution status in marine systems for example: study the trace metals and nutrients in bottom sediments of the Southport Broad water [7], in surficial sediments of the northwest coast of Baja California, Mexico [8], Lake Mariout Drainage System [9, 10], pesticides pollution and treatment techniques [11], and study the ecological conditions of Mariout Lake and relation to their suitability for fish living [12].

Previous studies have proven the presence of pollution in places close to drainage sites on the Mediterranean Sea [13, 14]. Several studies have looked at the distribution and concentration of Cu, Cd, Zn, Co, Ni, Pb, Mn, and Fe in Qalaa and Umum Drains utilizing the Chelex-100 resin for particulate and dissolved metals detection [9, 10, 12]. These drains led the introduction of several PTEs to the Mediterranean coast of Egypt [15, 16]. This work aimed to assess the existing levels of concentrations of Cu, Cd, Zn, Co, Ni, Mn, Fe and Al in water and surface sediment of four studied areas at Qalaa and Umum Drains, LMFB and S-LMMB in Alexandria city, Egypt. The structure of the article is as follows. The materials and experimental techniques employed in this work are presented in Sect. 2. The results and discussion for the heavy metals in the water and sediment gathered from the study region are detailed in Sect. 3. We conclude the work and give the results in Sect. 4.

2 Material and methods

2.1 Study area

The agricultural drainage waters from the watershed agricultural fields of Alexandria and El-Bohaira Provinces enter Mariout Lake via two major drains, the Qalaa and Umum Drains, respectively (Fig. 1). The heavily contaminated Qalaa Drain on the southeast edge of the Lake Mariout Main Basin (LMMB), where its dirty water enters the LMMB. However, Umum Drain borders LMMB on its extreme west side, and a large portion of its water feeds this basin via frequent unlawful breaches caused by fishers on its east bank, particularly in the region adjacent to LMMB's southwest corner [9–11]. Prior to the building of the East wastewater treatment plant (EWTP) in 1993, Qalaa Drain was filled with a significant amount of oxygen-consuming debris, which caused the water to be perpetually anoxic and emit poisonous and malodorous odours (mostly H_2S) [10]. As this drain is the primary supply of water for the LMMB, and its water still contains H_2S, the majority of the LMMB, particularly its eastern half, has deteriorated. The unsuitability of LMMB water for live aerobic organisms, including fish, has an effect on the fish harvest [10]. According to the Egyptian Environmental Affair Agency [12], the water quality of this drain contains H_2S and a number of elements in quantities that exceed the recommended maximums. However, the dumping of agricultural and industrial waste into the seas along the Egyptian coasts causes numerous marine pollution issues [12].

2.2 Sampling and analysis

The present study is concerned with collecting surface water, and sediment samples in the lower reach of both Qalaa and Umum Drains besides LMFB and the southern side of LMMB (Fig. 1). Eighteen sampling sites were selected, covering the downstream part of the two drains before reaching the south part of Lake Mariout besides the southern part of the LMMB and LMFB during the summer of 2007. Three of these seven sampling sites [Sites (I), (II), and (VI)] were flowing waters from three key subsidiary pumping stations (PSs) called Dishudi, Haris, and Abis, respectively, in the Umum Drain course. The other four sites were located in the Umum Drain's main stem downstream section.

In Qalaa drain, eight sampling sites were sampled starting from Qalaa PS (mixture between wastewater effluent from EWTP and the agriculture drainage water from east Alexandria city). In contrast, the others were

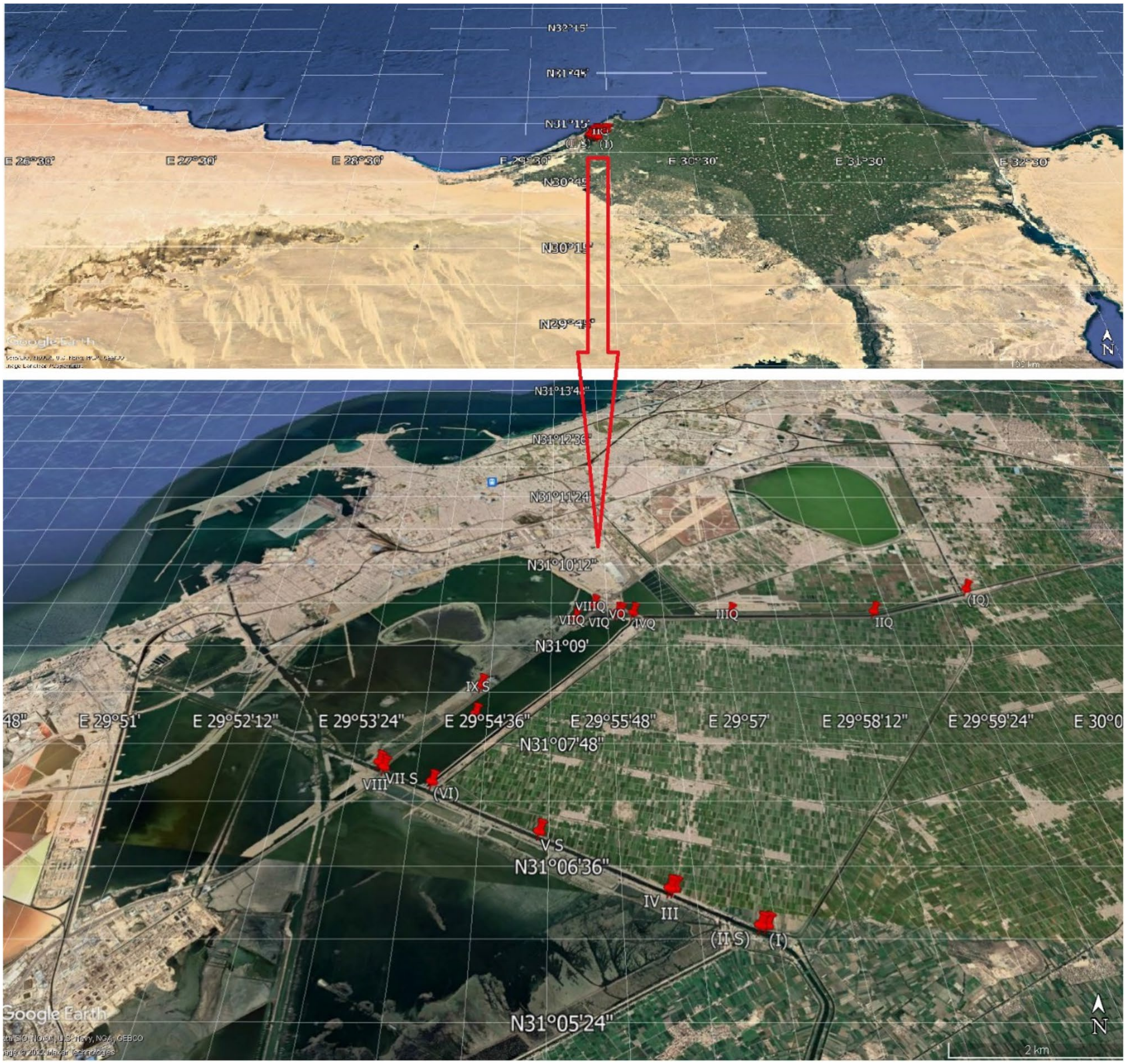

Fig. 1 The location of sampling sites in the four studied areas (Qalaa and Umum Drains, LMFB and S-LMMB)

distributed along the drain course downstream before joining Lake Mariout (at its southeast part). Further, two sites were located at LMMB. One (station VIII) was in the SW-LMMB near Umum Drain inlet, while the other (Station IX) faced Qalaa Drain inlet to the SE-LMMB. The last station was in the center of the LMFB.

A 5-L plastic sampling bottle was used to collect the water samples, with at least 4 L of each water sample being used for metals analysis. Sub-water sample was used for the measurement of water temperature and pH. Each temperature, Secchi disc transparency depth STD and the water column total depth were in situ measured. Water samples for dissolved oxygen (DO) or hydrogen sulphide (H_2S) measurements were independently collected using an APHA-DO Sample and analyzed according to APHA [17] and Grasshoff and Kremling [18]. Millipore 0.45 m filter membrane was used to filter the water samples before the metal analysis. The filtrate was pre-concentrated by passing it through Chelex-100 resin in ammonia form, and the eluted metals were collected. Particulate metals were also identified by digesting the TSM left on the filters [19]. The metals in the acid extract were examined using an Atomic Absorption Spectrophotometry Perkins-Elemer 2380 equipment, including dissolved and particulate metals. The concentrations of metals after passing through columns containing Chelex-100 were determined after solutions with known various metal concentrations were passed through them. The efficiency for the tested metals was computed after the findings were compared to the actual standard values, and it was within (97 ± 0.5%).

