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Heavy Metal Pollution in Soils Exposed to Landfill Leachate: A Case Study of Astaneh Ashrafiyeh, Guilan, Iran

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ABSTRACT

Unsanitary landfills pose a significant threat to human and animal health, the functions of soil and water ecosystems through release of heavy metals. Open and unsanitary landfills near cities and forests are a problem in northern Iran. This research aimed to study the concentration of heavy metals in the dumpsites of Kisom, Kashal Azadsara, Nazoksara, and Amirkiasar (Astaneh Ashrafiyeh County, Guilan province, Iran). For this purpose, 46 composite samples were collected from the downslope and upslope soils of various landfills (0-30 and 30-60 cm depths) in Astaneh County. Heavy metals were extracted using nitric and hydrochloric acids, and their concentration was measured by ICP-OES. The investigation of metal concentrations in the soil of landfills revealed high levels of arsenic (23–30 mg/kg) and lead (138–357 mg/kg), exceeding the risk thresholds. Based on the geo-accumulation (Igeo) and contamination factor (CF) indexes, elements lead (Pb) and arsenic (As) in Kisom and Amirkiasar landfills, were classified as moderate-moderate and very high-strong contamination respectively. Outcomes of the Pollution Load (PLI) and Modified Contamination Degree (mCd) indexes showed that the Kisom landfill and its downstream areas were in the moderate contamination classification. Calculation of ecological risk (ER) demonstrated that the Kisom landfill and its downstream areas are at significant to moderate risk from lead. In addition, the Kisom landfill has a 49% possibility of heavy metal pollution and the other sites have a 21% probability of contamination according to the mean ERM index.

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INTRODUCTION

The production of waste is an inevitable part of human life, and population growth is increasing it. As a result, the global growth of municipal solid waste (MSW) is of paramount importance to current activities (Peng et al., 2023). Inaccurate waste disposal negatively affects people's grade of life and damages the environment (De Sousa et al., 2023). Worldwide, more than 1.3 billion tons of municipal solid waste are generated annually, and this will exceed 2.2 billion tons in 2025 (Abdollahi Saadatlu et al. 2022). People are worried about the pollution of the ecosystems by heavy metals from waste disposal sites around the world (Hashmi et al., 2024; Sanga & Pius, 2024). Municipal solid waste, a mixture of human and animal waste and other industrial and agricultural waste, is released into soil or water during disposal. Proper disposal is important because they can cause environmental damage if improperly managed (Du & Li, 2023, Rouhani & Hejcman, 2024). Currently, an average of 2,000 tons of garbage accumulates daily in the country's northern forests, covering an area of about 300 hectares. The result of

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this accumulation is leachate, which pollutes the surface water, the soil, and the groundwater, and also causes the death of many living organisms in its path (Rouhani & Hejcman, 2024, Ashrafi et al., 2022). Wang et al. (2022) estimated 100,000 landfills in America (abandoned, active, and closed), 150,000 in Europe, and 20,000 in China, highlighting the importance of this MSW destination type. In the earth's crust, heavy metals occur inherently, but human activities release them into the environment. Heavy metals are a major problem in leachate due to their harmful environmental and bioaccumulative potential. In ecosystems, they are transformed into persistent and non-biodegradable pollutants (Hou et al. 2019). In addition to posing a threat to environment, they can also imperil food safety, adversely affect regional crops, and be a health hazard, particularly to persons living in the vicinity of landfills (Jayasundara et al., 2023). This requires continuous monitoring of heavy metal content in the soil surrounding the site, even after inactivation (Marinho et al., 2022; de Souza et al., 2023). Beinabaj et al. (2023) investigated the heavy metals in leachate, soil and plants near the Tehran landfill. The results indicated that the soil of landfill and vegetation were subject to heavy metal contamination from leachate. Pu et al. (2024) reported that Cu > Zn > Cr > Pb > Ni > As > Cd > Hg were the highest exceedance multiples for heavy metal concentrations in the humus soil. The study of 48 soil samples around Tehran landfill found the following heavy metals in descending order: Al > Fe > Mn > Zn > Cr > Cu > Pb > Ni > Co > As > Cd. The ecological indices studied showed a moderate to high level of heavy metal contamination (Karimian et al., 2021).

Currently, waste collection and transportation in some villages of northern Iran remain primitive, with waste often dumped around residential areas, along roads, and near water sources. In the best cases, the collected waste is transported to environmentally problematic municipal waste disposal centers and dumped there. Open burning of waste is another unsanitary way of disposing of such materials. Therefore, the aim of this research was to investigate the level of heavy metal pollution in the soil around the landfills of Kisom, Kashal Azadsara, Nazoksara, and Amirkiaser villages (Astaneh Ashrafiyeh city, Gilan province, Iran).

