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Application of geoaccumulation index and enrichment factor for assessing metal contamination in the sediments of Kafrain Dam, Jordan

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Abstract An investigation is reported of the degree of metal pollution in the sediments of Kafrain Dam and the origin of these metals. Fourteen sampling sites located at Kafrain Dam were chosen for collecting the surface, cutbank, and dam bank sediment samples. The sediment samples have been subjected to a total digestion technique and analyzed by atomic absorption spectrometer for metals including Pb, Zn, Cd, Ni, Co, Cr, Cu, Mn, and Fe. XRD analyses indicate that the sediments of Kafrain Dam are mainly composed of calcite, dolomite, quartz, orthoclase, microcline, kaolinite, and illite reflecting the geology of the study area. The enrichment factor (EF) and geoaccumulation index (I_{geo}) have been calculated and the relative contamination levels assessed in the study area. The calculations of I_{geo} are found to be more reliable than of those of EF. The enrichment of metals in the study area has been observed to be relatively high. I_{geo} results reveal that the study area is not contaminated with respect to Ni, Co, Cr, Cu, and Mn; moderately to strongly contaminated with Pb; and strongly to extremely contaminated with Cd and Zn. The high contents of Pb, Cd, and Zn in the study area result from anthropogenic activities in the catchment area of the dam site. These sources mainly include the agricultural activities, sewage discharging from various sources within the study area (effluent of wastewater treatment plants, treated and untreated wastewaters, and irrigation return water), and the several industries located in the area. Degrees of correlations among the various metals in the study area are suggested by the results and the intermetallic relationship.

Keywords Metals · Enrichment factor · Dam sediments · Correlation analysis · Geoaccumulation index · Jordan

Introduction

Pollution associated with metals is a serious problem due to their toxicity and their ability to accumulate in the biota. One of the most crucial properties of metals is that they are not biodegradable in the environment (Nuremberg 1984; Forstner 1990;

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Harte et al. 1991; Schuurmann and Market 1998). The levels of metals in aquatic ecosystems have increased drastically in recent decades as a result of inputs from anthropogenic activities (Forstner and Wittmann 1983; Nriagu 1989; Gómez-Parra et al. 2000).

Sediment quality has been recognized as an important indicator of water pollution (Larsen and Jensen 1989) since sediments are the main sink for various pollutants, including metals discharged into the environment (Williams et al. 1996; Balls et al. 1997; Dassenakis et al. 1997; Tam and Wong 2000; Bettinetti et al. 2003). Sediments also play a significant role in the remobilization of contaminants in aquatic systems under favorable conditions and in interactions between water and sediment. Comprehensive methods for identifying and assessing the severity of sediment contamination have been introduced in order to protect the aquatic life community (Van de Guchte 1992; Chapman 2000).

Metals in sediments can be classified, on the basis of the primary accumulation mechanism, as adsorptive and exchangeable, bound to carbonate phases and Fe/Mn oxides, bound to organic matter and sulfides, and residual metals (Salomons and Forstner 1984). The adsorption of metals is influenced by several physical and chemical parameters such as pH, oxidative–reductive potential, dissolved oxygen, organic and inorganic carbon content, and the presence in the water phase of some anions and cations that can complex or co-precipitate the water-dissolved or suspended pollutants (Izquierdo et al. 1997; Wen and Allen 1999, Zoumis et al. 2001).

The environmental pollution with metals in the Kafrain Dam in Jordan has not been previously assessed or investigated, to the best of the authors' knowledge. Such an investigation is required if the environmental impacts in the region of the dam are to be understood quantitatively and qualitatively. The main objectives of the current study are: (1) to determine if sufficiently high concentrations of any metals exist in the reservoir of the Kafrain Dam, such that they can be considered toxic to the aquatic environment, and (2) to assess the extent and degree of metals, and the origin of these metals, using the enrichment factor and the geoaccumulation index of the metals. The metals considered of concern in the investigation are Pb, Zn Cd, Ni, Co, Cr, Cu, Mn, and Fe.

Study area

Water resources in Jordan consist primarily of surface water and groundwater, with treated wastewater being used for irrigation, mostly in the Jordan Valley (Mohsen 2007). Over 90% of Jordan, with a total area of about 88,778 km^2, receives less than 200 mm of annual rainfall. Therefore, several dams have been constructed in Jordan, including the King Talal, the Wadi Al-Arab, and the Kafrain Dams.

The Kafrain Dam is an earth-fill dam that was constructed in 1967 at the entrance of the Wadi Kafrain (Fig. 1) into the Jordan Valley. The height of the dam is 37 m and the reservoir storage capacity is about 11 Mm^3. The water of the dam is mainly used for irrigating downstream lands and for recharging the underlying aquifer (Salameh 1996).

The Wadi Kafrain drains an area west of Amman with an extent of 189 km^2 lying at elevations ranging from 1,200 m above sea level down to areas lying below sea level in the Jordan Valley. Precipitation in the eastern parts of the catchment, averaging 500 mm year^{-1}, may fall in the form of snow, whereas in the western parts the average reaches only 150 mm year^{-1} and falls completely in the form of rain (Salameh 1996). The average discharge of the Wadi Kafrain is 6.4×10^6 m^3 year^{-1}, consisting of 1.6×10^6 m^3 year^{-1} flood flow and 4.8×10^6 m^3 year^{-1} base flow.

The geological map and cross-section at the dam axis are shown in Fig. 2. The soil underlying the dam body consists mainly of thick alluvial deposits to about a 60 m depth (Malkawi and Al-Sheriadeh 2000). These deposits are comprised of poorly sorted silty clay, sandy gravel with occasional lenses of boulders or silty sands of various cementation. The geology of the dam site is mainly composed of limestone, marl, and a massive crystalline limestone. To the right abutment, a limestone and marly limestone formation varies in thickness and dips steeply to the northeast. The left abutment is composed of a dolomitic limestone formation. The formation dips to the northwest.