Only ten sampling sites were sampled for sediments using the Van-Veen Grab sampler. Four were from Umum Drain, two from LMMB, three from Qalaa Drain, and the last sample was from LMFB. The sediment samples were kept in self-sealed plastic bags and stored in an icebox. The sediment samples after dryness in an oven at 60 °C were used to determine some of their physical and chemical properties (such as grain size, OC and ON) in addition to the contents of the metal (Cu, Cd, Zn, Co, Ni, Mn, Fe and Al). The Grain size were determined using the sieve and pipette analysis methods [20]. The organic carbon (OC) content in the sediment was determined according to the method described by Gaudette et al. [21]. Known portion of the sediment samples was grinded and passed through a 63 µm screen; 0.2 g of the dry grinded sediment sample was oxidized using 10 mL of 1 N dichromate solution in a 500 mL conical flask. Then 20 mL of concentrated H_2SO_4 acid was carefully added and mixed gently for about one minute. After 30 min, the contents were diluted with distilled water to 200 mL, then 10 mL orthophosphoric acid and 1 mL diphenylamine indicator were added. (0.4 N) ferrous ammonium sulphate was used to titrate the sample (FAS). The identical procedure was followed for the blank determination but without the sediment sample.

The micro Kjeldahl technique determined the Organic nitrogen (ON) in the sediment according to Moore and Gorsline [22]. Where 0.2 g of dried sediment sample was placed in a Kjeldahl flask and 3 ml of conc. H_2SO_4 was added. The mixture was heated gently initially, then over a strong flame for a total 15 min. After slightly cooling, a few drops of 30% hydrogen peroxide were added and the heating was continued for 10 min. The cooled sample solutions were washed into a stream distilling unit of the Kjeldahl type and mixed with 40% NaOH. The two solutions were mixed, and the resulting ammonia was distilled over the acid trap by stream drive. The evolved gas is carefully passed through 10 mL of 0.01 N HCl for ten min. The acid solution is boiling and back titrated with 0.01 N NaOH to clear the pale orange endpoint using a few drops of methyl red indicator.

The studied PTEs were determined using the method described by Oregioni & Aston [23]. 0.3 g of the dried and grounded sediment sample was treaded with 3 mL conc. HNO_3, 2 ml conc. $HClO_4$ and 1 mL conc. HF in a Teflon beaker and left for 24 h as a pre-digestion step and then heated on the hot plate at 180 °C for near dryness. Then 1 mL conc. HCl was added and repeats heating again and cooling to room temperature. The sample is transferred and completed to 25 mL by 1% HNO_3 in a measuring flask [23, 24]. The analysis was performed using the AAS. The metal concentrations were expressed as µg/g.

3 Results and discussion

3.1 Water

The measured physical and chemical parameters are listed in Table 1. Both air and water temperature distributions in the investigated areas have a common pattern, the highest air temperature (33.14 °C) and the lowest (30.69 °C). While, the highest water temperature (30.08 °C) and the lowest one (27.6 °C). Transparency was measured in all areas except in Qalaa Drain because the water of Qalaa Drain is always dark in color because its water contains H_2S and is mostly loaded with black iron sulphide (FeS) [9, 10]. The waters of both S-LMMB and LMFB show transparency values that ranged between 40 and 55 cm, and for deep wastewater, it ranged from 35 to 70 cm with an average of 50.71 cm. The drainage water of Qalaa Drain has the lowest value of TSM (5.2 mg/L) due to its water containing over 70% of wastewater from EWTP, and the rest is agriculture drainage water.

On the other hand, Umum Drain has a low TSM at sites I and III compared to LMMB, due to its great depth. Low pH values characterize the water of Qalaa Drain, ranging from 6.84 to 7.7, with an average of 6.93 compared to the other waters of the studied areas. However, the presence of H_2S appears to be the main reason for this slightly acidic pH. The lowest Clv was always recorded in the water of Qalaa Drain, ranging from 0.53 to 0.72 g Clv/L with an average of 0.65 g Clv/L. The water of Umum Drain has a higher Clv values ranging from 0.72 to 1.98 g Clv/L, with an average of 1.22 g Clv/L, whereas the highest value of Clv is located in LMFB, where it reached 2.88 g Clv/L, and this may be attributed to the fact that the water in this region stays for a long time, and thus exposed more to the process of evaporation, in addition to the fact that the region does not receive fresh water from any other sources. The waters of Umum Drain, LMMB and LMFB are always aerated with O_2 concentration of 7.04, 4.4 and 4.68 mg O_2/L, respectively, compared to the Qalaa drain, which constantly carries hydrogen sulfide, reflecting the increased oxygen consumption in the Qalaa drain water that exceeds the amount of dissolved oxygen available in the Qalaa drain, resulting in an euxinic state in this drain.

3.2 PTEs in water

The results for the measured PTEs are listed in Tables 2 and 3. In Umum Drain, the dissolved Cu is the dominant form of total-Cu (T-Cu), with average concentrations of

Table 1 Physicochemical characteristics of the four studied aquatic systems, Umum Drain, Qalaa Drain, LMMB and LMFB, during Summer 2007

	Depth (M)	STD (cm)	WT (°C)	A. Tem	pH	Clv (g/L)	DO/H_2S (mg/L)	TSM
Umum Drain								
(Is)	1.75	60	27.1	35.0	7.23	1.40	1.82	36.8
(IIs)	1.25	40	27.7	35.0	7.31	1.98	8.38	112.4
IIIs	3.50	50	27.8	34.0	7.33	0.72	4.25	43.5
IVs	4.25	50	27.8	33.0	7.50	1.04	5.14	55.8
Vs	4.00	50	27.8	32.0	7.39	1.09	5.57	48.7
(VIs)	1.00	35	28.2	32.0	7.56	1.21	17.07	102.1
VIIs	1.75	70	27.9	31.0	7.69	1.10	7.05	66.1
Mean	2.50	50.71	27.76	33.14	7.43	1.22	7.04	66.49
Qalaa Drain								
(IQ)	1.00	10	30.6	32.0	7.07	0.53	*23.1*	5.2
IIQ	–	–	30.4	32.0	6.88	0.55	*25.5*	66.0
IIIQ	–	–	31.1	31.5	6.88	0.65	*33.5*	52.5
IVQ	–	–	30.2	29.0	6.85	0.70	*30.1*	56.2
VQ	–	–	30.0	29.0	6.85	0.70	*30.1*	25.8
VIQ	–	–	30.0	29.0	6.84	0.72	–	23.3
VIIQ	–	–	29.6	30.0	6.88	0.67	–	–
VIIIQ	–	–	28.7	33.0	7.20	0.71	–	48.2
Mean			30.08	30.69	6.93	0.65	*28.46*	39.60
LMMB								
VIIIs	1.25	55	27.5	31.0	7.27	0.99	5.02	58.9
IXs	1.00	40	27.7	32.0	7.21	0.99	3.83	108.2
Mean	1.125	47.50	27.6	31.5	7.24	0.99	4.425	83.55
L.M.F.B.								
LMFB	1.00	40	29.8	33.0	8.31	2.88	4.68	46.9

IQ Qalaa PS, *s* surface water, *Q* Qalaa Drain

1.44 µg/L. In Qalaa Drain, where the anoxic conditions were privilege the average concentrations of D-Cu is 0.82 µg/L. This confirms the formation of the barley soluble CuS. In Umum Drain, both D-Cd and particulate-Cd (P-Cd) are present in equal concentrations. The average concentration of D-Cd is 0.51 µg/L and represents 51% of T-Cd. In the anoxic water of Qalaa Drain, the average D-Cd concentration is 0.49 µg/L, while the average concentration of P-Cd is 0.43 µg/L. The average concentration of D-Zn in Umum Drain is 23.41 µg/L, while in Qalaa Drain is 18.81 µg/L. On the other hand, the average concentration of P-Zn in Umum Drain is 19.51 µg/L, while in Qalaa Drain is higher and reaches 29.66 µg/L.

The average concentration of D-Co in Umum Drain is 1.79 µg/L, while in Qalaa Drain is 1.03 µg/L. On the contrary, the average concentration of P-Co in Umum Drain is 0.80 µg/L, while in Qalaa Drain is 0.92 µg/L. It is worth mentioning that the dissolved Co is the dominant form in both Drains. The average concentration of D-Ni in Umum Drain is 3.82 µg/L, while in Qalaa Drain is slightly lower, recorded 3.20 µg/L. Moreover, the average concentration of P-Ni in Umum Drain is 2.33 µg/L, while in Qalaa Drain is 1.79 µg/L. As Qalaa Drain water is mostly oxygen-depleted and always bearing a high concentration of H_2S, such conditions result in the transferring of Mn(III) to the more soluble Mn(II) and almost all Mn is present in the dissolved form. While in the oxic water of Umum Drain it behaves oppositely as most of Mn is present in the particulate form Mn(III). The average concentration of D-Mn in Umum Drain is 2.69 µg/L, while in Qalaa Drain is (24.24 µg/L). On the other hand, the average concentration of P-Mn in Umum Drain is 49.60 µg/L, while in Qalaa Drain is 5.94 µg/L. The reducing condition in Qalaa Drain seems insufficient to form the soluble reduced Fe (II). The average concentration of D-Fe represents 4.51 and 8.65 µg/L for Umum and Qalaa Drains, respectively. While, the average concentration of P-Fe in Umum Drain is 64.60 µg/L, while in Qalaa Drain is 52. 43 µg/L.