MATERIALS AND METHODS

Study area and sampling

Astaneh Ashrafiyeh is a city in Gilan province (northern Iran), located at latitude 37°15′ and longitude 49°56′ east of the prime meridian, with an average altitude of about 3 meters above sea level. The population of this county is 108,130 of whom about 52% live in urban areas and 48% in rural areas. The main products of Astaneh Ashrafiyeh include peanuts, silk, rice, tea, and beans. Among these, peanuts, silk, and rice are especially well-known for their high quality.

The amount of dry waste collection in Astaneh Ashrafiyeh and Kiashahr ports is 1,600 to 2,000 and 800 to 1,000 kg/day, respectively. In this study, in order to explore the possible impact of solid waste disposal on the downslope soil in the areas of open dumps, 46 soil samples were gathered in the direction of the slope and at intervals of 0 and 50 meters and in some cases 100 and 200 meters from depths of 0-30 and 30-60 cm. For composite samples at each station, four samples were collected within a 10 meters radius and combined at the same location. Then, soils were stored in large plastic bags for heavy metal analysis. The villages studied were 1- Kashal Azadsara, 2- Amirkiaser, 3- Nazoksara, and 4 – Kisom.

Heavy metal measurement

For the extraction and measurement of heavy metals, 1 g of soil was added to a 125 ml beaker. It was blended with 10 ml of 1:1 nitric acid. It was then placed on an electric stove at 95°C for 10 to 15 minutes, taking care not to boil the solution. After cooling, 5 ml of nitric acid was poured and the beaker lid closed for 30 minutes for reflux. This action was repeated twice for further reflux. The solution was evaporated to a volume of 5 ml without boiling.

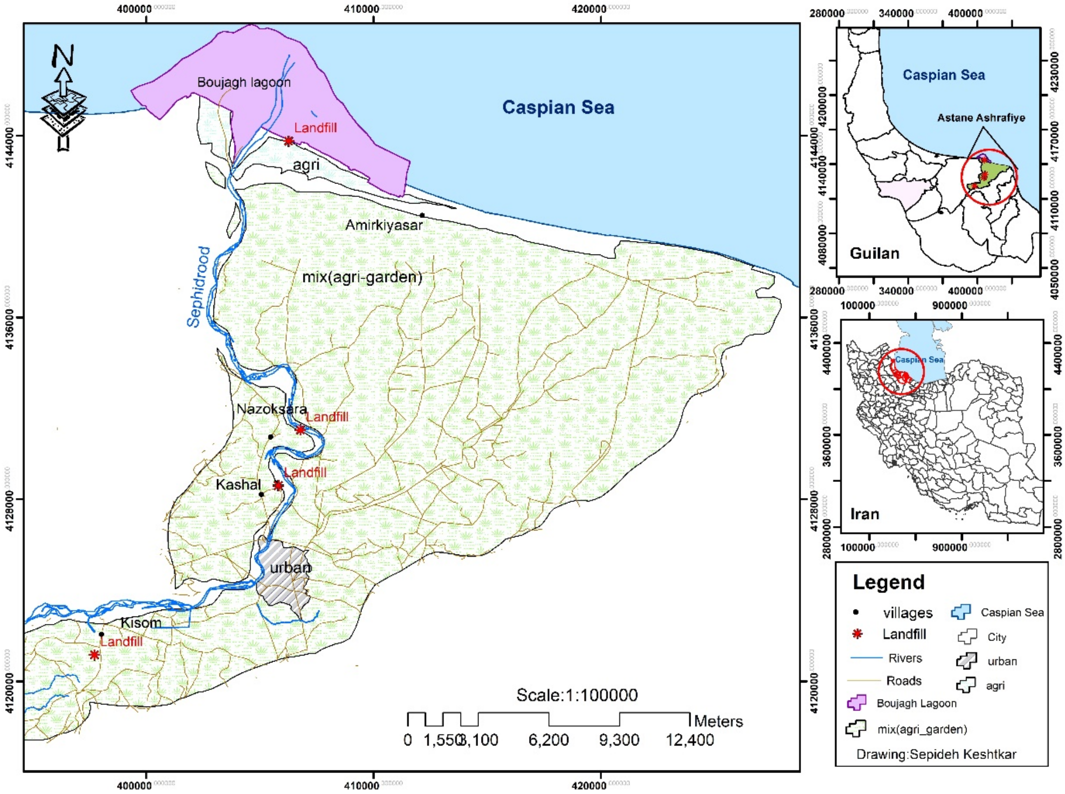

Fig. 1. Sampling locations of study area

Table 2. Description of Contamination Factor (CF) (Hakanson 1980)