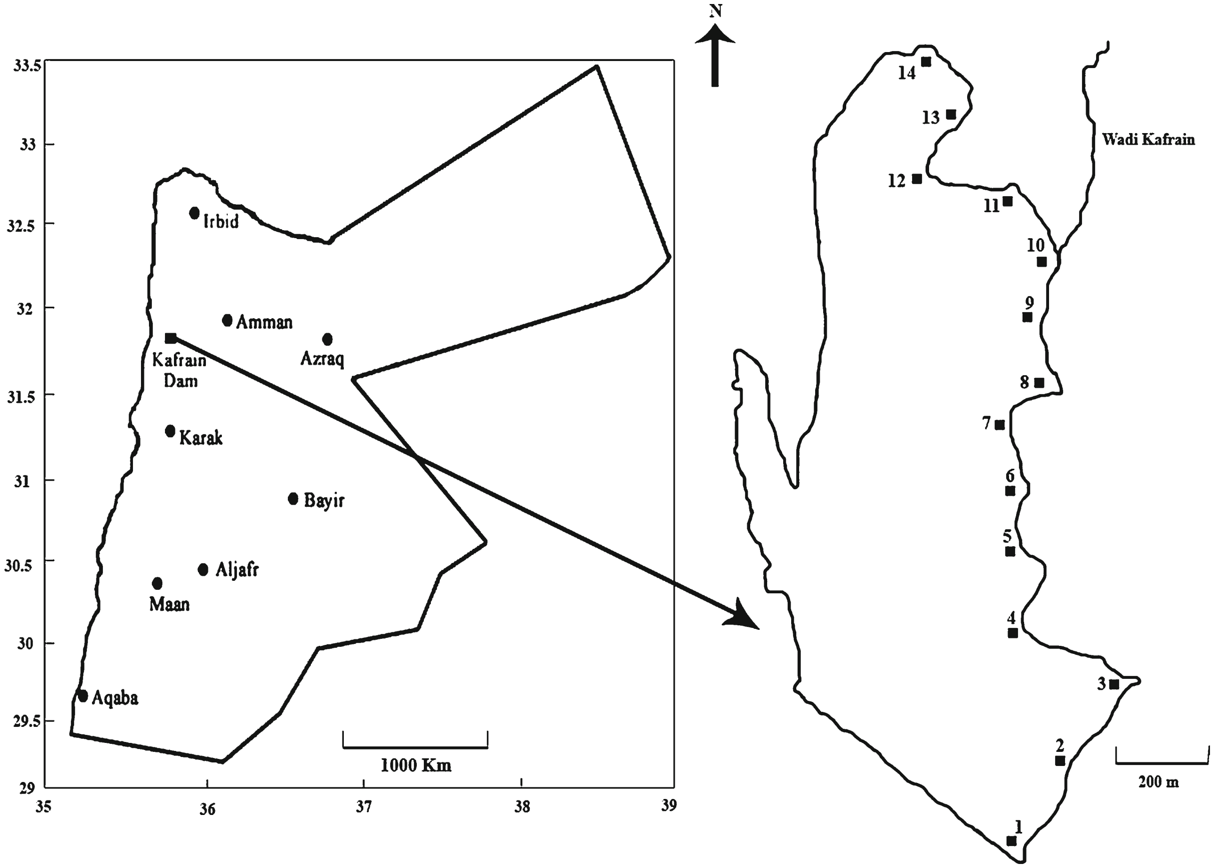

Fig. 1 Jordan map showing the location of Kafrain Dam reservoir with sampling sites

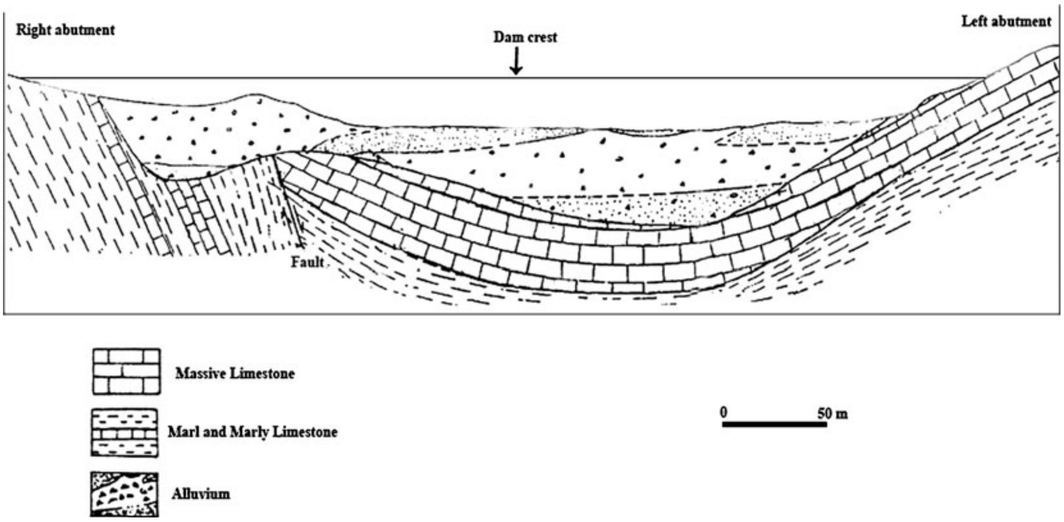

Fig. 2 Diagrammatic geological section of Kafrain Dam

The reservoir area of the Kafrain Dam consists of alluvial deposits underlying bedrock. The edge of the reservoir area is composed of highly permeable silty clay. The types of bedrock in the reservoir area are limestone and marly limestone. These beds occur on the eastern limb of the north-south trending anticline. To the northwest of the reservoir area, a permeable sandstone is exposed in the core of the anticline; the minimum elevation of the exposure is approximately 50 m. To the east of the reservoir area, dolomitic limestone, massive limestone, chalk, and marl formations in addition to limestone and marl are the materials of the bedrock. These formations are partly disrupted by minor folds and faults. On the valley floor the bedrock is massive limestone, marl, and marly limestone. The bedrock looks like a syncline fold comprised by the two north-south faults. These faults probably mark the boundary between alluvium and bedrock in most places (Salameh 1996; Malkawi and Al-Sheriadeh 2000).

Materials and methods

Fourteen sampling sites (Fig. 1) located at the Kafrain Dam were selected for collecting 42 sediment samples. The sediment samples were collected in December 2008. Three sediment samples were collected from each site. The first is collected from the surface of the dam bottom, the second from the cutbank on the east side, and the third from the dam bank of the east side. The sediment samples were transported to the laboratory in polyethylene bags and dried in an oven at 60°C for 24 h. Different grain size fractions were selected for the analysis of metals: <2 μm fraction (Müller 1979; Rubio et al. 2000; Abu-Rukah 2001); <63 μm fraction (Calmano and Wellerhaus 1982); <150 μm fraction (Williams et al. 2000); and <2 mm fraction (Zollmer and Irion 1993). In the present study, the contamination of sediments with particle size fractions below 2 μm were investigated using the pipette method (Gee and Bauder 1986), in which a sample is pipetted at different times and various depths of the suspension of the sample in a measuring cylinder. The pipetted suspension is condensed and dried, and the mass ratio of the pipetted fraction is determined by weighing. Then, 0.5 g of the pipetted fraction was digested using 4 ml of HNO_3 (65%), 2 ml of HF (40%), and 4 ml of $HClO_4$ (70%). The solution of the digested samples was analyzed with an atomic absorption spectrometer (PYE UNICAM SP9) for lead (Pb), zinc (Zn), cadmium (Cd), nickel (Ni), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), and iron (Fe). For quality control, all sediment samples were analyzed in triplicate and mean values were calculated. A blank was also run at the same time and no detectable contamination was found when aliquots of reagents were processed and analyzed with the samples. The absorption wavelength and detection limits of metals were as follows: 228.8 nm and 0.0006 ppm for Cd, 240.7 nm and 0.007 ppm for Co, 324.7 nm and 0.003 ppm for Cu, 248.3 nm and 0.005 ppm for Fe, 279.5 nm and 0.003 ppm for Mn, 232.0 nm and 0.008 ppm for Ni, 217.0 nm and 0.02 ppm for Pb, and 213.9 nm and 0.002 ppm for Zn.

The accuracy of the atomic absorption spectrometer measurements was assessed by analyzing the standard reference material NIST, SRM 1646 (estuarine sediment). The calculation of the correlation coefficient was performed using the Statistical Program for the Social Sciences software package.

Forty-two sediment samples were ground in an agate mortar for whole-sample mineralogy analysis using the XRD method. The sample powders were packed in circular cavity holders and their XRD patterns were obtained using a Scintag Pad V diffractometer operated at 45 kV and 40 mA. The diffraction peaks between $2\theta = 2°$ and $2\theta = 60°$ were recorded. The peak search for minerals in the diffraction data was accomplished using the Diffraction Management System Software for Windows NT (DMSNT version 1.34). The software compares d-spacing and intensity of each mineral with those of reference mineral standards.

Results and discussion

Mineralogical composition

The XRD examination reveals that the non-clay mineral constituents of the surface, cutbank, and dam bank sediments of the Kafrain Dam are dolomite, calcite, quartz, orthoclase, and microcline (Fig. 3). Kaolinite and illite are the dominant clay minerals in the three types of sediments. The mineralogical composition of the sediments is reflected by the geology of the study area. The sediment samples obtained from the surface, cutbank, and dam bank exhibit somewhat similar mineralogical compositions. Calcite and dolomite are mainly derived from limestone, and the dolomilitic limestone formation exposed in the dam site and the reservoir area. Quartz is probably derived from the adjacent Kurnub sandstone exposed to the northwest of the reservoir area. Orthoclase is probably derived from the nearby basalt study area.