3.3 Sediment

The obtained results for the sediment analysis are listed in (Table 4). The main important feature of the sediments collected from Umum Drain is mostly muddy sand (mud > 78% of the total sediment), while those of Qalaa Drain are of mud content < 58%. In Umum Drain, the

Table 2 Values of dissolved metals (µg/L) in the waters of the Umum Drain, Qalaa Drain, LMMB and LMFB

Dissolved metals (µg/L)	Cu	Cd	Zn	Co	Ni	Mn	Fe
Umum Drain							
(Is)	0.54	0.32	5.8	0.17	4.7	2.5	2.7
(IIs)	3.19	0.64	28.3	2.1	4.07	2.9	6.9
IIIs	2.51	0.52	44.1	2.25	4.68	3.7	9.9
IVs	1.25	0.2	29.2	0.45	2.88	2.0	4.4
Vs	0.82	0.8	27.9	1.41	2.13	3.7	2.7
(VIs)	1.05	0.61	20.7	1.52	2.93	1.0	2.9
VIIs	0.73	0.46	7.9	4.66	5.32	3.0	2.1
Mean	1.44	051	23.41	1.79	3.82	2.69	4.51
Qalaa Drain							
(IQ)	2.33	0.39	29.4	1.18	3.86	15.7	3.1
IIQ	0.46	0.16	30.1	0.43	2.77	21.4	3.1
IIIQ	0.70	0.6	23.3	1.12	1.63	10.7	10.8
IVQ	1.03	0.55	25.7	1.1	2.61	40.9	5.8
VQ	1.14	0.78	9.9	0.87	1.98	17.2	4.4
VIQ	0.35	0.54	6.5	1.43	3.96	19.3	7.0
VIIQ	0.98	0.26	17.0	0.48	3.11	50.5	31.3
VIIIQ	0.57	0.6	8.6	1.59	5.68	18.2	3.7
Mean	0.95	0.49	18.81	1.03	3.20	24.24	8.65
LMMB							
VIIIs	0.97	0.62	3.5	1.18	4.98	3.1	2.0
IXs	1.09	0.48	13.1	1.35	4.44	2.1	1.1
Mean	1.03	0.55	8.3	1.27	4.71	2.6	1.55
LMFB							
LMFB	0.44	0.28	5.3	0.23	2.68	2.5	2.4

values of OC ranged from 0.98% at station III to 2.92% at station I, (Dishudi PS), with an average of 1.75%. In Qalaa Drain, the concentration of OC varied from 1.32% at station IQ to 2.20% at station IIQ, with a mean of 1.82%. These are less compared to LMFB (11.5%). The last is relatively a stagnant basin, highly eutrophic and contains hydrophytes (rooted plants). The ON content of Umum Drain ranged between 0.17% at station IV and 0.48% at station I in Dishudi PS with a mean of 0.30%. In the Umum Drain, the station I contains the highest values for both ON and OC. In Qalaa Drain, the ON ranged between 0.20% at station IIQ and 0.35% at the station IQ with a mean of 0.28%. These values in both drains are still less than that in LMFB (1.01%).

3.4 PTEs in sediments

The range and mean concentrations of the studied PTEs are shown in Table 4. A comparison between the levels of these metals in the sediments of the present areas with those recorded in the standard rocks and in other world wide areas are shown in Tables 5 and 6, respectively. The concentration of Cu in the Umum Drain ranged from 41.0 µg/g at station IV to 94.8 µg/g at station II with an average of 66.5 µg/g. The high concentration level of Cu is also noticed at station I, about 78 µg/g. In LMMB, at station VI (near Qalaa Drain inlet) the Cu concentration is 59.7 µg/g, while at station V (near Umum Drain outlet) the Cu concentration is 49.4 µg/g. The sediment of LMFB has almost the same concentration level (57.5 µg/g), which is closer to that of Umum Drain. The Qalaa Drain sediments are remarkably enriched with Cu compared to those of Umum Drain, which ranged from 136.3 µg/g at station IQ to 72.1 at station IIIQ with mean of 100.6 µg/g.

This high concentration level may be attributed to the contamination from the primary treated sewage discharged into the drain from EWTP, which lead to the privilege of euxinic condition that encourages the precipitation of Cu as insoluble CuS. The level of Cu in the oxic sediments of Umum Drain and LMFB are more or less at the same level as that in the crust but are higher than that in shale rock. Obviously, the level in the sapropetic sediments of the Qalaa Drain is the highest. The Cd concentrations in Umum Drain sediments fluctuated between 2.50 µg/g at station I and 12.1 µg/g at station III, with a mean of 5.9 µg/g. In Qalaa Drain, it ranged between 1.9

Table 3 Values of particulate metals (µg/L) in the waters of the four studied aquatic systems, Umum Drain, Qalaa Drain, LMMB and LMFB

Particulate metals (µg/L)							
	Cu	Cd	Zn	Co	Ni	Mn	Fe
Umum Drain							
(Is)	0.57	0.27	8.2	0.26	3.61	42.9	54.3
(IIs)	0.67	0.21	27.5	0.96	2.34	45.0	104.2
IIIs	0.58	0.3	5.6	0.59	1.25	40.4	58.2
IVs	1.06	1.08	33.7	1.95	1.43	43.8	50.9
Vs	0.69	0.54	26.8	0.4	3.03	51.3	57.9
(VIs)	0.61	0.5	4.9	1.05	2.41	78.1	81.9
VIIs	1.54	0.6	29.9	0.38	2.27	45.7	44.8
Mean	0.82	0.50	19.51	0.80	2.33	49.60	64.60
Qalaa Drain							
(IQ)	0.49	0.24	42.3	ND	2.24	5.2	13.0
IIQ	0.44	0.52	34.6	0.67	1.69	3.0	17.4
IIIQ	3.24	0.26	18.0	ND	1	7.6	65.9
IVQ	5.46	0.26	31.6	ND	1.64	6.9	84.8
VQ	2.62	0.42	14.3	1.36	1.17	1.1	59.0
VIQ	3.36	0.36	11.4	0.82	1.88	3.1	67.9
VIIQ	31.26	0.73	71.2	0.62	2.26	17.5	46.5
VIIIQ	4.03	0.62	13.9	1.11	2.46	3.1	64.9
Mean	6.63	0.43	29.66	0.92	1.79	5.94	52.43
LMMB							
VIIIs	0.64	0.41	6.4	0.72	1.99	42.5	66.3
IXs	0.77	0.3	16.6	0.59	1.8	60.3	155.5
Mean	0.71	0.36	11.50	0.66	1.90	51.40	110.90
LMFB							
LMFB	0.64	0.45	16.4	1.68	1.06	38.8	12.3

Table 4 Physicochemical characteristics and values of PTEs in the sediment (µg/g) of the four aquatic systems Umum Drain, LMMB, Qalaa Drain and LMFB

Station	Mud	OC	ON	Cu	Cd	Zn	Co	Ni	Mn	Fe	Al
	%			µg/g							
Umum Drain											
(I)	90.5	2.92	0.48	78.8	2.5	875	27.7	90.1	59	47,758	37,673
(II)	60	1.72	0.33	94.8	6.7	625	42.2	82.9	379	38,525	31,433
III	86	0.98	0.23	41.0	12.1	857	18.3	23.3	1330	43,526	36,822
IV	–	1.37	0.17	51.3	2.6	768	19.9	33.0	82	35,598	31,263
Mean	78.6	1.75	0.3	66.5	5.9	781	27.0	57.3	463	41,351	34,298
LMMB											
V	85	2.6	0.24	49.4	7.1	384	31.8	80.5	1579	50,821	34,945
VI	84	4.16	0.46	59.7	8.5	1138	16.9	82.8	87	41,594	33,478
Mean	84	3.38	0.35	54.6	7.8	761	24.3	81.6	833	46,207	34,211
Qalaa Drain and LMFB											
(IQ)	76	2.2	0.35	136.3	3.2	1116	21.0	77.8	390	42,910	35,800
IIQ	50	1.32	0.2	93.4	3.9	367	13.3	45.4	383	25,025	25,438
IIIQ	47	1.93	0.28	72.1	1.9	929	33.1	79.9	122	37,919	34,305
Mean	57.4	1.82	0.28	100.6	3.0	804	22.5	67.7	298	35,284	31,848
LMFB											
LMFB	–	11.49	1.01	57.5	4.1	742	34.0	64.3	99	24,891	23,874

Table 5 Typical background concentrations in sediments (µg/g) of the studied PTEs in the present and earlier recorded in the study areas and in standard rocks and sediments