CF	Description
<1	Low Contamination
1- 3	Moderate Contamination
3- 6	Considerable Contamination
>6	Very High Contamination

After cooling, 3 ml of 30% hydrogen peroxide and 2 ml of distilled water were added. Then, beaker was refluxed for 15 minutes with the addition of 10 ml of distilled water and 5 ml of concentrated hydrochloric acid. After cooling, beaker contents were filtered and poured into a 50 mL glass balloon. The filter paper and beaker were washed with 1:100 hydrochloric acid, and the glass balloon was made up to volum (Shariati et al., 2019; Karimian et al., 2021). Elemental measurements were performed with an ICP OES (VARIAN VISTA MPX).

Heavy metal contamination indexes

Contamination Factor (CF)

The contamination factor was computed based on equation 1, where Cm background is the mean metal concentration in background reference and Cm sample is the element content in soil (Martin and Meybeck, 1979). The contamination status of each element was determined by comparing the results of the calculations with Table 2.

$$CF = \frac{Cm_{metal}}{Cm_{background}} \quad (1)$$

Table 3. Groups and description of Modified contamination degree (mCd)

mCd	Description
< 1.5	Zero to the very low degree of contamination
1.5-2	Low degree of contamination
2-4	Moderate degree of contamination
4-8	High degree of contamination
8-16	The very high degree of contamination
16-32	The extremely high degree of contamination
≥ 32	Ultra-high degree of contamination

Modified contamination degree (mCd)

Modified contamination degree is an index for determining the degree of elements pollution in an area. Where n is the number of measured parameters and Cd is the total of pollution factor. The calculation results were classified based on Table 3 for each station (Abrahim & Parker 2008).

$$Cd = \sum_{i=1}^{8} C_f^i \quad (2)$$

$$mCd = \frac{\sum_{i=1}^{8} C_f^i}{n} \quad (3)$$

$$\text{Igeo} = \log 2\left[\frac{C_n}{1.5B_n}\right] \quad (4)$$

Pollution load (PLI)

This index can be an estimate of the class of metals contamination in an area. PLI values vary from zero (unpolluted) to 10 (highly polluted). Values below 1 indicate unpolluted and above 1 indicate heavy metal pollution (Harikumar et al., 2009).

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

Geo-accumulation (Igeo)

This index is determined according to the following formula (6).

$$\text{Igeo} = \log 2\left[\frac{C_n}{1.5B_n}\right] \quad (6)$$

Bn is the quantity of metal in the shale and Cn is the element content in the soil (Muller 1979; Harikrishnan *et al.* 2017).

Potential Ecological Risk (PER)

C is the contamination factor, Ca is the element content in soil, and Cb is the quantity of the heavy metal in the reference. Ecological risk factor of each of the elements is E, and T is the biological toxicity of each of the elements with values as follows, Zn = 1, Cu=6, Cr = 2, As = 10, Ni = 6, and Pb = 6 (Hakanson, 1980).

$$E = TC \quad (7)$$

Table 4. Group and description of Geo-accumulation (Igeo)

Class	Igeo	Description
0	<0	Unpolluted
1	0-1	Unpolluted to moderately polluted
2	1-2	Moderately polluted
3	2-3	Moderately to strongly polluted
4	3-4	Strongly polluted
5	4-5	strongly to extremely polluted
6	>6	Extremely

Table 5. Classification of E values and Potential Environmental Risk Index (PER)

E and PER value	Description
E <40; PER <150	Low risk
40 ≤ E <80; 150 ≤ PER <300	Medium risk
80 ≤ E <160; 300 ≤ PER <600	Significant risk
High risk: 160 ≤ E <320; PER ≥ 600	High risk
E ≥ 320.	Very high risk

$$C = \frac{C_a}{C_b} \tag{8}$$

$$PER = \sum E = \sum TC \quad 8 \tag{9}$$

Mean ERM quotient index

Metals occur as complex mixtures in soils, so the average ERM quotient was applied to assess the potential biological effect of metals. Cx is the soil content of element x, n is the number of elements, ERMx is the Effect range medium of x (Jamshidi & Bastami, 2016).

$$\text{Mean ERM quotient} = \sum\left(\frac{C_x}{ERM_x}\right)/n \tag{10}$$

RESULTS AND DISCUSSIONS

Heavy metals contents in soils

Comparing the concentration of elements in samples from the outfall and downslope stations with the standards and permissible limits of soil (Table 6), it was observed that the elements arsenic and lead were higher than the aforementioned standards at all points. However, levels were below the detection limit of 1 mg/kg for mercury and cadmium. Figure 2 also shows the contents of lead and arsenic, which were higher than the standards in all landfills. Threshold limits are the following: As = 5, Pb = 60, Cr = 100) (Toth et al., 2016).