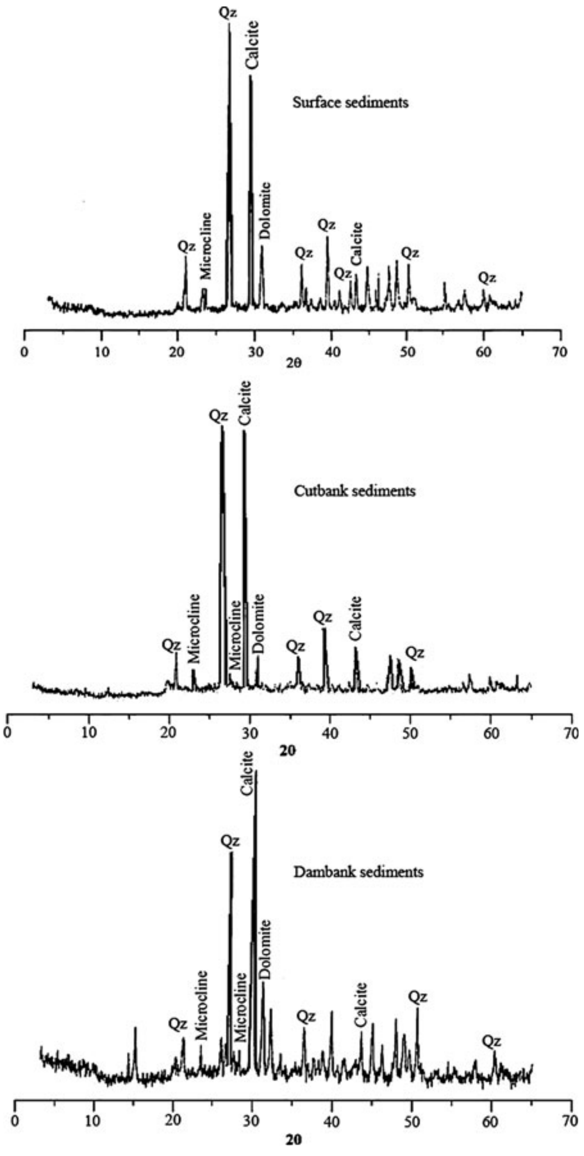

Fig. 3 Result of X-ray diffraction at site 11

Metal levels

Surface sediments

The results showed that Fe has the highest mean concentration in the surface sediments, followed by Mn, Cr, Pb, Zn, Ni, Cu, Co, and Cd (Table 1). A comparison of the metal concentrations in the surface sediments with the corresponding values of these metals in the average shale (Turekian and Wedepohl 1961) reveals that all the sampling sites of the surface sediments are polluted with Pb, Cd, Co, and Cr. On the contrary, the locations studied had Fe concentrations less than those for average shale, which indicates that there are no major sources of pollution for Fe in the study area. Further, almost all the sampling sites were observed to exhibit higher Zn and Ni concentrations in the surface sediments than average shale. The same behavior is observed for some sites where Cu and Mn levels are higher than average shale. The average concentrations of Mn, Fe, Co, Ni, Cu, Zn, Pb, Cr, and Cd determined in the surface sediments of Kafrain Dam are higher than those of these metals in uncontaminated sediments and soils. According to Bowen (1979), the levels of Mn, Fe, Co, Ni, Cu, Zn, Pb, Cr, and Cd in uncontaminated sediments and soils are 550, 26,000, 9.1, 19, 25, 60, 19, 54, and 0.35 ppm, respectively.

Observed metal contents in the surface sediments of the Kafrain Dam are compared in Table 2 with those of similar studies of dam sediments in other regions in the world. The current study differentiated between three dam compartments (the surface of the dam bottom, the cutbank, and the dam bank), whereas the other studies focused on the surface sediments. The concentration of Cd in the Kafrain Dam ranked three out of five studies. The average concentration of Cd obtained in this study was lower than that of Pulicat Lake, India (Kamala-Kannan et al. 2007), and the Seyhan Dam (Cevik et al. 2009). The high content of Cd observed in these studies is due to anthropogenic sources including fertilizers and

Table 1 Average, minimum, maximum, and standard deviation of metal concentrations (ppm) in the surface, cutbank, and dam bank sediments of the Kafrain Dam

Sampling sites	Pb	Cd	Zn	Ni	Co	Cr	Cu	Mn	Fe
	20	**0.3**	**95**	**68**	**19**	**90**	**45**	**850**	**47,000**
	Surface sediments								
1	283	11	89	97	44	100	40	543	25,680
2	69	9	180	101	59	206	47	723	35,310
3	127	11	133	98	102	178	78	851	43,090
4	92	10	110	78	32	124	37	634	30,450
5	109	9	93	72	58	118	24	524	52,950
6	121	8	95	60	76	139	25	674	33,670
7	113	5	124	89	43	151	28	624	34,150
8	92	5	99	61	47	142	35	660	34,600
9	156	13	128	170	62	222	400	1,052	44,820
10	128	10	115	136	84	210	50	834	42,920
11	171	10	91	114	38	149	38	622	30,540
12	142	9	108	109	47	119	37	757	34,930
13	221	51	184	151	80	241	51	1,144	54,610
14	115	8	75	59	36	111	23	513	26,060
Average	138.5	12.1	116	99.6	57.7	157.9	65.2	725.4	37,412.9
Minimum	69	5	75	59	32	100	23	513	25,680
Maximum	283	51	184	170	102	241	400	1,144	54,610
Standard deviation	62.1	11.4	31.6	34.0	22.5	47.3	94.0	185.2	9,046.6
	Cutbank sediments								
1	75	8	42	60	350	47	18	213	9,100
2	79	7	70	93	37	90	25	492	20,260
3	113	6	65	74	18	75	16	471	18,550
4	155	10	60	90	44	81	27	402	19,220
5	141	11	86	103	38	84	28	517	24,290
6	86	10	60	86	57	50	18	326	16,720
7	78	6	115	77	29	49	24	338	13,520
8	176	10	65	117	42	121	19	427	15,600
9	134	9	58	73	500	112	22	335	16,230
10	147	10	35	99	45	84	12	208	9,500
11	171	9	78	122	42	117	22	424	18,800
12	129	10	57	106	43	114	42	623	23,670
13	133	7	43	60	63	51	10	152	9,450
14	120	10	46	83	43	53	14	220	14,030
Average	124.1	8.8	62.9	88.8	96.5	80.6	21.2	367.7	16,352.9
Minimum	75	6	42	60	18	47	10	152	9,100
Maximum	176	11	115	122	500	121	42	623	24,290
Standard deviation	34.0	1.7	20.6	19.3	142.6	27.6	8.1	136.7	4,900.5

pesticides used in agricultural activities near the areas of the studies. Concentrations of Cr, Mn, and Zn are lower than those of these metals in sediments of the Sehyah Dam and Keban Dam Lake, Turkey (Cevik et al. 2009; Kulahci and Sen 2008). However, the range of concentrations of Cu is higher than the corresponding values in the sediments of the Wadi Al-Arab and Ziqlab Dams in Jordan, and the Ataturk Dam and the Egbe Dam in Pakistan (Karadede and Unlu 2000; Abu-Rukah 2001; Ghrefat and Yusuf 2006; Adefemi et al. 2007). The concentration of Fe ranked second out of seven studies. The average concentration of Fe was only lower than that of Fe in the

Table 1 (continued)

