

# Sediment Toxicity and Ecological Risk of Trace Metals from Streams Surrounding a Municipal Solid Waste Landfill

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**Abstract** The present study is an attempt to assess the pollution intensity and corresponding ecological risk of heavy metals such as Cd, Ni, Pb, Cu, Zn and Cr using various indices like geo-accumulation index, concentration factor, pollution loading and ecological risk index. In all 21 surface sediments samples were collected from the stream flowing around the solid waste disposal landfill of Qayen city in southeastern Iran. Although  $I_{geo}$  values for Cd varied greatly, sites 18–21 with class 5 show heavy loads of Cd (values between 4.13 and 4.45). PLI values (3.37–12.89) clearly suggest strong contamination with respect to the measured metals. This study clearly indicates that the contamination risk in the downstream reservoir is much higher than upstream sites due to transfer and accumulation of leached metals from upstream to downstream.

**Keywords** Surface sediment contamination · Concentration factor · Geo-accumulation index · Potential ecological index

Heavy metals pollution is a ubiquitous environmental problem (Sayyed and Sayadi 2011; Barbieri et al. 2014). In the fluvial environment, the sources of heavy metals are both natural and anthropogenic and include atmospheric deposition; chemical weathering rocks; agricultural practices; municipal, residential and industrial effluents; or through secondary sources like reworking of soils and sediments through addition of various types of wastes (Sayadi and Rezaei 2014; Demirak et al. 2006). Solid waste disposal

landfill is one of the most important anthropogenic sources of trace as well as heavy elements (Olivares-Rieumont et al. 2007; Sayadi and Sayyed 2011). The distribution of such elements in the sediments close by residential or industrial areas can provide evidence of the impacts of human activities on the ambient ecosystem and therefore aid in assessing the risks associated with leachate springing out from the landfill (Gonçalves et al. 2004). In an aquatic environment sediments are considered to be the main repositories for various pollutants, including heavy metals, as they play a principal role in the transport and storage of hazardous metals (Bettinetti et al. 2003). Since accumulation of heavy metals in the sediments often poses health risks and detrimental effects on river ecosystems the quantification of toxicity of contaminated sediment can be assessed with the help of geo-accumulation index, enrichment factor and pollution load index (Sayadi et al. 2010; Sekabira et al. 2010). The potential toxicity of Cd, Ni, Pb, Cu, Zn and Cr were assessed using consensus-based sediment quality guidelines method and geo-accumulation index method in the surface sediments of the Pearl River in South China and showed the potential toxicity of Cu was the highest while for Cd it was the lowest (Hongyi et al. 2009).

The main objectives of this study were to determine the concentrations of heavy metals Cd, Ni, Pb, Cu, Zn and Cr in the surface sediment samples; and to characterize sediment toxicity and ecological risk of heavy metals using various geochemical indices.

## Materials and Methods

A total of 21 surface sediment samples were collected in February 2013 from the streams surrounding the landfill of Qayen city, located in the southeastern Iran (Fig. 1).

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Surface sediment samples (top 10 cm) were collected from the streams and immediately transferred to polythene bags and were transported to the laboratory for further analysis.

In the laboratory these collected samples were air-dried at room temperature, ground and sieved through 230-mesh nylon sieve. For the total heavy metal content analysis, 500 mg of each dried sediment sample was digested by  $\text{HClO}_4$ ,  $\text{HCl}$ ,  $\text{HNO}_3$  and  $\text{HF}$  (Merck) (Olivares-Rieumont et al. 2007). The solutions of the digested samples were analyzed for Cd, Ni, Pb, Cu, Zn and Cr using Atomic Absorption Spectrophotometer (Shimadzu; AA-7000 series) by flame mode.

Quantification of sediment pollution was conducted by using contamination factor (CF), pollution load index (PLI), ecological risk index (RI) and geo-accumulation index ( $I_{\text{geo}}$ ). The geo-accumulation index ( $I_{\text{geo}}$ ) was calculated using the formula given by Müller (1986) as follows:

$$I_{\text{geo}} = \log_2(C_n/1.5 \times B_n)$$

where  $C_n$  is the concentration of metal (n) and  $B_n$  is the background concentration of the metal (n). The factor 1.5 in the equation is used as the possible variation in background values due to lithogenic effects and weathering (Müller 1986).