Background	Cu	Cd	Zn	Co	Ni	Mn	Fe	Al	Reference
Umum Drain	66.47	5.94	781.2	27.00	57.32	462.5	41,351	34,298	Present work
Qalaa Drain	100.60	2.99	803.7	22.47	67.69	297.9	35,284	31,848	Present work
LMFB	57.5	4.08	741.6	34.00	64.33	99.0	24,891	23,874	Present work
Granit	10	0.2	40	1	0.5	400	27,000	77,000	[28]
Basalt	100	0.2	100	48	150	1,500	86,000	88,000	[28]
Shale	45	0.3	95	19	68	850	47,600	80,000	[28]
Crust	55	0.1	70	25	75	950	56,000	82,000	[28]
Unpolluted sediment	33	0.11	95	–	–	770	41,000	–	[29]
Mariout sediment	38	0.2	94	–	–	958	25,600	–	[30]
Sea water	0.003	0.00011	0.01	0.0001	0.002	0.002	0.1	0.1	[31]

Table 6 A comparison between the mean values of the PTEs in the sediments (µg/g) of Umum and Qalaa Drains and LMFB with those in sediments of other world aquatic systems [37–50]

Location	Cu	Cd	Zn	Co	Ni	Mn	Fe	Al	References
Umum Drain	66.47	5.94	781.2	27.00	57.32	462.5	41,351	34,298	Present work
Qalaa Drain	100.60	2.99	803.7	22.47	67.69	297.9	35,284	31,848	Present work
LMFB	57.50	4.08	741.6	34.00	64.33	99.00	24,891	23,874	Present work
Egyptian aquatic systems									
Lake Manzalah	26.34	0.026	30.326	20.36	40.73	38.15	8342.5	–	[37]
Nasser Lake (Min–Max)	19.22–41.82	0.13–0.349	26.9–98.36	–		92.8–619.7	6170–21,000	–	[41]
Lake Edku	30.00	–	–	–	–	145.0	8500		[33]
	19.00	7.30	317.0	–	–	115.0	2360		[34]
	36.77	1.47	344.5	–	–	1390.0	6250		[35]
Lake Brollus	18.00	–	40.0	–	–	–	3500		[42]
	25.00	5.20	90.0	–	–	85.0	1790		[34]
	47.49	4.62	217.3	–	–	850.9	2752		[35]
Lake Manzalah	74.00	11.8	164.0	–	–	847.0	3590		[34]
	7.89	1.36	48.4	–	–	–	–		[43]
	315.36	84.8	432.1	–	–	419.6	3339		[35]
El-Max Bay, Egypt	17.53	4.97	222.7	6.41	–	250.8	1683	–	[36]
Eastern Harbor Egypt	14.09	3.80	64.7	32.29	–	95.0	582	––	[44]
Worldwide aquatic systems									
Badovci Lake	61.2	< 1	122	13	305	660	19,084	17,002	[38]
Uzunçayır Dam Lake	29.45	–	62.81	–	237.8	631.6	31,740	–	[39]
Silesian Upland, Southern Poland (Min–Max)	8.0–20	2.0–6.0	57–116	53–72	10–16	–	–	–	[40]
Blackwater Estuary in UK	24.00	0.34	89.0	–	–	–	–	–	[45]
Tames Estuary in UK	61.00	1.30	219.0	–	–	–	–	–	[46]
Rhine Estuary in Germany	600.0	45.0	2900.0	–	–	–	–	–	[32]
Narraganset bay in USA	190.0	0.80	250.0	–	–	–	–	–	[47]
James bay in Canada	13.00	1.40	36.0	–	–	–	–	–	[48]
New Calbar River	25.50	12.80	31.6	–	3.20	ND	ND	–	[49]
Sangana River	13.41	N.D	16.37	–	15.52	7.88	10.075	–	[50]

and 3.9 µg/g with an average of 3.0 µg/g, which is slightly higher than that of Umum Drain. In LMMB, the Cd concentrations were 7.05 µg/g at station V (oxic sediment) and 8.53 µg/g at station VI (anoxic sediment). These levels are higher than that in either LMFB (4.08 µg/g) or Umum Drain. The level of Cd in the sediments of the present study areas are extremely higher compared to those in the standard sediments (Table 5); but they are still lower than

those recorded in Manzalla Lagoon (Table 6). In Umum Drain, the concentrations of Zn varied from 625 µg/g at station II to 875 µg/g at station I, with a mean of 781 µg/g. In Qalaa Drain sediment the concentration values of Zn are higher than those found in Umum Drain at station V near to those in LMMB, it ranged between 366 µg/g at station IIQ and 1116 µg/g at station (IQ) with a mean value of 803 µg/g. In LMFB, the Zn concentration is generally more or less at the same level as in the oxic sediments of Umum Drain. From Table 5; it is easy to see that the level of Zn concentrations in the sediments of the four present areas is at least six times that in shale rocks, reflecting contamination of these sediments with this metal.

In Umum Drain, the Co concentrations in the sediment ranged from 18.3 µg/g at station III to 42.2 µg/g at station II with an average of 27 0.0 µg/g. In Qalaa Drain sediments, the concentrations of Co is fluctuated between 13.3 µg/g at station IIQ and 33.1 at station IIIQ with a mean of 22.5 µg/g, which is slightly lower than Umum Drain. In LMMB, Co concentrations fluctuate between 31.8 µg/g at station V and 16.9 µg/g at station VI. Usually, the main source of nickel comes from the metallurgical industries, burning of fossil fuels, municipal wastewater, and geological weathering [25, 26]. In Umum Drain sediments, the concentration of Ni varied from 23.0 µg/g at station III to 90.1 µg/g at station I, with mean of 57.3 µg/g. The high value of Ni in the sediment is related to the high load of suspended matter from the pump stations along the coarse of Umum drain as mentioned by Nriagu and Pacyna [26]. In LMMB, 82.8 µg/g is in the anoxic sediments at station VI, while the lowest was 80.5 µg/g in the oxic sediments at station V. Both values in LMMB are generally higher than in LMFB (64.3 µg/g). In Qalaa Drain sediments, Ni ranged from 45.41 µg/g at station IIQ to 79.9 µg/g at station IIIQ, with a mean of 67.7 µg/g. From Table 5, the concentration level of Ni in the sediments is quite close to that in shale rocks; as suggested by Nriagu and Pacyna [26], The main sources of Ni in are: metallurgical industries, burning of fossil fuels, municipal wastewater, and geological weathering in our study the municipal wastewater in Qalaa drain may be the reason for high Ni Concentrations. Manganese is usually found in the form of carbonates, oxides, silicates, and sulphides in minerals [27]. Mn concentrations in Umum Drain sediments ranged from 59 µg/g at station I to 1330 µg/g at station III, with a mean of 462 µg/g.

In Qalaa Drain, the values of Mn ranged between 121 µg/g at station IIIQ and 389 µg/g at station IQ, with a mean of 297 µg/g. This means the concentration is considerably less than that in Umum Drain. This could be attributed to the anoxic condition, which is always prevailing in Qalaa Drain led to the solublization of Mn oxyhydroxides to the more soluble Mn(II). The concentration values in LMFB sediment are surprisingly low about 99 µg/g. In south LMMB, Mn value is the highest with a value of 1579 µg/g in the oxic sediment at station V, which is neighboring to the inlet from Umum Drain, compared to station VI (87 µg/g), near the inlet of Qalaa discharge. The low value 87 µg/g is mostly attributed to the reducing condition. From Table 5, the level of Mn in the sediments of the present study areas is lower than that in the shale rocks. The Fe concentrations in Umum Drain fluctuated between 35,598 µg/g at station IV, and 47,759 µg/g at station I, with an average of 41,351 µg/g. In Qalaa Drain, the concentration values of Fe ranged between 25,025 µg/g at station II and 42,910 µg/g at station IQ, with a mean of 35,284 µg/g, which is lower than that recorded at Umum Drain. In south LMMB, the concentrations of Fe are low, about 41,594 µg/g at station VI and about 50,821 µg/g at the oxic sediment at station V. The last is about two times more than that found in LMFB 24,891 µg/g. Aluminum (Al) is the second most abundant metal after Fe in the sediment of the four studied areas. As mentioned before, for Mn, both Fe and Al also show concentration levels lower than those found in standard rocks, including shale. This reflects the dilution of these sediments with other sediments of lesser content of these dominant metals (Mn, Fe and Al).

The values that were obtained for the PTEs in this investigation were compared with their corresponding values in various aquatic sediments from different areas across the world (Table 6). The levels of copper, cadmium, and zinc are all more here than what was discovered in the Rhine Estuary in Germany [32]. Copper levels in the Qalaa and Umum Drains, as well as in the LMMB and LMFB, were found to be significantly greater than those found in Lake Edku and Lake Borollus (Table 6) [33–35]. When compared to the levels that were documented in Lake Manzalah [34, 35], the concentration of copper in Umum Drain is significantly lower. The concentration of manganese in the four regions that were investigated was found to be greater than what was found in Lake Edku by Abdel-Moati and El-Sammak [29], but it was found to be less than what Samir and Shaker [35] found in the same lake. Abdalah [36] recorded a higher concentration of Co at El-Mex Bay and in the Eastern Harbor of Alexandria, but this value for the concentration of Co is lower. The order of abundance of the metals in the sediments of the present study areas was Fe > Al > Zn > Mn > Cu > Ni > Co > Cd. While in shale the order is Al > Fe > > Mn > > Zn > Ni > Cu > > Co > > Cd.