Sampling sites	Pb	Cd	Zn	Ni	Co	Cr	Cu	Mn	Fe
	20	**0.3**	**95**	**68**	**19**	**90**	**45**	**850**	**47,000**
	Dam bank sediments								
1	146	9	40	50	57	63	27	390	6,100
2	117	12	62	79	36	92	27	362	14,430
3	125	10	55	72	56	68	19	476	16,180
4	128	8	162	30	60	68	13	363	8,670
5	97	9	67	90	69	44	20	388	20,870
6	88	11	39	43	32	39	25	398	10,950
7	34	3	58	74	13	69	25	452	7,310
8	161	8	50	75	61	83	21	509	12,990
9	132	9	62	85	27	113	28	433	19,000
10	193	14	79	143	75	161	29	488	23,230
11	203	31	74	127	74	118	20	621	21,730
12	230	10	43	100	87	117	33	872	24,870
13	73	7	74	112	58	100	21	383	19,550
14	126	9	33	106	600	22	13	614	10,830
Average	132.4	10.7	64.1	84.7	93.2	82.6	22.9	482.1	15,479.3
Minimum	34	3	39	30	13	22	13	362	6,100
Maximum	230	31	162	143	600	161	33	872	24,870
Standard deviation	52.6	6.4	31.6	31.6	147.3	37.2	5.8	140.2	6,179.1

Bold numbers represent the background values of metals in average shale (ppm; Turekian and Wedepohl 1961)

Sehyah Dam (Cevik et al. 2009). Concentrations of Pb recorded in the present study are higher than those of Pb in the Ziqlab Dam and the Egbe Dam (Abu-Rukah 2001; Adefemi et al. 2007). The concentrations of Co and Ni are lower than the corresponding values for these metals in the sediments of the Keban Dam (Kulahci and Sen 2008).

Cutbank sediments

The mean concentrations of metals in the cutbank sediments are summarized in Table 1. Fe has the highest mean concentration in the cutbank sediments, followed by Mn, Pb, Ni, Cr, Zn, Co, and Cd. The results demonstrate that almost all the sampling sites have higher Pb and Cd concentrations in the cutbank sediments than average shale. The same behavior is observed for some sites where Zn, Ni, and Co levels are higher than in average shale. Cu, Mn, and Fe concentrations at all the sampling sites were lower than for average shale, while Cr concentrations are lower in most of the sampling sites. The average concentrations of Co, Ni, Cu, Zn, Pb, Cr, Cd, Pb, Cd, and Ni determined in the cutbank sediments of Kafrain Dam are higher than those of these metals in uncontaminated sediments and soils.

Bank sediments

The results showed that Fe has the highest mean concentration in the bank sediments, followed by Mn, Pb, Co, Ni, Cr, Zn, Cu, and Cd (Table 1). All the sampling sites showed higher Pb and Cd concentrations in the bank sediments than average shale. The same behavior is observed for some sites where Ni and Co levels are higher than for average shale. Cu and Fe concentrations at all the sampling sites were lower than for average shale, while Zn and Cr concentrations are lower in most of the sampling sites. The average concentrations of Co, Ni, Cu, Zn, Pb, Cr, Cd, Pb, Cd, and Ni determined in the bank sediments of Kafrain Dam are higher than those of these metals in uncontaminated sediments and soils.

Metal distributions in the study area displayed no systematic trends, varying from one location to

Table 2 Average and standard deviation of metal concentrations (ppm) found in the surface sediments of different regions in the world

Dam name	Metal								
	Cd	Cr	Mn	Zn	Cu	Fe	Pb	Ni	Co
Kafrain Dam	10 ± 11.4 **(3)**	160 ± 42.3 **(3)**	730 ± 185.2 **(3)**	120 ± 31.6 **(5)**	70 ± 94.0 **(3)**	37,410 ± 9,046.6 **(2)**	140 ± 62.1 **(1)**	100 ± 34.0 **(2)**	60 ± 22.5 **(2)**
Wadi Al-Arab Dam[a]	9.0 ± 1.84 **(4)**	–	300 ± 98.0 **(4)**	340 ± 132.4 **(3)**	60 ± 31.8 **(4)**	11,270 ± 144.2 **(5)**	–	–	–
Ziqlab Dam[b]	0.0647 ± 0.56 **(5)**	36 ± 16.0 **(4)**	53 ± 26.7 **(7)**	74.7 ± 35.0 **(6)**	16 ± 8.1 **(6)**	4,290 ± 1,181.3 **(6)**	21.1 ± 8.3 **(3)**	46 ± 18.1 **(4)**	8.5 ± 2.9 **(3)**
Seyhan Dam[c]	21.5 ± 3.8 **(2)**	1,189.5 ± 217 **(2)**	8,036.3 ± 1,370 **(2)**	3,909 ± 65 **(2)**	198 ± 45.7 **(2)**	393,500 ± 57,500 **(1)**	–	–	–
Keban Dam Lake[d]	–	13,578 ± 8,086.7 **(1)**	37,863 ± 28,851.6 **(1)**	4,012 ± 1,448.6 **(1)**	3,977 ± 1,269.2 **(1)**	18,592 ± 12,215.5 **(3)**	–	3,912 ± 2,190 **(1)**	3,462 ± 1,721 **(1)**
Egbe Dam[e]	–	–	286.3 ± 133.3 **(6)**	187.5 ± 123.3 **(4)**	2 ± 0.87 **(7)**	600.3 ± 246.3 **(7)**	27 ± 24 **(2)**	–	–
Pulicat Lake[f]	64.2 ± 16.16 **(1)**	28.5 ± 28.51 **(5)**	–	–	–	–	8.3 ± 9.05 **(4)**	–	–
Ataturk Dam[g]	–	–	293.8 ± 887.5 **(5)**	60.0 ± 1.2 **(7)**	18.6 ± 5.7 **(5)**	15,926 ± 4,722.1 **(4)**	–	91.7 ± 67.8 **(3)**	–

Bold numbers in parentheses represent the rank of the Kafrain Dam for the different metal average concentrations compared to other regions

[a] Ghrefat and Yusuf (2006)

[b] Abu-Rukah (2001)

[c] Cevik et al. (2009)

[d] Kulahci and Sen (2008)

[e] Adefemi et al. (2007)

[f] Kamala-Kannan et al. (2008)

[g] Karadede and Unlu (2000)

another (Table 1). The difference in the distribution and concentration of metals in the sediments of the Kafrain Dam may be due to a number of parameters such as clay content, pH, organic matter content, cation exchange capacity, and iron and manganese oxides.

Enrichment factor and geoaccumulation index

In the present study, the enrichment factor (EF) is used to assess the level of contamination and the possible anthropogenic impact in the sediments of the Kafrain Dam. To identify anomalous metal concentrations, the geochemical normalization of the metal data to a conservative element, such as Al, Fe, or Si, is employed. Several authors successfully used Fe to normalize metal contaminants (Schiff and Weisberg 1999; Baptista Neto et al. 2000; Mucha et al. 2003; Conrad and Chisholm-Brause 2004; Cevik et al. 2009; Christophoridis et al. 2009; Meza-Figueroa et al. 2009; Bhuiyan et al. 2010; Esen et al. 2010). In the present study, Fe has been used as a conservative tracer to differentiate natural from anthropogenic components. The EF is defined as follows (Ergin et al. 1991):

$$\mathrm{EF} = \frac{\left(\frac{\mathrm{M}}{\mathrm{Fe}}\right)_{\mathrm{sample}}}{\left(\frac{\mathrm{M}}{\mathrm{Fe}}\right)_{\mathrm{backgroud}}} \qquad (1)$$

where $\left(\frac{\mathrm{M}}{\mathrm{Fe}}\right)_{\mathrm{sample}}$ is the ratio of metal and Fe concentrations of the sample, and $\left(\frac{\mathrm{M}}{\mathrm{Fe}}\right)_{\mathrm{background}}$ is the ratio of metal and Fe concentrations of a background.