Pollution factor and geo-accumulation index

An examination of the contamination factor in the soil samples from the villages of Kisom, Nazoksara, and Kashal Azadsara showed that the elements of chromium, Nickel, and iron were in the quality group I, which means that the contamination is low.

The concentration of iron and chromium was only in some of the Amirkiasar landfill stations

Table 6. Comparison of the soil heavy metals content (mg/Kg) (at 0-30 and 30-60 cm) with the relevant standards

Standards		As	Co	Cr	Cu	Ni	Pb	Zn	Fe	Mn
World surface rock average (Martin and Meybeck, 1979)		13	13	71	32	49	16	127	35900	750
Mean Earth's crust (Eslamizade et al., 2016)		5	20	100	50	80	14	75	41000	950
Threshold values (Toth et al., 2016)		5	20	100	100	50	60	200	-	-
Locations		**Concentration (mg/Kg)**								
Kisom (0-30 cm)	Max	30	18	55.5	92	52.4	347	177	34500	875
	Min	15	12	43	38	36	43	43	22600	732
	Average	22.87	15.25	49.87	54.50	43.85	180.5	105	29675	785.75
Kisom (30-60 cm)	Max	24	15	50	59	48	328	122	41000	932
	Min	18	11	40	28	33	57	47	30700	681
	Average	21.70	13.25	46.25	42.25	39.25	186.5	83.5	35025	813.25
Kashal Azadsara (0-30 cm)	Max	40	12	36	45	36	46	69	28000	681
	Min	12	6	27	32	21	24	10	21500	448
	Average	25.5	9.38	30.88	37.5	26.25	33.63	24.37	24400	578
Kashal Azadsara (30-60 cm)	Max	39	12	49	76	45	197	58	28600	700
	Min	18	6	16	30	16	5	10	17000	362
	Average	24	8.5	32.5	47.5	28.88	47.88	39.62	24050	563
Nazoksara (0-30 cm)	Max	35	21	57	76	52	42	74	32600	847
	Min	27	3.18	31	38	25	18	37	21500	523
	Average	32.25	10.42	47	50	39.5	28.75	58.5	27925	711.5
Nazoksara (30-60 cm)	Max	45	12	46	79	50	52	97	32000	1200
	Min	26	7	37	41	20	26	37	23000	548
	Average	35.25	10	41.5	53.25	33.5	40	72.75	27175	801.5
Amirkiasar (0-30 cm)	Max	33	18	114	55	34	62	160	68200	925
	Min	17	4	36	29	21	32	45	23700	474
	Average	25.57	11.85	78.57	41.14	27.42	48.57	97.57	44514	683.86
Amirkiasar (30-60 cm)	Max	31	16	128	51	37	73	173	71800	970
	Min	18	7	29	29	22	27	40	21400	451
	Average	24.14	11	80	39.85	28.71	47.57	89.85	43371	684.14

classified as quality group II (moderate pollution). The results for the Kashal Azadsara waste disposal stations showed that copper and arsenic elements were in some points and lead in all stations in quality group II (moderate pollution), and arsenic in one point was classified as quality group IV.

The results for the village of Kisom showed that the elements copper, arsenic, and cobalt were in all stations, and iron, manganese, and nickel were in some stations, classified as quality group II (moderate pollution), while lead was in all points classified as quality group IV (high pollution) (Table 7). At the Nazoksara disposal stations, the elements copper, arsenic, and lead were in all stations, and cobalt and manganese were in some points, classified as quality group II (moderate pollution) (Table 7).

The results for the Amirkiaser disposal site indicate that arsenic is in all samples (disposal site and downstream areas) classified as quality group II, meaning moderate pollution. The elements cobalt, chromium, copper, zinc, and manganese are in some samples, and lead in downstream stations 50 and 100 meters away, also classified as moderate pollution. Additionally, lead in the disposal site and downstream stations 100a is classified as quality group III, indicating significant pollution (Table 7).