3.5 Pollution indices

3.5.1 Enrichment factor (EF)

EF values were interpreted as suggested by Birth [51] for the metals studied with respect to the shale average [28].

$$EF = \frac{\left(\frac{x}{Al}\right)_{Sediment}}{\left(\frac{x}{Al}\right)_{Shale}} \quad (1)$$

where *x*/Al is the ratio of the PTEs to Al. The mean value of Cu enrichment factor in Umum Drain is > 3 and shows EF ranging from minor EF at stations III and IV to moderate enrichment at station I and moderate to severe at station II, Cd shows high enrichment value ranging from severe at station I and station IV to very severe at stations III and II, while Zn is showing severe EF enrichment at all stations. The enrichment of Zn at all stations of Umum Drain may be attributed to the fishing boats' sides. Zn and Cd are known as a marker of paint industries [52, 53]. On the other hand, low EF for Co, Ni, Mn and Fe are ranging from non to moderate enrichment. The EF in LMMB and LMFB show the same enrichment as in Umum Drain, ranging from high EF to low EF as the following Cd > Zn > Co = Cu = Ni = Fe = Mn. In Qalaa Drain the Cd and Zn show EF > 10 and range between severe and very severe enrichment, Cd has lower EF than in Umum Drain, while Zn EF is higher than in Umum Drain. Cu shows EF ranging from moderate enrichment to moderate to severe enrichment, it's clear that values of EF for Co, Ni, Mn and Fe are low, ranging from non to moderate enrichment. The minimum and moderate and maximum enrichment that was calculated for all analyzed metals in this study are listed in Table 7; the descriptive statics of all metals were also calculated and represented in Table 8 and Fig. 2.

3.6 Geoaccumulation index (I_{geo})

The geo-accumulation index (I_{geo}) can be calculated via Eq. (2):

$$I_{geo} = ln\left(\frac{C_n}{1.5B_n}\right) \quad (2)$$

where C_n is the measured concentration of the examined metal (*n*) in the sediment or TSM μg/g, 1.5 is the factor used for lithologic variation of trace metals, and B_n is the background value of the same metals according to concentration in shale rocks. Based on the I_{geo} data suggested by Förstner et al. [54], and Müller & Suess [55], the geo-accumulation index, with respect to each metal in the sediment of the studying area is ranked in Table 9. In Umum Drain, among the whole 8 studied metals, the I_{geo} of Cd was ranked from moderate to strong contamination at station III (I_{geo} class = 3–4), I_{geo} value of Cd in LMMB, Qalaa Drain and LMFB was ranked between moderate and moderate to strong. I_{geo} of Zn in Umum, Qalaa Drains, LMMB and LMFB was ranked between moderate to moderate to strong (I_{geo} class = 2–3) (Table 9). On the other hand, the rest of the metals (Cu, Co, Ni, Mn, Fe and Al) in Umum and Qalaa Drains, LMMB and LMFB were ranked from practically uncontaminated to moderate (I_{geo} class = 0–1). These results might indicate that the study area has a heavy accumulation of Cd and Zn, which apparently comes from sewer and from the primary treated discharge of WTP in

Table 7 Enrichment Factor (EF) (*x*/Al) of the PTEs in the sediment of the four studied aquatic systems, Umum Drain, LMMB, Qalaa Drain and LMFB

	Cu	Cd	Zn	Co	Ni	Mn	Fe	Al
Umum Drain								
(I)	3.72	17.70	19.56	3.09	2.81	0.15	2.17	1
(II)	5.36	56.50	16.74	5.65	3.10	1.13	2.10	1
III	1.98	87.27	19.60	2.09	0.74	3.40	2.02	1
IV	2.92	22.01	20.68	2.68	1.24	0.25	1.95	1
Mean	3.49	45.87	19.15	3.38	1.98	1.23	2.06	1
LMMB								
V	2.51	53.80	9.25	3.83	2.71	4.25	2.49	1
VI	3.17	67.95	28.62	2.12	2.91	0.25	2.13	1
Mean	2.84	60.87	18.94	2.98	2.81	2.25	2.31	1
Qalaa Drain and LMFB								
(IQ)	6.77	23.91	26.25	2.47	2.56	1.02	2.05	1
IIQ	6.53	40.99	12.14	2.21	2.10	1.42	1.69	1
IIIQ	3.74	14.54	22.79	4.07	2.74	0.33	1.89	1
Mean	5.68	26.48	20.39	2.91	2.47	0.92	1.88	1
LMFB	4.28	45.57	26.16	6.00	3.17	0.39	1.79	1

Table 8 Enrichment Factor (EF) statistical analysis of the PTEs in the sediment of the four studied aquatic systems, Umum Drain, LMMB, Qalaa Drain and LMFB

	Cu	Cd	Zn	Co	Ni	Mn	Fe	Al
Umum Drain								
Mean	3.49	45.87	19.15	3.38	1.98	1.23	2.06	1
SE	0.72	16.30	0.84	0.78	0.58	0.76	0.05	0
Median	3.32	39.25	19.58	2.89	2.03	0.69	2.06	1
SD	1.43	32.61	1.68	1.57	1.16	1.51	0.10	0
Min	1.98	87.27	16.74	2.09	0.74	0.15	1.95	1
Max	5.36	183.47	20.68	5.65	3.10	3.40	2.17	1
Qalaa Drain								
Mean	5.68	26.48	20.39	2.91	2.47	0.92	1.88	1
SE	0.97	7.74	4.25	0.58	0.19	0.32	0.11	0
Median	6.53	23.91	22.79	2.47	2.56	1.02	1.89	1
SD	1.68	13.41	7.36	1.01	0.33	0.55	0.18	0
Min	3.74	14.54	12.14	2.21	2.10	0.33	1.69	1
Max	6.77	40.99	26.25	4.07	2.74	1.42	2.05	1
LMMB								
Mean	2.84	60.87	18.94	2.98	2.81	2.25	2.31	1
SE	0.33	7.07	9.69	0.85	0.10	2.00	0.18	0
Median	2.84	60.87	18.94	2.98	2.81	2.25	2.31	1
SD	0.47	10.00	13.70	1.21	0.14	2.83	0.26	0
Min	2.51	53.80	9.25	2.12	2.71	0.25	2.13	1
Max	3.17	67.95	28.62	3.83	2.91	4.25	2.49	1

LMMB and EWTP in Qalaa Drain which include the industrial wastes in addition to fishing boats in LMFB and discharge from Drainage pump stations at Umum Drain.

3.6.1 Contamination factor (*CF*) and contamination degree (*CD*)

Hakanson [56] has suggested a contamination factor (C_F^i) and the degree of contamination (C_D) to describe the contamination of given toxic substance by Eqs. (3) and (4):

$$C_F^i = \frac{C_{0-1}^i}{C_n^i} \tag{3}$$

$$C_D = E_{i=1}^7 C_F^i \tag{4}$$

where C_F^i is the mean content of the substance; and C_n^i is the reference value of the substance (Table 10).

The contamination factor (C_F^i) and contamination degree (C_D) of the sediment sample are given in Table 10. In Umum Drain both Stations II and III indicate a very high degree of contamination, the value of $C_D > 28$. While stations I and IV indicated a considerable degree of contamination with the value of $14 < C_D > 28$. Both stations V and VI in LMMB indicate a very high degree of contamination, the value of $C_d > 28$. On LMFB station show a considerable degree of contamination, the value of $C_D = 26.06$. In Qalaa Drain, the stations IIIQ and IIQ indicated a considerable degree of contamination, with values of $C_D = 21.91$ and 21.64 respectively, while station IQ shows a very high degree of contamination value of $C_D > 28$.