The intensity of the pollution can be classified from the values of geo-accumulation index as follows:  $I_{\text{geo}} \leq 0$  unpolluted (Class 0);  $0 < I_{\text{geo}} < 1$  unpolluted to moderately polluted (Class 1);  $1 < I_{\text{geo}} < 2$  moderately polluted

(Class 2);  $2 < I_{\text{geo}} < 3$  polluted (Class 3);  $3 < I_{\text{geo}} < 4$  heavily polluted (Class 4);  $4 < I_{\text{geo}} < 5$  heavily to very heavily polluted (Class 5) and  $I_{\text{geo}} \geq 5$  very heavily polluted (Class > 5) (Müller 1986).

Contamination factor was obtained by dividing the concentration of each heavy metal in the sediment sample ( $C_{\text{heavy metal}}$ ) by the concentration of heavy metals in background sediments ( $C_{\text{background}}$ ):

$$CF = C_{\text{heavy metal}}/C_{\text{background}}$$

With the help of contamination factor values the intensity of contamination can be inferred (Hakanson 1980) as follows: low contamination,  $CF < 1$ ; moderate contamination,  $1 < CF < 3$ ; considerable contamination,  $3 < CF < 6$ ; and very high contamination,  $CF > 6$ .

Pollution load index (PLI) is defined as the nth root of the product of the contamination factor ( $CF_{\text{metals}}$ ):

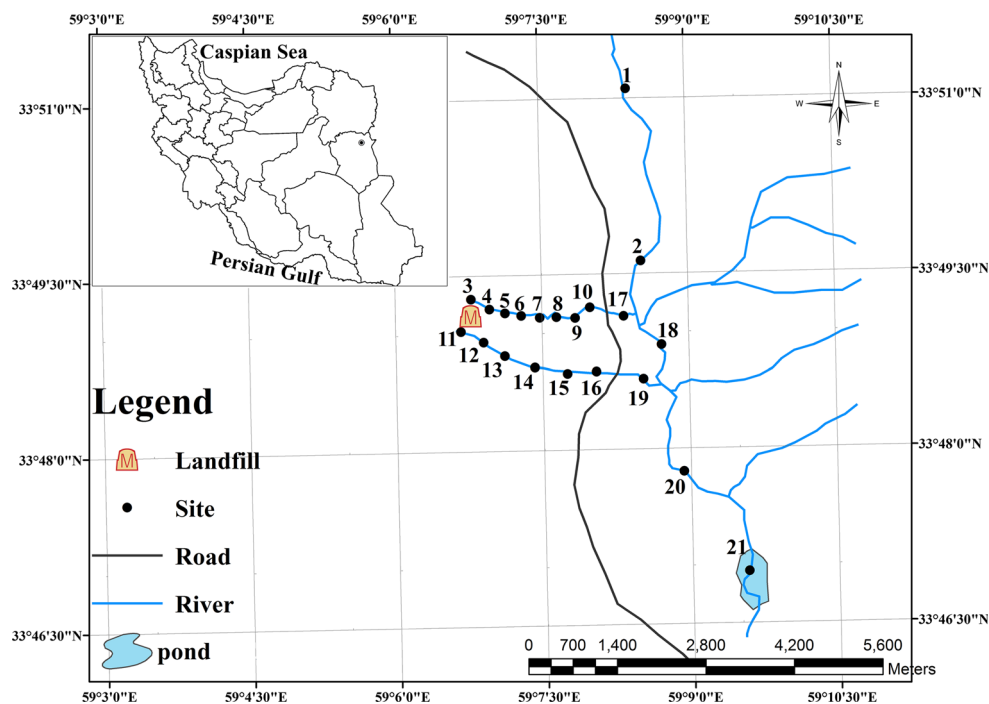
$$PLI = (CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n)^{1/n}$$

PLI values greater than unity imply heavy metal pollution and below unity suggest the level of pollution below tolerable threshold limit (Tomlinson et al. 1980).