The geo-accumulation index (Igeo) results demonstrated that the concentrations of nickel, manganese, iron, zinc, chromium, cobalt, and copper were classified as non-polluted. The analysis of lead concentrations using the index revealed that lead was moderately polluted in three stations at the Amirkiaser disposal site, moderately to strongly polluted at one point in Kisom, and strongly polluted at two points in Kisom. The index results for arsenic indicated

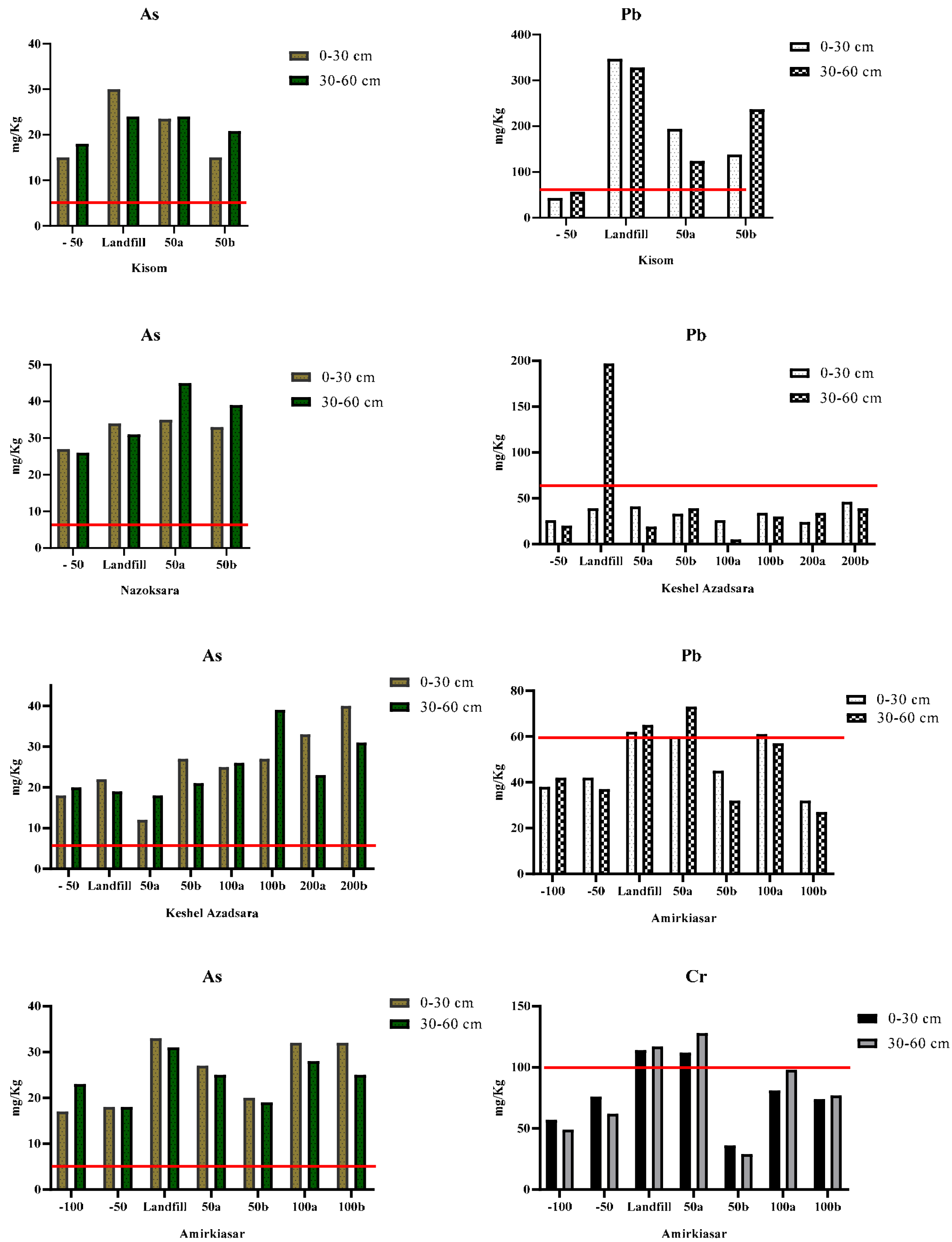

Fig. 2. Concentrations of Arsenic, Lead, and Chromium in the Astaneh Ashrafiyeh landfills over threshold limits Values present the distance from the landfill, and negative values indicate distances upslope of the landfills. Different letters indicate different directions.