3.6.2 Ecotoxilogical sense of PTEs contamination

The ecotoxilogical sense of PTEs contamination was determined using sediment quality guidelines (SQGs) developed for marine and estuarine ecosystems [57, 58]. Sediments were classified as non-polluted, moderately polluted and heavily polluted, based on SQG of USEPA [59] as shown in Table 11. The toxicity unit values shown in Table 11 indicate that station VI in LMMB near the discharge from Qalaa Drain into LMMB and station IQ in Qalaa Drain are more polluted compared to the others. Station V in the LMMB is low polluted compared to the others. The concentrations of Cu and Zn in Umum Drain, Qalaa Drain, LMMB, and LMFB in comparison with SQGs values showed that the study area is heavily polluted with both Cu and Zn (> 50), while the value of Cd in each Umum Drain, Qalaa Drain, LMMB and LMFB is lower than SQGs (< 25) (Table 11). On the other hand, according to SQGs values in the stations I (Dishudi PS) and II (Hares PS) in Umum Drain are heavy polluted with Ni (> 50), while stations III and IV in the same drain show moderate pollution with Ni (25–50), while, both of LMMB and LMFB

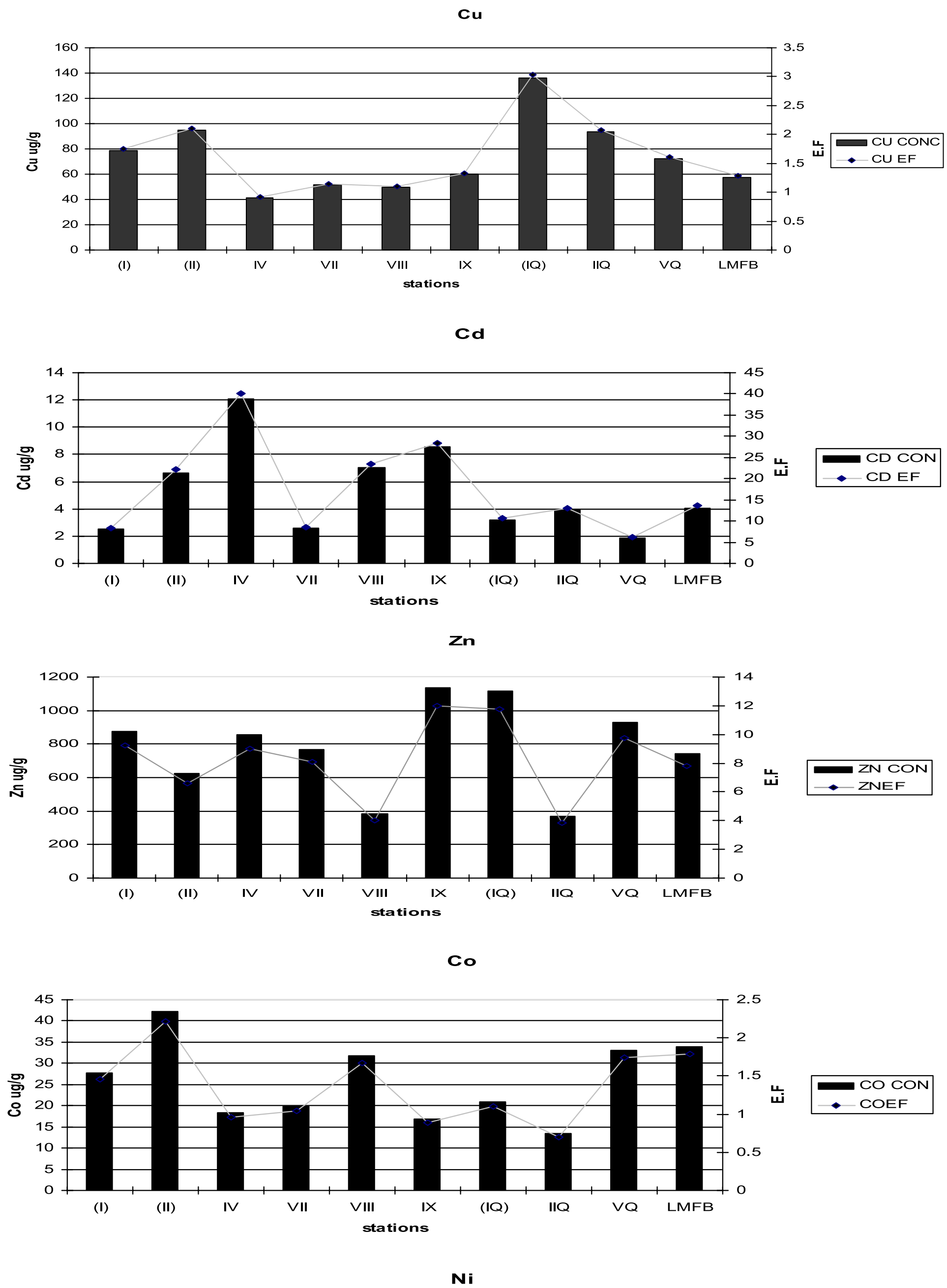

Fig. 2 PTEs contents (bar charts) and Enrichment Factor (scatter plot with connecting line)

are heavily polluted with Ni (> 50). Qalaa Drain sites are polluted with Ni with values ranging between 25 and 50.

3.6.3 Pollution loading index (PLI)

Tomlinson et al. [60] and Satyanarayana et al. [61] applied a simple method using the pollution loading index (PLI) to study the extent of pollution load in sediments, which can be calculated using Eq. (5).

$$\mathrm{PLI} = \left(CF_1 \times CF_2 \times CF_3 \times \ \ldots \ CF_n\right)^{1/n} \tag{5}$$

The calculated *PLI* value for the studied locations was reported in Table 12. The *PLI* value of < 1 is non-polluted whereas *PLI* value of > 1 is polluted. The values of the *PLI* at all sites in the studying area are > 1, which indicated that all studied locations have high pollution loading. The highest *PLI* value was recorded at station V in LMMB with a value of 2.367, while the lowest PLI value was found at station IV in Umum Drain with a value of 1.2, which indicated that both were the highest and lowest value are > 1.

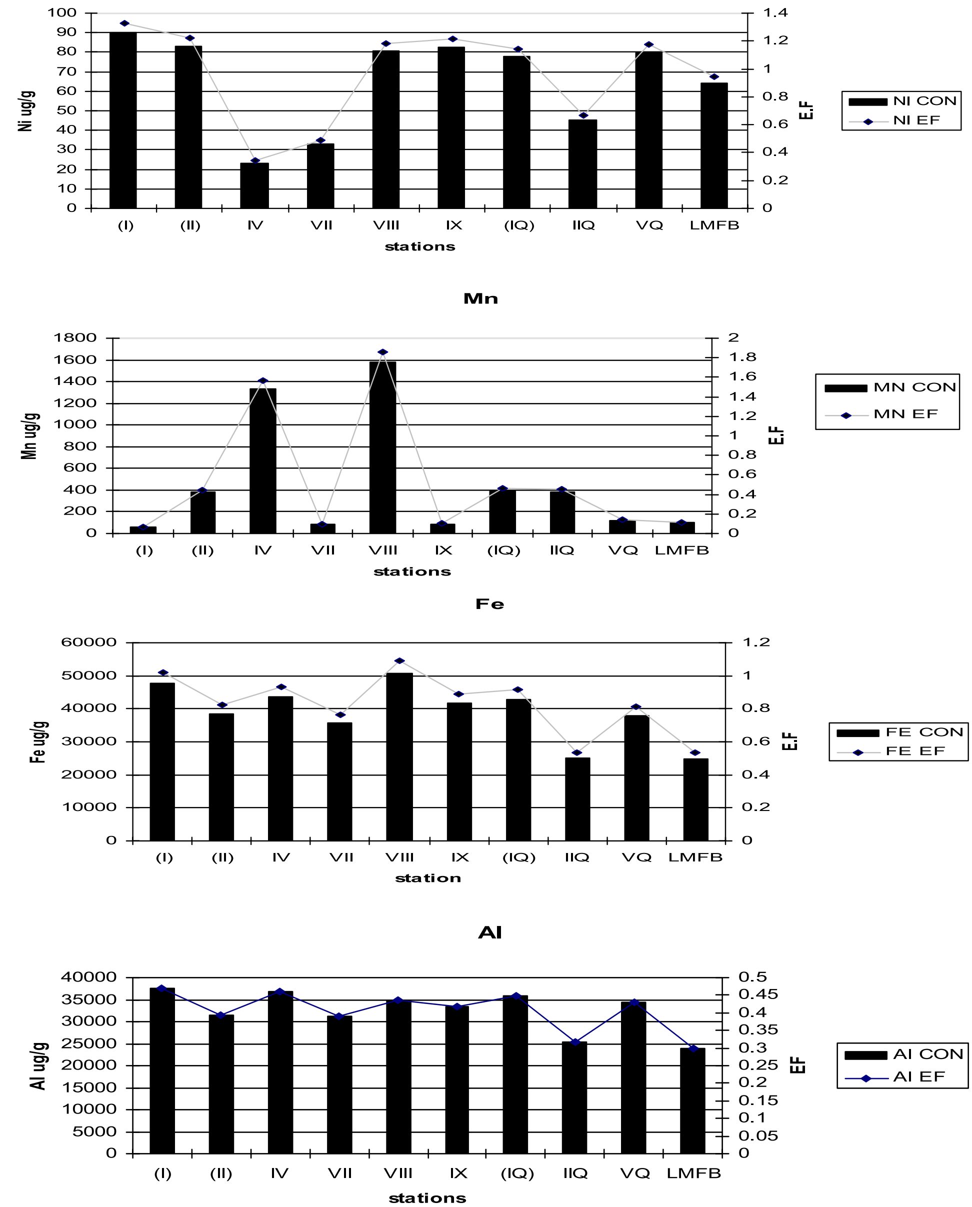

Fig. 2 (continued)