Ecological risk index (RI; Hakanson 1980) is defined as the summation of the change in the concentrations of the metals in the samples with respect to their background values considering toxicological factor. The mathematical relation of RI can be shown as:

$$RI = \sum_{i=0}^n \left( T_i \times \frac{C_i}{C_o} \right)$$

**Fig. 1** Map of the streams showing the location of sampling sites



where,  $n$  is the number of heavy metals;  $T_i$  is the toxic-response factor for a given substance (for Cd, Cr and Zn 30, 2 and 1 respectively; and 5 for Pb, Cu and Ni; Yang et al. 2009);  $C_i$  represents metal concentration in sediment and  $C_0$  is the regional background value of heavy metals. On the basis of the ecological risks index four categories of ecological risks are recognized (Hakanson 1980) i.e. low ( $RI < 150$ ,  $RI_l$ ); moderate ( $150 \leq RI \leq 300$ ,  $RI_m$ ); high ( $300 > RI > 600$ ,  $RI_h$ ) and very high ( $RI > 600$ ,  $RI_v$ ).

## Results and Discussion

The mean concentrations of Cd, Ni, Pb, Cu, Zn, and Cr in surface sediment samples are shown in Table 1. Mean Cd concentrations were greatest at site 21 at 11.18 mg/kg and lowest at site 1 at 0.82 mg/kg. The concentration of Pb at site 11 is the highest with a mean value of 84.07 mg/kg. While lowest lead concentration is at site 2 with a mean value of 37.51 mg/kg. The highest Cu concentration is at site 15 with a mean value of 75.32 mg/kg and the lowest Cu concentration is at site 1 with a mean value of 17.90 mg/kg. In summary the contents of Cd, Ni, Pb, Cu, Zn, and Cr were considerably higher than the background

**Table 1** Mean concentrations of trace metals (mg/kg) in stream sediments near the landfill Qayen city

Site	Cd	Ni	Pb	Cu	Zn	Cr
1	0.82	18.01	41.38	17.9	48.55	63.02
2	1.12	15.27	37.51	23.64	52.34	62.97
3	1.75	31.75	51.76	26.54	62.12	74.36
4	1.19	30.66	56.22	37.5	87.77	75.15
5	1.83	42.15	48.31	42.08	98.49	83.98
6	2.32	41.99	53.78	40.63	89.10	84.31
7	2.63	52.04	52.61	32.75	76.66	74.76
8	3.41	53.2	56.19	36.29	84.94	89.58
9	3.88	53.86	62.03	37.52	87.82	89.04
10	3.25	46.89	59.2	36.4	91.20	106.05
11	2.3	48.31	84.07	36.6	85.67	113.33
12	2.56	46.52	65.29	38.13	89.25	115.62
13	4.61	58.75	65.21	27.23	93.74	126.2
14	7.5	58.99	62.48	65.44	103.15	130.47
15	6.17	59.26	62.59	75.43	176.53	129.21
16	5.55	59	58.16	64.09	149.99	135.25
17	7.36	63.57	55.73	65.38	123.01	148.01
18	8.93	58.86	59.25	67.15	127.15	137.54
19	10.97	62.62	38.14	40.69	127.49	158.83
20	9.82	65.73	75.19	71.26	160.77	161.77
21	11.18	61.36	77.7	72.25	159.09	171.33
Background <sup>a</sup>	0.34	11.28	5.17	9.62	11.56	10.36

<sup>a</sup> Sayadi et al. (2008)

level and at the same time the mean concentrations of these heavy metals are higher than those found in river sediments from other regions of Iran (Sayadi et al. 2010; Sheykhi and Moore 2013).