Table 7. Contamination factor index in the soil (0-30 cm) of sampling points

Station/CF	Pb	Ni	Mn	Zn	Fe	Cu	Cr	Co	As
Kashal Azadsara	2.44	0.49	0.67	0.54	0.61	1.09	0.38	0.46	1.69
Kashal Azadsara (50a)	2.56	0.43	0.65	0.08	0.61	0.97	0.38	0.54	0.92
Kashal Azadsara (50b)	2.06	0.53	0.89	0.49	0.69	1.41	0.51	0.77	2.08
Kashal Azadsara (100a)	1.63	0.53	0.87	0.08	0.71	1.19	0.41	0.85	1.92
Kashal Azadsara (100b)	2.13	0.47	0.7	0.08	0.6	1.00	0.38	0.92	2.08
Kashal Azadsara (200a)	1.50	0.73	0.91	0.08	0.76	1.28	0.51	0.85	2.52
Kashal Azadsara (200b)	2.88	0.65	0.88	0.08	0.78	1.25	0.49	0.85	3.08
Kashal Azadsara (-50)	1.62	0.45	0.88	0.11	0.67	1.18	0.42	0.54	1.5
Kisom	21.69	1.11	0.98	1.06	0.82	1.41	0.78	1.31	2.31
Kisom (50a)	12.13	0.92	1.17	0.51	0.89	1.19	0.68	1.08	1.77
Kisom (50b)	8.63	0.86	1.07	1.39	0.96	1.34	0.75	1.38	1.81
Kisom (-50)	2.68	0.73	0.97	0.34	0.63	2.87	0.6	0.92	1.15
Nazoksara	1.81	0.98	1.04	0.45	0.83	1.38	0.8	0.85	2.62
Nazoksara (50a)	1.63	0.67	0.93	0.58	0.76	1.31	0.69	1.62	2.69
Nazoksara (50b)	2.63	1.06	1.13	0.92	0.9	2.38	0.72	0.24	2.54
Nazoksara (-50)	1.12	0.51	0.7	0.3	0.6	1.18	0.43	0.5	2.07
Amirkiasar	3.88	0.67	1.23	0.81	1.89	1.53	1.61	1.31	2.56
Amirkiasar (50a)	3.75	0.65	0.92	1.17	1.58	1.50	1.58	1.23	2.08
Amirkiasar (50b)	2.81	0.43	0.7	0.58	0.67	0.97	0.51	0.69	1.54
Amirkiasar (100a)	3.81	0.69	1.03	1.26	1.49	1.72	1.14	1.38	2.46
Amirkiasar (100b)	2.00	0.47	0.95	0.57	1.28	1.13	1.04	0.85	2.46
Amirkiasar (-50)	2.62	0.57	0.92	0.35	0.66	0.90	1.07	0.3	1.38
Amirkiasar (-100)	2.37	0.43	0.63	0.63	1.08	1.25	0.80	0.7	1.30
Minimum	1.12	0.43	0.63	0.08	0.6	0.90	0.38	0.24	0.92
Maximum	21.69	1.11	1.23	1.39	1.89	2.87	1.61	1.62	3.08

that its concentration was moderately polluted at six points at Amirkiasar and one point at Kashal Azadsara (Table 8).

Pollution status of the region with PLI, mCd, PER and ERM Mean indices

Kashal: The evaluation of metal pollution indices such as PLI and mCd in soil 0–30 cm showed that based on the PLI factor, the disposal site and downstream stations were non-polluted. According to the Cd index, the soil of these stations was classified as moderately polluted. The mCd index indicated that these stations had zero to very low contamination levels (Table 9).

Kisom: The assessment of metal contamination with PLI and mCd in soil 0–30 cm demonstrated that based on the PLI factor, the downstream stations were non-polluted, and the disposal site had moderate pollution. The mCd index showed that the downstream stations had low pollution, and the disposal site had moderate pollution (Table 9).

Nazoksara: The investigation of metal pollution by PLI revealed that the downstream locations and disposal site were non-contaminated. According to the Cd index, the soil of two downstream stations and the disposal site was classified as moderately polluted. The mCd index indicated that all stations had zero to very low contamination levels (Table 9).

Amirkiasar: Based on the PLI factor, the disposal site and downstream stations 50 and 100a had moderate pollution, and stations 50 and 100b were non-polluted. According to the Cd index, the soil of the disposal site and downstream stations 50 and 100a was classified as having significant pollution, and stations 50 and 100b had moderate pollution. The mCd index indicated that these stations had zero to very low pollution levels (Table 9).