The world average shale and the world average soil are among the materials often used to provide background metal levels. The regional geochemical background values for these metals are not available. Thus, the background concentrations of Pb, Zn, Cd, Ni, Co, Cr, Cu, Mn, and Fe in the average shale obtained from Turekian and Wedepohl (1961) (Table 3) are used in this study. These values are commonly used as background values in sediment studies to quantify the extent and degree of metal pollution (Lopez-Sanchez et al. 1996; Jones and Turki 1997; Sanchez et al. 1998; Datta and Subramanian 1998; Loska and Wiechula 2003; Cevik et al. 2009; Nobi et al. 2010).

According to Zhang and Liu (2002), EF values between 0.5 and 1.5 indicate the metal is entirely from crustal materials or natural processes, whereas EF values greater than 1.5 suggest that the sources are more likely to be anthropogenic. Table 3 shows EF values for Pb, Zn, Cd, Ni, Co, Cr, Cu, and Mn. The values of EF suggest that Cd, Pb, Co, Ni, Cr, Zn, Cu, and Mn are from anthropogenic inputs. The EF values are interpreted as the levels of metal pollution suggested by Chen et al. (2007). Chen et al. suggested that EF < 1 indicates no enrichment, EF $= 1$–3 indicates minor enrichment, EF $= 3$–5 indicates moderate enrichment, EF $= 5$–10 indicates moderately severe enrichment, EF $= 10$–25 indicates severe enrichment, EF $= 25$–50 indicates very severe enrichment, and EF > 50 indicates extremely severe enrichment. Values of EF are calculated in the

Table 3 Average and standard deviation of metal concentrations and average shale (ppm) (Turekian and Wedepohl 1961), and enrichment factor values in the surface, cutbank, and dam bank sediments of the Kafrain Dam

Metal	Surface sediments		Cutbank sediments		Dam bank sediments		Average shale
	Mean ± SD	EF	Mean ± SD	EF	Mean ± SD	EF	
Pb	138.5 ± 62.1	9.25	124.1 ± 34.0	19.32	132.4 ± 52.6	22.38	20
Cd	12.1 ± 11.4	48.15	8.8 ± 1.7	91.14	10.7 ± 6.4	116.12	0.3
Zn	116 ± 31.6	1.58	62.9 ± 20.6	2.01	64.1 ± 31.6	2.50	95
Ni	99.6 ± 34.0	1.93	88.8 ± 19.3	4.11	84.7 ± 31.6	4.17	68
Co	57.7 ± 22.5	3.85	96.5 ± 142.6	18.34	93.2 ± 147.3	18.72	19
Cr	157.9 ± 42.3	2.24	80.6 ± 27.6	2.69	82.6 ± 37.2	3.02	90
Cu	65.2 ± 94.0	1.65	21.2 ± 8.1	1.31	22.9 ± 5.8	1.75	45
Mn	755.4 ± 185.2	1.09	367.7 ± 136.7	1.22	482.1 ± 140.2	1.97	850
Fe	37,412.9 ± 9,046.6	–	16,352.9 ± 4,900.5	–	15,479.3 ± 6,179.1	–	47,000

current study following the method of Chen et al. (2007).

The resulting EF values demonstrate that Pb, Cd, Zn, Ni, Co, Cr, Cu, and Mn are enriched in the surface, cutbank, and dam bank sediments of the Kafrain Dam (Table 3). The EF values for Cd are the highest among the metals and it has a severe to extremely severe enrichment. The EF values also indicate that Pb has moderately severe to severe enrichment, Co has moderately to severe enrichment, and Ni, Cr, Cu, and Mn have minor enrichment. The enrichment of metals in the study area has been observed to be relatively high in the three types of sediments. All metals in the dam bank sediments are more enriched compared to the other types of sediments (Table 3). The difference in EF values for the different metals in the dam sediments may be due to the difference in the magnitude of input for each metal in the sediment and/or the difference in the removal rate of each metal from the sediment. Metals can be released with the water phase when changes occur in conditions like pH, redox potential, ionic strength, and the concentration of organic complexing agents (Calmano et al. 1990).

The EF results in the other regions exhibit different degrees of metals enrichment. Ghrefat and Yusuf (2006) and Cevik et al. (2009) calculated EF in the same way as in this study, whereas Abu-Rukah (2001) used a simple metal/normalizer ratio. The values of EF in the Kafrain Dam are higher than those of EF in the Wadi Al-Arab Dam. The determined values of EF in the sediment of Wadi Al-Arab Dam show that Mn and Cu are derived from the crustal materials, whereas Zn and Cd are enriched by 3.6 and 30 times, respectively (Ghrefat and Yusuf 2006). The Seyhan Dam sediments are treated as having a moderately severe enrichment with Cd, while Cr and Mn have minor enrichments (Cevik et al. 2009). The sediments of the Ziqlab Dam are enriched with Pb and Cd by 1.07 and 2.16, respectively, while Zn, Mn, Ni, Cu, Cr, and Co are depleted in the sediments (Abu-Rukah 2001). EF values greater than 1 suggest that the sources are more likely to be anthropogenic.

Possible sediment enrichment of metals in aquatic sediments was evaluated in terms of the geoaccumulation index (I_{geo}) of Müller (1979). This index was originally defined for metal concentrations in the <2 μm fraction and developed for the global standard shale values (Müller 1979). The formula used for the calculation of I_{geo} is expressed as follows:

$$I_{\mathrm{geo}} = \mathrm{Log}_2\left(\frac{\mathrm{C_n}}{1.5\ \mathrm{B_n}}\right) \tag{2}$$

Here, C_n is the measured concentration in the sediment for metal n, B_n is the background value for the metal n (Turekian and Wedepohl 1961), and the factor 1.5 is used because of possible variations of the background data due to lithological variations. The quantity I_{geo} is calculated using the global average shale data from Turekian and Wedepohl (1961).

The geoaccumulation index includes seven grades. The highest grade (class 6) reflects a 100-fold enrichment above background values (Table 4). The geoaccumulation index results indicate that the surface, cutbank, and dam bank sediments are uncontaminated with respect to Ni, Co, Cr, Cu, and Mn (Table 5). The Pb accumulation level is moderate to strong (Table 5). The study area is strongly to extremely contaminated with Cd and Zn (Table 5). The high contents of Pb, Cd, Zn, and Cr are probably a result of anthropogenic activities in the catchment area of the dam site. Different towns and villages, like Wadi Sir and Naur, discharge their wastes along the Wadi Kafrain or its tributaries. In addition, the Wadi Sir and Hussein Medical Center waste treatment plants end up in the Wadi Kafrain or its tributary wadis (Salameh 1996). Moreover, the

Table 4 Geoaccumulation index (I_{geo}) (Muller 1981) for contamination levels in sediments

I_{geo} class	I_{geo} value	Contamination level
0	$I_{\mathrm{geo}} \leq 0$	Uncontaminated
1	$0 < I_{\mathrm{geo}} < 1$	Uncontaminated/moderately contaminated
2	$1 < I_{\mathrm{geo}} < 2$	Moderately contaminated
3	$2 < I_{\mathrm{geo}} < 3$	Moderately/strongly contaminated
4	$3 < I_{\mathrm{geo}} < 4$	Strongly contaminated
5	$4 < I_{\mathrm{geo}} < 5$	Strongly/extremely contaminated
6	$5 < I_{\mathrm{geo}}$	Extremely contaminated