In order to quantify the heavy metal pollution,  $I_{geo}$  index (geo-accumulation index) was calculated (Table 2) which indicates that the values of  $I_{geo}$  for Ni are below 2 for all sediment samples, suggesting these sediments to be unpolluted to moderately polluted while with respect to Cu, most of the sediment samples were categorized as moderately polluted or polluted (sample sites 14–18 and 20–21). The values of  $I_{geo}$  for Pb and Cr indicate sediment samples to be polluted and heavily to very heavily polluted. The  $I_{geo}$  values for Zn in most of the sites fell in class 4 (heavily polluted) and other sites show variable values i.e. site 1 falls in class 1; sites 2–5 fall in class 2; sites 6–12 fall in class 3; sites 13–17 fall in class 4; sites 18–21 fall in class 5. In summary this study reveals that the surface sediments around the solid waste disposal landfill area have been slightly to strongly contaminated with the heavy metals Cd, Ni, Pb, Cu, Zn, Cr according to  $I_{geo}$  values. The average  $I_{geo}$  indicated that the pollution degree of six heavy metals decreased in following sequence:  $Pb > Cd > Cr > Zn > Cu \geq Ni$ . Sources and accumulation of these metals from landfill in the environment are well documented (Barbieri et al. 2014; Claret et al. 2011; Suyash and Pawar 2011).

The CF, PLI and RI values (Table 3) indicate the sediments are very highly contaminated (CF values) with respect to the heavy metals with few sampling showing lower contamination (e.g. Cu in the sites 1–13; Cd in the sites 1–5; Zn in the sites 1–3 which show values  $< 6$ ). Barring a few exceptions, the concentrations of heavy metals at all sampling sites exhibited very high contamination by the toxic metals as revealed by the values of PLI (ranging between 3.37 and 12.89) suggesting that the sediments are strongly contaminated (Tomlinson et al. 1980).

The potential ecological risks of the heavy metals in the sediments from the Qayen River were analyzed using the Ecological risk index (RI; (Hakanson 1980) which indicate that there is an increasing trend of potential ecological risk from the upstream to downstream (Table 3) with minimum RI of 146 in site 1 and maximum RI of 1173 in site 21. The sites 6–13 show high ecological risk ( $300 \leq RI \leq 600$ ) and the others from sites 14–21 show extremely high ecological risks levels with  $RI > 600$ .

From the fact that the ecological risk in the reservoir of downstream area (site 21) is higher than the upstream area it can be concluded that the metals are being transferred and accumulated from upstream to downstream resulting in the increasing metals concentration in a stretch of sediment flow downstream. This confirms the idea that pollutants in sediments, particularly heavy metals, tend to increase along the distance of travel for a moving sediment body (Bartoli

**Table 2** Geo-accumulation index for all sediment samples

Site	Cd		Ni		Pb		Cu		Zn		Cr	
	I <sub>geo</sub>	Class	I <sub>geo</sub>	Class	I <sub>geo</sub>	Class	I <sub>geo</sub>	Class	I <sub>geo</sub>	Class	I <sub>geo</sub>	Class
1	0.69	1	0.09	1	2.42	3	0.31	1	1.49	2	2.02	3
2	1.13	2	-0.15	0	2.27	3	0.71	1	1.59	2	2.02	3
3	1.78	2	0.91	1	2.74	3	0.88	1	1.84	2	2.26	3
4	1.22	2	0.86	1	2.86	3	1.38	2	2.34	3	2.27	3
5	1.84	2	1.32	2	2.64	3	1.54	2	2.51	3	2.43	3
6	2.19	3	1.31	2	2.79	3	1.49	2	2.36	3	2.44	3
7	2.37	3	1.62	2	2.76	3	1.18	2	2.14	3	2.27	3
8	2.74	3	1.65	2	2.86	3	1.33	2	2.29	3	2.53	3
9	2.93	3	1.67	2	2.99	3	1.38	2	2.34	3	2.52	3
10	2.67	3	1.47	2	2.93	3	1.33	2	2.39	3	2.77	3
11	2.17	3	1.51	2	3.44	4	1.34	2	2.30	3	2.87	3
12	2.33	3	1.46	2	3.07	4	1.40	2	2.36	3	2.90	3
13	3.18	4	1.80	2	3.07	4	0.92	1	2.43	3	3.02	4
14	3.88	4	1.80	2	3.01	4	2.18	3	2.57	3	3.07	4
15	3.60	4	1.81	2	3.01	4	2.39	3	3.35	4	3.06	4
16	3.44	4	1.80	2	2.91	3	2.15	3	3.11	4	3.12	4
17	3.85	4	1.91	2	2.85	3	2.18	3	2.83	3	3.25	4
18	4.13	5	1.80	2	2.93	3	2.22	3	2.87	3	3.15	4
19	4.43	5	1.89	2	2.30	3	1.50	2	2.88	3	3.35	4
20	4.27	5	1.96	2	3.28	4	2.30	3	3.21	4	3.38	4
21	4.45	5	1.86	2	3.32	4	2.32	3	3.20	4	3.46	4