4 Conclusion

The results of the Physicochemical parameters revealed that the water of Qalaa Drain is characterized by low pH values ranging from 6.84 to 7.7 with average of 6.93 compared to the other waters of the studied areas. However, the presence of H_2S appears to be the main reason for this slightly acidic pH. The lowest Clv was always recorded in the water of Qalaa Drain ranging from 0.53 to 0.72 g Cl/L with an average of 0.65 g Cl/L. The waters of Umum Drain, LMMB and LMFB are always aerated with O_2 concentrations of 7.04, 4.4 and 4.68 mg O_2/L, respectively, compared to the Qalaa drain, which constantly carries H_2S, reflecting the increased oxygen consumption in the Qalaa drain water that exceeds the amount of dissolved oxygen available in the Qalaa drain, resulting in an euxinic state in this drain. The PTEs results demonstrated that the concentrations of all analyzed dissolved metals in the waterways of the current study sites remain within USEPA's accepted safe levels, *i.e.* they are still well below the maximum allowable limits, to biota and, ultimately, humans. For sediment, the concentration levels of Cd, Cu, Co, Ni, and Zn during the study period in all sites exceed the world average concentration of shale rocks. Fe and Al concentrations are less than their concentration in shale rocks except for station I (Dishudi PS) in Umum Drain and station V in LMMB. On the other hand, the concentration level of Mn was lower than its background concentrations in shale rocks except for station III in Umum Drain and station V in LMMB which is

Table 9 I_{geo} classes according to (shale rocks) of the PTEs in the sediment of the four studied aquatic systems, Umum Drain, LMMB, Qalaa Drain and LMFB

	Cu	Cd	Zn	Co	Ni	Mn	Fe	Al
Umum Drain								
(I)	1	2	3	0	0	0	0	0
(II)	1	3	2	1	0	0	0	0
III	0	4	2	0	0	1	0	0
IV	0	2	2	0	0	0	0	0
Mean	0	3	2	0	0	0	0	0
LMMB								
V	0	3	1	1	0	1	0	0
VI	0	3	3	0	0	0	0	0
Mean	0	3	2	0	0	0	0	0
Qalaa Drain and LMFB								
(IQ)	1	2	3	0	0	0	0	0
IIQ	1	3	1	0	0	0	0	0
IIIQ	1	2	2	1	0	0	0	0
Mean	1	2	2	0	0	0	0	0
LMFB	0	3	2	1	0	0	0	0

Table 10 The terminologies used to describe the contamination factor (C_F^i)

C_F^i	C_d	Description
$C_F^i < 1$	$C_d < 7$	Low degree of contamination
$1 < C^i{}_f < 3$	$7 < C_d < 14$	Moderate degree of contamination
$3 < C_F^i < 6$	$14 < C_d < 28$	Considerable degree of contamination
$C_F^i > 6$	$C_d > 28$	Very high degree of contamination

higher than its concentration in shale rocks. The value of Cd in each of Umum Drain, Qalaa Drain, LMMB and LMFB is lower than SQGs, which shows that the study area is heavily polluted with both Cu and Zn. On the other hand, the concentrations of Cu and Zn in Umum Drain, Qalaa Drain, LMMB and LMFB in comparison with SQGs values showed that the study area is heavily polluted with both Cu and Zn. Both the greatest and lowest PLI values, both of which were greater than 1, showed that the sediment that was analyzed was polluted. The highest PLI value was 2.367, and the lowest PLI value was 1.2. However, this study is an environmental monitoring of the metals in the studied area, and future research is necessary to quantitatively investigate other environmental pollutants like petroleum hydrocarbons, polychlorinated hydrocarbons, and pesticides and study their effects on the water ecology of the studied area.

Table 11 Heavy metal concentrations in shales (µg/g) and according to various recommendations, compared to sediment quality guidelines (SQG)

Metal	SQG			Shale	ERM	PEL	TEL	ERL
	Non polluted	Moderate polluted	Heavily polluted					
Cu	> 25	25–50	> 50	45	270	110.00	18.70	34.00
Cd	–	–	–	0.3	9.60	4.20	0.68	1.20
Zn	> 90	90–200	> 200	95	410	270	124.00	150
Co	–	–	–	19	–	–	–	–
Ni	> 20	20–50	> 50	68	51.60	43	15.90	20.90
Mn	–	–	–	850	–	–	–	–
Fe	–	–	–	47,600	–	–	–	–
Al	–	–	–	80,000	–	–	–	–

TEL threshold effect level, *ERM* median effect range, *SQG* sediment quality guidelines, *ERL* low effect range, *PEL* probable effect level

Table 12 The values of contamination factors and pollution loading index and toxicity unit of the PTEs in the sediment of the four studied aquatic systems, Umum Drain, LMMB, Qalaa Drain and LMFB during the summer of 2007

	Contamination factor (C_F^i)								CD	PLI	Tu
	Cu	Cd	Zn	Co	Ni	Mn	Fe	AL			
Umum Drain											
(I)	1.75	8.33	9.21	1.46	1.32	0.07	1.02	0.47	23.64	1.31	6.65
(II)	2.11	22.2	6.58	2.22	1.22	0.45	0.82	0.39	35.99	1.82	6.69
III	0.91	40.17	9.02	0.96	0.34	1.57	0.93	0.46	54.36	1.71	6.96
IV	1.14	8.6	8.08	1.05	0.49	0.1	0.76	0.39	20.61	1.02	4.69
Mean	1.48	19.83	8.22	1.42	0.84	0.55	0.88	0.43	33.65	1.47	6.25
LMMB											
V	1.1	23.5	4.04	1.67	1.18	1.86	1.09	0.44	34.88	1.92	5.42
VI	1.33	28.43	11.98	0.89	1.22	0.1	0.89	0.42	45.26	1.44	8.71
Mean	1.22	25.97	8.01	1.28	1.2	0.98	0.99	0.43	40.07	1.68	7.07
Qalaa Drain and LMFB											
(IQ)	3.03	10.7	11.75	1.1	1.14	0.46	0.92	0.45	29.55	1.76	7.94
IIQ	2.08	13.03	3.86	0.7	0.67	0.45	0.54	0.32	21.64	1.18	4.19
IIIQ	1.6	6.23	9.77	1.74	1.18	0.14	0.81	0.43	21.91	1.33	6.4
Mean	2.24	9.99	8.46	1.18	1	0.35	0.76	0.4	24.37	1.42	6.18
LMFB	1.28	13.6	7.81	1.79	0.95	0.12	0.53	0.3	26.37	1.2	5.74

CD contamination degree, *PLI* pollution loading index, *Tu* toxicity unit

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Data availability All data is available to the reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare no competing interests.

References

1. Ruilian YU, Xing Y, Yuanhui ZHAO, Gongren HU, Xianglin TU (2008) Heavy metal pollution in intertidal sediments from Quanzhou Bay, China. J Environ Sci 20(6):664–669
2. DeForest DK, Brix KV, Adams WJ (2007) Assessing metal bioaccumulation in aquatic environments: the inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration. Aquat Toxicol 84(2):236–246
3. Fu F, Wang Q (2011) Removal of heavy metal ions from wastewaters: a review. J Environ Manag 92(3):407–418
4. Hosono T, Su CC, Siringan F, Amano A, Onodera SI (2010) Effects of environmental regulations on heavy metal pollution decline in core sediments from Manila Bay. Mar Pollut Bull 60(5):780–785
5. Callender E (2005) Heavy metals in the environment. In: Environmental geochemistry treatise on geochemistry, 2nd edn, vol 9, 67. https://www.elsevier.com/books/environmental-geochemistry/sherwood-lollar/978-0-08-044643-1
6. Vidović J, Dolenec M, Dolenec T, Karamarko V, Rožič PŽ (2014) Benthic foraminifera assemblages as elemental pollution bioindicator in marine sediments around fish farm (Vrgada Island, Central Adriatic, Croatia). Mar Pollut Bull 83(1):198–213
7. Burton ED, Phillips IR, Hawker DW (2004) Trace metals and nutrients in bottom sediments of the Southport Broadwater. Australia Mar Pollut Bull 48(3–4):378–384
8. Muñoz-Barbosa A, Gutiérrez-Galindo EA, Segovia-Zavala JA, Delgadillo-Hinojosa F, Sandoval-Salazar G (2004) Trace metal enrichment in surficial sediments of the northwest coast of Baja California, Mexico. Mar Pollut Bull 48(5–6):596–603
9. El-Rayis OA, Hassaan MA, Hemada EI (2014) Suitability of lake Mariout drainage system (Qalaa and Umum Drains waters) for water reuse. Blue Biotechnol J 3(2):265–277
10. Hassaan MA, El-Rayis OA (2018) Suitability of lake Mariout drainage system (Qalaa and Umum drains waters) for water reuse. Indian J Mar Sci 47(07):1460–1467
11. Hassaan MA, El Nemr A (2020) Pesticides pollution: classifications, human health impact, extraction and treatment techniques. Egypt J Aquat Res 46:207–220
12. Abazakh M, El-Rayis O, El-Sabrouti M (2009) Study on the ecological conditions of Mariout Lake Main Basin in relation to their suitability for fish living in the basin. Egypt J Aquat Res 35:119–130
13. Pourret O, Hursthouse A (2019) It's time to replace the term "heavy metals" with "potentially toxic elements" when reporting environmental research. Int J Environ Res Public Health 16(22):4446