Table 5 Index of geoaccumulation (I_{geo}) and contamination level for mean metal concentrations in the surface, cutbank, and dam bank sediments of Kafrain Dam

Metal	I_{geo} and contamination level[a]		
	Surface sediments	Cutbank sediments	Dam bank sediments
Pb	2.11 (MC/SC)	1.99 (MC)	2.00 (MC/SC)
Cd	4.47 (SC/EX)	4.26 (SC/EX)	4.40 (SC/EX)
Zn	4.95 (SC/EX)	4.89 (SC/EX)	4.93 (SC/EX)
Ni	−0.11 (UC)	−0.23 (UC)	−0.37 (UC)
Co	−0.34 (UC)	−1.25 (UC)	−1.26 (UC)
Cr	0.17 (MC)	−0.83 (UC)	−0.86 (UC)
Cu	−0.61 (UC)	−1.76 (UC)	−1.61 (UC)
Mn	−0.86 (UC)	−1.89 (UC)	−1.45 (UC)

MC moderately contaminated, *MC/SC* moderately/strongly contaminated, *SC* strongly contaminated, *EX* extremely contaminated

[a] UC denotes uncontaminated/slightly contaminated

irrigation return water, the presence of a dumping site and industrial activities nearby the dam site, and the use of chemical fertilizers and pesticides in the agricultural activities are considered additional sources of pollution (Salameh 1996). Cd is a relatively rare metal. It has no essential biological functions and is highly toxic to plants and animals. The major hazard to human health from Cd is its chronic accumulation in kidneys (Alloway 1990). Pb is also a highly toxic metal for plants and animals (Alloway 1990; Kennish 1992; Routh and Ikramuddin 1996). The solubility of Pb is controlled principally by $PbCO_3$, and low-alkalinity and low-pH waters can have higher Pb concentrations (Gowd et al. 2010). Also, Zn is generally considered a toxic element and its solubility is heavily pH dependent; Zn is nearly insoluble under neutral pH, but becomes much more soluble when pH drops to 6 (Forstner and Wittmann 1983; Alloway 1990). Despite the high contents of Cr in the sediments of the study area, the sediments have been classified as uncontaminated with Cr. Cr is a low mobility element, especially under moderately oxidizing and reducing conditions and near-neutral pH values. Cr^{6+} adsorption decreases with increasing pH, and Cr $^{3+}$ adsorption increases with increasing pH. On the other hand, Cr^{6+} is toxic for biological systems (Gowd et al. 2010).

The results of I_{geo} in the sediments of other regions exhibit various degrees of metals contamination. In these studies, Fe was used to normalize metal contaminants. Ghrefat and Yusuf (2006) reported that the sediments of the Wadi Al-Arab Dam are uncontaminated with Mn, Fe, and Cu, moderately contaminated with Zn, and strongly to extremely contaminated with Cd. The elevated concentrations of Pb, Zn, and Cd are due to anthropogenic sources near the dam site. These sources mainly include fertilizers and pesticides used in agricultural activities, and the effluent of the Irbid City treatment plant (Salameh 1996). The I_{geo} results reveal that the sediments in the Ziqlab Dam are uncontaminated to moderately contaminated with Pb and Cd (Abu-Rukah 2001). The concentrations for the elements Mn, Zn, Co, Ni, Cr, Cu, and Fe are below contamination levels. The results of I_{geo} reveal that the sediments of the Seyhan Dam are strongly to moderately polluted with Cd (Cevik et al. 2009). The sediments of Keratsini harbor, Greece are heavily polluted in terms of Cd, Pb, and Zn, and highly contaminated with respect to Cu and Cr (Galanopoulou et al. 2009).

The EF values show that as the values of metals vary the classification of contamination levels vary. The classification of contamination levels based on I_{geo} does not always vary as the contents of metals vary. Consequently, the calculations of I_{geo} are more reliable than those of EF for assessing metal pollution in the current study.

Both I_{geo} and EF depend on the background data used, grain size, and bonding forms of metals. Rubio et al. (2000) calculated I_{geo} for the sediments of Ria de Vigo, NW Spain, using three background values, two of them regional values and the third the global average shale data from Turekian and Wedepohl (1961). The results show that significant differences are observed between backgrounds used for Cr, Pb, and Cu. The term I_{geo} is affected by the content of the samples and the geochemical background values.

Fine-grained sediments tend to have relatively high metal contents, due in part to the high specific surface of the smaller particles. This enrichment is mainly due to surface adsorption and ionic attraction (McCave 1984; Horowitz and Elrick 1987). Also, coatings of organic matter are prevalent in fine-grained sediments, and these coatings bind a variety of trace elements. Yaqin et al. (2008) used I_{geo} to study source profiles of soil dust in China, and revealed that I_{geo} values for fine soil dusts are generally higher than those for coarse fractions of a given element and city. Thus, fine soil dusts tend to be more heavily contaminated than coarse dusts.

Correlation analyses

Pearson's correlation coefficients for Pb, Cd, Zn, Ni, Co, Cr, Cu, Mn, and Fe in the sediments of the Kafrain Dam are depicted in Table 6. The matrix summarizes the strength of the linear relationships between each pair of variables. All the metal pairs in the surface sediments exhibit positive relations (except for the Pb–Zn pair), but some of them were significant at the 95% and 99% confidence levels. The Pb–Cr ($r = 0.67$), Ni–Cr ($r = 0.73$), Cu–Mn ($r = 0.83$), Cu–Fe ($r = 0.78$), and Mn–Fe ($r = 0.93$) pairs are significantly positively correlated with each other at the 99% confidence level, which may suggest a common pollution source or a similar geochemical behavior for these metals. The Pb–Cd ($r = 0.57$), Pb–Cr ($r = 0.57$), Pb–Mn ($r = 0.68$), Ni–Cr ($r = 0.60$), and Cr–Cu ($r = 0.57$) pairs in the cutbank and dam bank sediments are significantly positively correlated with each other at 95% and 99% confidence levels. Negative and inverse correlations between metals indicate that these metals are derived from different sources and that this metal is not associated with other metals.

Table 6 Matrix of Pearson's correlation coefficient of metals in the surface, cutbank, and dam bank sediments of the Kafrain Dam

	Pb	Cd	Zn	Ni	Co	Cr	Cu	Mn	Fe
Surface									
Pb	1								
Cd	0.49	1							
Zn	−0.03	0.61[a]	1						
Ni	0.43	0.54[a]	0.54[a]	1					
Co	0.04	0.36	0.46	0.35	1				
Cr	0.01	0.57[a]	0.81[b]	0.77[b]	0.62[a]	1			
Cu	0.11	0.07	0.19	0.65[a]	0.16	0.48	1		
Mn	0.22	0.70[b]	0.71[a]	0.82[b]	0.61[a]	0.87[b]	0.57[a]	1	
Fe	0.01	0.58	0.52	0.49	0.64[a]	0.62[a]	0.28	0.65[a]	1
Cutbank									
Pb	1								
Cd	0.54[a]	1							
Zn	−0.15	−0.28	1						
Ni	0.62[a]	0.56[a]	0.24	1					
Co	−0.12	−0.02	−0.26	−0.46	1				
Cr	0.67[b]	0.35	0.07	0.73[b]	0.07	1			
Cu	0.02	0.25	0.40	0.42	−0.06	0.47	1		
Mn	0.15	0.14	0.47	0.58[a]	−0.28	0.62[a]	0.83[b]	1	
Fe	0.18	0.30	0.44	0.55[a]	−0.28	0.52	0.78[b]	0.93[b]	1
Dam bank									
Pb	1								
Cd	0.57[a]	1							
Zn	−0.01	0.05	1						
Ni	0.40	0.46	−0.20	1					
Co	0.07	−0.02	−0.26	0.25	1				
Cr	0.57[a]	0.39	0.20	0.60[a]	−0.42	1			
Cu	0.29	−0.02	−0.40	0.19	−0.49	0.57[a]	1		
Mn	0.68[b]	0.29	−0.33	0.45	0.34	0.26	0.24	1	
Fe	0.54[a]	0.44	−0.03	0.75[b]	−0.13	0.66[a]	0.35	0.46	1