**Table 3** Contamination factors (CF), pollution load index (PLI) and potential ecological risk (RI) for the sediment samples

Site	CF						PLI	RI	Risk grade
	Cd	Ni	Pb	Cu	Zn	Cr			
1	2.41	1.60	8.00	1.86	4.20	6.08	3.37	146	Low
2	3.29	1.35	7.26	2.46	4.53	6.08	3.60	171	Moderate
3	5.15	2.81	10.01	2.76	5.37	7.18	4.98	252	Moderate
4	3.50	2.72	10.87	3.90	7.59	7.25	5.30	214	Moderate
5	5.38	3.74	9.34	4.37	8.52	8.11	6.20	273	Moderate
6	6.82	3.72	10.40	4.22	7.71	8.14	6.41	320	High
7	7.74	4.61	10.18	3.40	6.63	7.22	6.24	344	High
8	10.03	4.72	10.87	3.77	7.35	8.65	7.05	422	High
9	11.41	4.77	12.00	3.90	7.60	8.59	7.41	470	High
10	9.56	4.16	11.45	3.78	7.89	10.24	7.19	412	High
11	6.76	4.28	16.26	3.80	7.41	10.94	7.24	354	High
12	7.53	4.12	12.63	3.96	7.72	11.16	7.15	359	High
13	13.56	5.21	12.61	2.83	8.11	12.18	7.99	542	High
14	22.06	5.23	12.09	6.80	8.92	12.59	10.10	816	Very high
15	18.15	5.25	12.11	7.84	15.27	12.47	10.94	711	Very high
16	16.32	5.23	11.25	6.66	12.98	13.06	10.13	644	Very high
17	21.65	5.64	10.78	6.80	10.64	14.29	10.52	805	Very high
18	26.26	5.22	11.46	6.98	11.00	13.28	10.81	944	Very high
19	32.26	5.55	7.38	4.23	11.03	15.33	9.90	1095	Very high
20	28.88	5.83	14.54	7.41	13.91	15.61	12.56	1050	Very high
21	32.88	5.44	15.03	7.51	13.76	16.54	12.89	1173	Very high

et al. 2012). The RI showed that heavy metals in the sediment samples exhibited higher potential risk which could be associated with poor landfill management (Bastami et al. 2014). This indicates that the Qayen municipal open dump solid waste disposal site is not constructed according to the standards of Iranian Department of Environment, without giving due consideration to the standards for site selection. This has resulted into the serious contamination of the surface sediments by the leachate coming out of landfills (Islam and Singhal 2004).

In the present study, the concentrations of Cd, Ni, Pb, Cu, Zn and Cr in the stream sediments near the landfill of Qayen city were analyzed and suggest that the potential ecological risk for these heavy metals present a high potential ecological risk. The risk in the reservoir of downstream area (site 21) is higher than the upstream area. In the case of heavy metals; Cd, Cr and Pb present strongest ecological risk because of the highest toxicity coefficient with the concentrations values of Cd, Cr and Pb are lower. However, metals can transfer from the sediment to other ecosystem components such as underground water, crops and animals and affect human health through the water supply and food chain. Although some of the heavy metals have shown beneficial effects on humans, their increasing concentration above the threshold is bound to have harmful effects on human. Therefore, it is necessary to design an environmental strategy not only to manage but also monitor the same with priority.

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