The results of calculating E and PER values for different elements at various stations showed that only lead was classified as posing a significant risk at Kisom (landfill), medium risk at Kisom (50a), and medium risk at Kisom (50b) (Table 10). The comparison of the mean contents of metals at four landfills with standards related to minimum and medium environmental risk

Table 8. Geo-accumulation index (I_{geo}) in the soil (0-30 cm) of sampling points

Station/Igeo	Pb	Ni	Mn	Zn	Fe	Cu	Cr	Co	As
Kashal Azadsara	0.69	-1.64	-1.18	-1.47	-1.32	-0.47	-2	-1.73	0.16
Kashal Azadsara (50a)	0.76	-1.83	-1.21	-4.32	-1.32	-0.64	-2	-1.51	-0.71
Kashal Azadsara (50b)	0.45	-1.51	-0.76	-1.64	-1.15	-0.10	-1.6	-0.97	0.46
Kashal Azadsara (100a)	0.11	-1.51	-0.81	-4.32	-1.08	-0.34	-2	-0.83	0.35
Kashal Azadsara (100b)	0.49	-1.69	-1.12	-4.32	-1.35	-0.60	-1.88	-0.71	0.46
Kashal Azadsara (200a)	0	-1.03	-0.73	-4.32	-0.97	-0.23	-1.6	-0.83	0.75
Kashal Azadsara (200b)	0.93	-1.21	-0.78	-4.32	-0.94	-0.26	-1.55	-0.83	<u>1.03</u>
Kashal Azadsara (-50)	0.11	-1.73	-1.2	-3.77	-1.32	-0.34	-1.83	-1.48	-0.7
Kisom	<u>3.85</u>	-0.49	-0.62	-0.51	-0.86	-0.09	-0.94	-0.20	0.61
Kisom (50a)	<u>3.01</u>	-0.81	-0.49	-0.10	-0.76	-0.17	-1	-0.12	0.27
Kisom (50b)	<u>2.52</u>	-0.70	-0.37	-1.55	-0.64	-0.34	-1.15	-0.48	0.85
Kisom (-50)	0.83	-1.02	-0.62	-2.15	-1.25	0.93	-1.31	-0.7	-0.37
Nazoksara	0.26	-0.62	-0.53	-1.73	-0.86	-0.13	-0.91	-0.83	0.80
Nazoksara (50a)	0.11	-1.18	-0.71	-1.39	-0.97	-0.20	-1.12	0.098	0.84
Nazoksara (50b)	0.80	-0.51	-0.41	-1.55	-0.74	0.66	-1.08	-2.64	0.76
Nazoksara (-50)	-0.41	-1.55	-1.12	-2.39	-1.36	-0.34	-1.78	-1.60	0.47
Amirkiasar	<u>1.36</u>	-1.18	-0.28	-0.89	0.33	0.03	0.09	-0.20	<u>1.69</u>
Amirkiasar (50a)	<u>1.32</u>	-1.22	-0.71	-0.38	0.07	0	0.07	-0.28	<u>1.38</u>
Amirkiasar (50b)	0.90	-1.83	-1.12	-1.4	-1.15	-0.64	-1.6	-1.12	<u>1.02</u>
Amirkiasar (100a)	<u>1.34</u>	-1.12	-0.55	-0.26	-0.01	0.19	-0.4	-0.12	<u>1.64</u>
Amirkiasar (100b)	0.41	-1.69	-0.66	-1.39	-0.23	-0.41	-0.53	-0.83	<u>1.64</u>
Amirkiasar (- 50)	0.80	-1.39	-0.71	-2.12	-1.18	-0.73	-0.49	-2.32	0.92
Amirkiasar (- 100)	0.66	-1.83	-1.25	-1.28	-0.47	-0.27	-0.91	-1.12	0.87