[a] Correlation is significant at the 0.05 level (two-tailed)

[b] Correlation is significant at the 0.01 level (two-tailed)

Conclusions

Sediment pollution in the present study was assessed using enrichment factor and geoaccumulation index geochemical approaches. The results indicate that the calculations of I_{geo} are more reliable than those of EF. The EF results demonstrate that metals in the study area are enriched. Based on values of I_{geo}, the surface, cutbank, and dam bank sediments are uncontaminated with respect to Ni, Co, Cr, Cu, and Mn, moderately to strongly contaminated with Pb, and strongly to extremely contaminated with Cd and Zn. The elevated values identified for Pb, Cd, and Zn are probably a result of anthropogenic activities in the catchment area of the dam site. These sources mainly include the effluent of wastewater treatment plants, treated and untreated wastewaters, and irrigation return water. The results of the correlation matrix analysis demonstrate that metals in the study area exhibit different degrees of correlation. Mineralogical analyses of the collected samples show the presence of clay minerals (illite and kaolinite), calcite, dolomite, quartz, orthoclase, and microcline. The results indicate that Pb in the Kafrain Dam exhibits higher metal concentrations compared to other studies performed in other areas of the world. Most of the studies reported high contents of Cd.

References

Abu-Rukah, Y. (2001). Metals distribution and speciation in sediments from Ziqlab Dam—Jordan. *Geological Engineering, 25*, 33–40.

Adefemi, O. S., Olaofe, O., & Asaolu, S. S. (2007). Seasonal variation in metal distribution in the sediment of major dams in Ekiti-State. *Pakistan Journal of Nutrition, 6,* 705–707.

Alloway, B. J. (1990). *Metals in soils*. London: Wiley.

Balls, P. W., Hull, S., Miller, B. S., Pirie, J. M., & Proctor, W. (1997). Trace metal in Scottish estuarine and coastal sediments. *Marine Pollution Bulletin, 34*, 42–50.

Baptista Neto, J. A., Smith, B. J., & McAllister, J. J. (2000). Metal concentrations in surface sediments in a nearshore environment, Jurujuba Sound, Southeast Brazil. *Environmental Pollution, 109*, 1–9.

Bettinetti, R., Giarei, C., & Provini, A. (2003). Chemical analysis and sediment toxicity bioassays to assess the contamination of the River Lambro (Northern Italy). *Archives of Environmental Contamination and Toxicology, 45*, 72–78.

Bhuiyan, M. A. H., Suruvi, N. I., Dampare, S. B., Islam, M. A., Quraishi, S. B., Ganyaglo, S., et al. (2010). Investigation of the possible sources of heavy metal contamination in lagoon and canal water in the tannery industrial area in Dhaka, Bangladesh. *Environmental Monitoring and Assessment*. doi:10.1007/s10661-010-1557-6.

Bowen, H. J. M. (1979). *Environmental chemistry of the elements.* New York: Academic.

Calmano, W., & Wellerhaus, S. (1982). Dredging of contaminated sediments in Weser estuary: Chemical forms of some metals. *Environmental Technology Letters, 3*, 199–208.

Calmano, W., Ahlf, W., & Forstner, U. (1990). Exchange of heavy metals between sediments components and water. In J. A. C. Brockaert, S. Gvear, & F. Adams (Eds.), *Metal speciation in the environment,* NATO ASI series G 23503.

Cevik, F., Göksu, M. Z., Derici, O. B., & Fındık, O. (2009). An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. *Environmental Monitoring and Assessment, 152*(1–4), 309–317.

Chapman, P. M. (2000). The sediment quality triad: Then, now and tomorrow. *International Journal of Environmental Pollution, 13*, 351–356.

Chen, C. W., Kao, C. M., Chen, C. F., & Dong, C. D. (2007). Distribution and accumulation of metals in sediments of Kaoshiung Harbor, Taiwan. *Chemosphere, 66*, 1431–1440.

Christophoridis, C., Dedepsidis, D., & Fytianos, K. (2009). Occurrence and distribution of selected heavy metals in the surface sediments of Thermaikos Gulf, N. Greece. Assessment using pollution indicators. *Journal of Hazardous Materials, 15*, 1082–1091.

Conrad, C. F., & Chisholm-Brause, C. J. (2004). Spatial survey of trace metal contaminants in the sediments of the Elizabeth River, Virginia. *Marine Pollution Bulletin, 49*, 319–324.

Dassenakis, M., Scoullos, M., & Gaitis, A. (1997). Trace metals transport and behaviour in the Mediterranean estuary of Acheloos river. *Marine Pollution Bulletin, 34*, 103–111.

Datta, D. K., & Subramanian, V. (1998). Distribution and fractionation of metals in the surface sediments of the Ganges–Brahmaputra–Meghna river system in the Bengal basin. *Environmental Geology, 36*(1–2), 93–101.

Ergin, M., Saydam, C., Basturk, O., Erdem, E., & Yoruk, R. (1991). Metal concentrations in surface sediments from the two coastal inlets (Golden Horn Estuary and Izmit Bay) of the northeastern Sea of Marmara. *Chemical Geology, 91*, 269–285.

Esen, E., Kucuksezgin, F., & Uluturhan, E. (2010). Assessment of trace metal pollution in surface sediments of Nemrut Bay, Aegean Sea. *Environmental Monitoring and Assessment, 160*, 257–266.

Forstner, U. (1990). *Contaminated sediments. Lecture notes in earth science.* Berlin: Spinger.

Forstner, U., & Wittmann, G. T. W. (1983). *Metal pollution in the aquatic environment*. New York: Springer.

Galanopoulou, S., Vegenopoulos, A., & Consispoliatis, N. (2009). Anthropogenic metal pollution in the surficial sediments of the Keratsini Harbor, Saronikos Gulf, Greece. *Water Air Soil Pollution, 202*(1–4), 121–130.

Gee, G. W., & Bauder, J. W. (1986). Particle-size analysis. In A. Klute (Ed.), *Methods of soil analysis, Part 1* (pp. 383–412). Madison: American Society of Agronomy.

Ghrefat, H. A., & Yusuf, N. (2006). Assessing Mn, Fe, Cu, Zn, and Cd pollution in bottom sediments of Wadi Al-Arab Dam, Jordan. *Chemosphere, 65*, 2114–2121.

Gómez-Parra, A., Forja, J. M., DelValls, T. A., Sáenz, I., & Riba, I. (2000). Early contamination by metals of the Guadalquivir estuary after the aznalcóllar mining spill (SW Spain). *Marine Pollution Bulletin, 40*, 15–23.

Gowd, S. S., Reddy, M. R., & Govil, P. K. (2010). Assessment of heavy metal contamination in soils at Jajmau (Kanpur) and Unnao industrial areas of the Ganga Plain, Uttar Pradesh, India. *Journal of Hazardous Materials, 174*, 113–121.

Harte, J., Holdren, C., Schneider, R., & Shirley, C. (1991). *Toxics A to Z, a guide to everyday pollution hazards* (pp. 478). Oxford, England: University of California Press.

Horowitz, A. J., & Elrick, K. A. (1987). The relation of stream sediment surface area, grain size and composition of trace element chemistry. *Applied Geochemistry, 2*, 437–451.