14. Pourret O, Bollinger JC, Hursthouse A (2021) Heavy metal: a misused term? Acta Geochim 40(3):466–471
15. El Nemr A (2003) Assessment of heavy metal pollution in surface muddy sediments of Lake Burullus, southeastern Mediterranean, Egypt. Egypt J Aquat Biol Fish 7(4):67–90
16. Khaled A, El Nemr A, El Sikaily A (2013) Heavy metals concentrations in biota of the Mediterranean Sea: a review, part I. Blue Biotechnol J 2(1):79–133
17. APHA (1995) Standard methods for the examination of water and wastewater, 19th edn. American Public Health Association Inc, New York, p 1100
18. Grasshoff, K., & Kremling, K. (1999) M. Ehrhardt. Methods of Seawater Analysis, 3rd ed., Wiley-VCH, ch 4, p109 and ch 5, p125.
19. Abdullah MI, Royle LG (1974) A study of the dissolved and particulate trace elements in the Bristol Channel. J Mar Biol Ass UK 54(1974):581–597
20. Folk RL (1974) Petrology of sedimentary rocks. Hemphill, Texas, p 184
21. Gaudette HE, Flight WR, Toner L, Folger DW (1974) Aninexpensive titration methods for the determination of organic carbon in recent sediments. J Sedim Petro 44(1):249–253
22. Moore JE, Gorsline DS (1960) Physical and chemical data forbottom sediments south Atlantic coast of the United States. United States Fish and Wildlife Service. Special Scientific Report-Fisheries No. 366
23. Oregioni B, Aston SR (1984) IAEA Monaco Laboratory, Internal Report. (Cited from Reference Methods in Pollution Studies No. 38, UNEP, 1986)
24. Hseu ZY, Chen ZS, Tsai CC, Tsui CC, Cheng SF, Liu CL, Lin HT (2002) Digestion methods for total heavy metals in sediments and soils. Water Air Soil Pollut 141(1):189–205
25. Szarek-Gwiazda E, Czaplicka-Kotas A, Szalińska E (2011) Background concentrations of nickel in the sediments of the Carpathian dam reservoirs (Southern Poland). Clean Soil Air Water 39(4):368–375
26. Nriagu JO, Pacyna JM (1988) Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 333(6169):134–139
27. Kuleshov V (2017) Isotope geochemistry: the origin and formation of manganese rocks and ores. Elsevier, Amsterdam
28. Taylor SR (1964) Abundance of chemical elements in the continental crust; a new table. Geochim Cos-mochim Acta 28:1273
29. Hassaan MA, El Nemr A, Madkour FF (2016) Environmental assessment of heavy metal pollution and human health risk. Am J Water Sci Eng 2(3):14–19
30. Saad MAH (1985) Influence of pollution on Lake Mariout, Egypt. II. Nutrient salts. Rev Int Oceanogr Med 79–80:50–63
31. Riley, J. P. & Skirrow, G. (Editors): Chemical Oceanography. Vol. 1 & 2. – London and New York: Academic Press 1965. 712 + 508 pp.
32. Förstner U, Muller G (1974) Schwermetalle in Flussen and Seen. Springer, Berlin
33. El-Ghobary H (1977) Distribution and partitioning of Cu and Ni in Lake Edku sediments. MSc Thesis. Faculty of Science, Alexandria University
34. Abdel-Moati MA, El-Sammak AA (1997) Man-made impact on the geochemistry of the Nile Delta Lakes. A study of metals concentrations in sediments. Water Air Soil Pollut 97:413–429
35. Samir MS, Shaker IM (2007) Assessment of heavy metals pollution in water and sediments and their effect on Oreochromis Niloticus in the Nile northern Delta Lakes, Egypt. Central Lab. for Aquaculture Research, Agricultural Research Center. Limnology Dept.
36. Abdalah MAM (2008) Speciation of trace metals in coastal sediments of El-Mex Bay South Mediterranean Sea-west of Alexandria (Egypt). Environ Monit Assess 132(1–3):111–123
37. Gawad SSA (2018) Concentrations of heavy metals in water, sediment and mollusk gastropod, Lanistes carinatus from Lake Manzala, Egypt. Egypt J Aquat Res 44(2):77–82
38. Malsiu A, Shehu I, Stafilov T, Faiku F (2020) Assessment of heavy metal concentrations with fractionation method in sediments and waters of the Badovci Lake (Kosovo). J Environ Public Health. https://doi.org/10.1155/2020/3098594
39. Kutlu B (2018) Dissemination of heavy-metal contamination in surface sediments of the Uzunçayır Dam Lake, Tunceli, Turkey. Hum Ecol Risk Assess Int J 24(8):2182–2194
40. Machowski R, Rzetala MA, Rzetala M, Solarski M (2019) Anthropogenic enrichment of the chemical composition of bottom sediments of water bodies in the neighborhood of a non-ferrous metal smelter (Silesian Upland, Southern Poland). Sci Rep 9(1):1–13
41. Goher ME, Ali MH, El-Sayed SM (2019) Heavy metals contents in Nasser Lake and the Nile River, Egypt: an overview. Egypt J Aquat Res 45(4):301–312
42. Moussa AA (1984) Estimation of metal pollutant levels in sediments from Lake Borollus, Egypt. VII. Journees Etud Pollutions, Lucerne, C.I.E.S.M.
43. Abdel-Baky TE, Hagras AE, Hassan SH, Zyadah MA (1998) Environmental impact assessment of pollution in Lake Manzala, I-Distribution of some heavy metals in water and sediment. J Egypt Ger Soc Zool 26(2):25–38
44. Abdallah MAM, Abdallah AMA (2008) Biomonitoring study of heavy metals in Biota and sediments in the Southern Coast of Mediterranean Sea. Egypt Environ Monit Assess 146:139–145
45. Emmerson RHC, O'reilly-Wiese SB, Macleod CL (1997) A multivariate assessment of metal distribution in in-ter-tidal sediment of the Blackwater Estusry, UK. Mar Pollut Bull 34(11):960
46. Attril MJ, Thomas RM (1995) Heavy metal concentration in sediment from the thimes estuary, Uk. Mar Pollut Bull 30(11):742
47. Goldberg ED, Gamble E, Griffin JJ (1977) Pollution history of Narragansett Bay as- recorded in sediments. Estuarine Coast Shelf Sci 5:549
48. Glooschenko WA, Capocianco J, Cobum J (1981) Geochemical distribution of trace metals and organochlorine contaminants of a Lake Ontario shoreline marsh. Water Air Soil Pollut 15:197
49. Horsfall MJ, Spiff A (2002) Distribution and partitioning of trace metals in sediments of the lower reaches of the New Calabar River, Port-Harcourt, Nigeria. Environ Monit Assessment 78:309–326
50. NAOC (2006) Nigerian A gip Oil Company: Environmental Impact Assessment of Tebidaba East-A Exploration Drilling Project, Report No. 5-0515
51. Birth G (2003) A scheme for assessing human impacts on coastal aquatic environments using sediments. In: Woodcofie CD, Furness RA (eds) Coastal CIS 2003. Wollongong University Papers in Center for Maritime Policy, 14, Australia
52. Yasar D, Aksu AE, Uslu O (2001) Anthropogenic pollution in Izmit Bay: heavy metal concentrations in surface sediments. Turk J Eng Environ Sci 25:299–313
53. Lin YP, Teng TP, Chang TK (2002) Multivariate analysis of soil heavy metals pollution and landscape pattern in Changhua County in Taiwan. Landsc Urban Plan 62:19–35
54. Förstner U, Ahlf W, Calmano W (1993) Sediment quality objectives and criteria development in Germany. Water Sci Technol 28:307
55. Müller PJ, Suess E (1979) Productivity, sedimentation rate and sedimentary Organic matter in the oceans. I. Organic carbon presentation. Deep Sea Res. 26:1347

56. Hakanson L (1980) Ecological risk index for aquatic pollution control. A sediment logical approach. Water Res 14(5):975–1001
57. Bakan G, Ozkoc HB (2007) An ecological risk assessment of the impact of heavy metals in surface sediments on biota from the mid-Black Sea coast of Turkey. Int J Environ Stud 64(I):45–57
58. MacDonald DD, Ingersoll CG, Berger TA (2000) Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch Environ Contam Toxicol 39:20–31
59. Perin G, Bonardi M, Fabris R, Simoncini B, Manente S, Tosi L, Scotto S (1997) Heavy metal pollution in central Venice Lagoon bottom sediments: evaluation of the metal bioavailability by geochemical speciation procedure. Environ Technol 18:593–604
60. Tomlinson DC, Wilson JG, Harris CR, Jeffery DW (1980) Problems in the assessment of heavy metals levels in estuaries and the formation of a polluation index. Helgol Meeresuntersuchungen 33(1):566–575
61. Satyanarayana D, Panigrahy PK, Sahu SD (1994) Metal pollution in harbor and coastal sediments of Visakhapatnam, east coast of India. Indian J Mar Sci 23(I):52–54