Izquierdo, C., Usero, J., & Gracia, I. (1997). Speciation of metals in sediments from salt marshes on the southern Atlantic coast of Spain. *Marine Pollution Bulletin, 34,* 123–128.

Jones, B., & Turki, A. (1997). Distribution and speciation of metals in surficial sediments from the Tees estuary, north-east England. *Marine Pollution Bulletin, 34*(10), 768–779.

Kamala-Kannan, S., Batvari, B., Lee, K., Kannan, N., Krishnamoorthy, R., Shanthi, K., et al. (2007). Assessment of metals (Cd, Cr and Pb) in water, sediment and seaweed (Ulva lactuca) in the Pulicat Lake, South East India. *Chemosphere, 71*(7), 1233–1240.

Kamala-Kannan, S., Batvari, B., Lee, K., Kannan, N., Krishnamoorthy, R., Shanthi, K., et al. (2008). Assessment of metals (Cd, Cr and Pb) in water, sediment and seaweed (Ulva lactuca) in the Pulicat Lake, South East India. *Chemosphere, 71*(7), 1233–1240.

Karadede, H., & Unlu, E. (2000). Concentrations of some metals in water, sediment and fish species from the Ataturk Dam Lake (Euphrates), Turkey. *Chemosphere, 41*, 1371–1376.

Kennish, M. J. (1992). *Ecology of estuaries: Anthropogenic effects. Marine Science Series*. USA: CRC.

Kulahci, F., & Sen, Z. (2008). Multivariate statistical analyses of artificial radionuclides and metals contaminations in deep mud of Keban Dam Lake, Turkey. *Applied Radiation and Isotopes, 66,* 236–246.

Larsen, B., & Jensen, A. (1989). Evaluation of the sensitivity of sediment monitoring stationary in pollution monitoring. *Marine Pollution Bulletin, 20,* 556–560.

Lopez-Sanchez, J. F., Rubio, R., Samitier, C., & Rauret, G. (1996). Trace metal partitioning in marine sediments and sludges deposited off the coast of Barcelona (Spain). *Water Resources, 30*(1), 153–159.

Loska, K., & Wiechula, D. (2003). Application of principal component analysis for the estimation of source metal contamination in surface sediments from Rybnik Reservoir. *Chemosphere, 51*, 723–733.

Malkawi, A. I. H., & Al-Sheriadeh, M. (2000). Evaluation and rehabilitation of dam seepage problems. A case study: Kafrein dam. *Engineering Geology, 56*, 335–345.

McCave, I. N. (1984). Size spectra and aggregation of suspended particles in the deep ocean. *Deep Sea Research, 31*, 329–352.

Meza-Figueroa, D., Maier, R. M., de la O-Villanueva, M., Gómez-Alvarez, A., Moreno-Zazueta, A., Rivera, J., et al. (2009). The impact of unconfined mine tailings in residential areas from a mining town in a semi-arid environment: Nacozari, Sonora, Mexico. *Chemosphere, 77*(1), 140–147.

Mohsen, M. S. (2007). Water strategies and potential of desalination in Jordan. *Desalination, 203*, 27–46.

Mucha, A. P., Vasconcelos, M. T. S. D., & Bordalo, A. A. (2003). Macrobenthic community in the Doura estuary: Relations with trace metals and natural sediment characteristics. *Environmental Pollution, 121*, 169–180.

Müller, G. (1979). Schwermetalle in den Sedimenten des Rheins—Veränderungen seit 1971. *Umschau, 24*, 778–783.

Muller, G. (1981). Die Schwermetallbelstung der sedimente des Neckars und seiner Nebenflusse: Eine Bestandsaufnahme. *ChemikerZeitung, 105*, 156–164.

Nobi, E. P., Dilipan, E., Thangaradjou, T., Sivakumar, K., & Kannan, L. (2010). Geochemical and geo-statistical assessment of heavy metal concentration in the sediments of different coastal ecosystems of Andaman Islands, India. *Estuarine, Coastal and Shelf Science, 87*(2), 253–264.

Nriagu, J. O. (1989). A global assessment of the natural sources of atmosphere trace metals. *Nature, 338*, 47–49.

Nuremberg, H. W. (1984). The voltammetric approach in trace metal chemistry of natural waters and atmospheric precipitation. *Analytica Chimica Acta, 164*, 1–21.

Routh, J., & Ikramuddin, M. (1996). Trace-element geochemistry of Onion Creek near Van Stone lead–zinc mine (Washington, USA). *Chemical Geology, 133*, 211–224.

Rubio, B., Nombela, M. A., & Vilas, F. (2000). Geochemistry of major and trace elements in sediments of the Ria de Vigo (NW Spain). *Marine Pollution Bulletin, 40*, 968–980.

Salameh, E. (1996). *Water quality degradation in Jordan: Impacts on environment, economy and future gener-*

ations resources base. Jordan: Royal Society of the Conservation of Nature.

Salomons, W., & Forstner, U. (1984). *Metals in the hydrocycle*. New York: Springer.

Sanchez, J., Marino, N., Vaquero, M. C., Ansorena, J., & Legórburo, I. (1998). Metal pollution by old lead–zinc mines in Urumea river valley (Basque country, Spain). Soil, biota and sediment. *Water Air Soil Pollution, 107*, 303–319.

Schiff, K. C., & Weisberg, S. B. (1999). Iron as a reference element for determining trace metal enrichment in Southern California coast shelf sediments. *Marine Environmental Research, 48*, 161–176.

Schuurmann, G., & Market, B. (1998). *Ectotoxicology, ecological fundamentals, chemical exposure, and biological effects.* New York: Wiley.

Tam, N. F. Y., & Wong, W. S. (2000). Spatial variation of metals in surface sediments of Hong Kong mangrove swamps. *Environmental Pollution, 110*, 195–205.

Turekian, K. K., & Wedepohl, K. H. (1961). Distribution of the elements in some major units of the earth's crust. *Geological Society of America, 72*, 175–192.

Van de Guchte, C. (1992). The sediment quality triad: an integrated approach to assess contaminated sediments. In P. J. Newman, M. A. Piavaux, & R. A. Sweeting (Eds.), *River water quality, ecological assessment and control.* Brussels: ECSC-EEC-EAEC (417–423).

Wen, X., & Allen, H. E. (1999). Mobilization of metals from Le An River sediments. *Science of Total Environment, 227*, 101–108.

Williams, T. M., Rees, J. G., Kairu, K. K., & Yobe, A. C. (1996). Assessment of contamination by metals and selected organic compounds in coastal sediments and waters of Mombasa, Kenya. Technical Report W C-96-37, 85 pp.

Williams, T. M., Rees, J. G., & Setiapermana, D. (2000). Metals and trace organic compounds in sediments and waters of Jakarta Bay and the Pulau Seribu Complex, Indonesia. *Marine Pollution Bulletin, 40*, 277–285.

Yaqin, J. I., Yinchang, F., Jianhi, W. U., Tan, Z. H. U., Zhipeng, B., & Chiqing, D. (2008). Using geoaccumulation index to study source profiles of soil dust in China. *Journal of Environmental Sciences, 20*, 571–578.

Zhang, J., & Liu, C. L. (2002). Riverine composition and estuarine geochemistry of particulate metals in China—Weathering features, anthropogenic impact and chemical fluxes. *Estuarine Coastal and Shelf Science, 54*, 1051–1070.

Zollmer, V., & Irion, G. (1993). Clay mineral and metal distribution in the northeastern North Sea. *Marine Geology, 111*, 223–230.

Zoumis, T., Schmidt, A., Grigorova, L., & Calmano, W. (2001). Contaminants in sediments: Remobilization and demobilization. *The Science of the Total Environment, 266*, 195–202.