Table 9. PLI and mCd indices in 0-30 cm soil of sampling points

Station	PLI	Description	mCd	Description
Kashal Azadsara	0.76	Unpolluted	0.93	Zero to the very low degree of contamination
Kashal Azadsara (50a)	0.57	Unpolluted	0.79	Zero to the very low degree of contamination
Kashal Azadsara (50b)	0.89	Unpolluted	1.04	Zero to the very low degree of contamination
Kashal Azadsara (100a)	0.69	Unpolluted	0.91	Zero to the very low degree of contamination
Kashal Azadsara (100b)	0.66	Unpolluted	0.93	Zero to the very low degree of contamination
Kashal Azadsara (200a)	0.76	Unpolluted	1.01	Zero to the very low degree of contamination
Kashal Azadsara (200b)	0.8	Unpolluted	1.21	Zero to the very low degree of contamination
Kashal Azadsara (-50)	0.64	Unpolluted	0.81	Zero to the very low degree of contamination
Kisom	<u>1.59</u>	Moderate contamination	<u>3.48</u>	Moderate degree of contamination
Kisom (50a)	<u>1.27</u>	Moderate contamination	<u>2.26</u>	Moderate degree of contamination
Kisom (50b)	<u>1.42</u>	Moderate contamination	<u>2.01</u>	Moderate degree of contamination
Kisom (-50)	0.96	Unpolluted	1.21	Zero to the very low degree of contamination
Nazoksara	<u>1.05</u>	Moderate contamination	1.19	Low degree of contamination
Nazoksara (50a)	<u>1.06</u>	Moderate contamination	1.20	Low degree of contamination
Nazoksara (50b)	<u>1.11</u>	Moderate contamination	1.39	Low degree of contamination
Nazoksara (-50)	0.69	Unpolluted	0.82	Low degree of contamination
Amirkiasar	<u>1.5</u>	Moderate contamination	<u>1.72</u>	Low degree of contamination
Amirkiasar (50a)	<u>1.42</u>	Moderate contamination	<u>1.60</u>	Low degree of contamination
Amirkiasar (50b)	0.82	Unpolluted	0.99	Zero to the very low degree of contamination
Amirkiasar (100a)	<u>1.47</u>	Moderate contamination	<u>1.66</u>	Low degree of contamination
Amirkiasar (100b)	<u>1.05</u>	Moderate contamination	1.19	Zero to the very low degree of contamination
Amirkiasar (-50)	0.79	Unpolluted	0.97	Zero to the very low degree of contamination
Amirkiasar (-100)	0.9	Unpolluted	1.02	Zero to the very low degree of contamination

Table 10. E values and potential environmental risk index (PER) of sampling points (0-30 cm)

Station/CF	Pb	Ni	Zn	Cu	Cr	As	PER
Kashal Azadsara	14.64	2.94	0.54	6.54	0.76	16.9	42.32
Kashal Azadsara (50a)	15.36	2.58	0.08	5.82	0.76	9.2	33.8
Kashal Azadsara (50b)	12.36	3.18	0.49	8.46	1.02	20.8	46.31
Kashal Azadsara (100a)	9.78	3.18	0.08	7.14	0.82	19.2	40.2
Kashal Azadsara (100b)	12.78	2.82	0.08	6	0.76	20.8	43.24
Kashal Azadsara (200a)	9	4.38	0.08	7.68	1.02	25.2	47.36
Kashal Azadsara (200b)	17.28	3.9	0.08	7.5	0.98	30.8	60.54
Kashal Azadsara (-50)	9.72	2.7	0.11	7.08	0.84	15	35.45
Kisom	130.14	6.66	1.06	8.46	1.56	23.1	170.98
Kisom (50a)	72.78	5.52	0.51	7.14	1.36	17.7	105.01
Kisom (50b)	51.78	5.16	1.39	8.04	1.5	18.1	85.97
Kisom (-50)	16.08	4.38	0.34	17.22	1.2	11.5	50.72
Nazoksara	10.86	5.88	0.45	8.28	1.6	26.2	53.27
Nazoksara (50a)	9.78	4.02	0.58	7.86	1.38	26.9	50.52
Nazoksara (50b)	15.78	6.36	0.92	14.28	1.44	25.4	64.18
Nazoksara (-50)	6.72	3.06	0.3	7.08	0.86	20.7	38.72
Amirkiasar	23.28	4.02	0.81	9.18	3.22	25.6	42.32
Amirkiasar (50a)	22.5	3.9	1.17	9	3.16	20.8	33.8
Amirkiasar (50b)	16.86	2.58	0.58	5.82	1.02	15.4	46.31
Amirkiasar (100a)	22.86	4.14	1.26	10.32	2.28	24.6	40.2
Amirkiasar (100b)	12	2.82	0.57	6.78	2.08	24.6	43.24
Amirkiasar (-50)	15.72	3.42	0.35	5.4	2.14	13.8	47.36
Amirkiasar (-100)	14.22	2.58	0.63	7.5	1.6	13	60.54
Minimum	6.72	2.58	0.08	5.40	0.76	9.2	-
Maximum	130.14	6.66	1.39	17.22	3.22	30.8	-

Table 11. Comparison of the content of elements in the landfill with the standards (Long et al., 1995)

Standards	As	Cu	Ni	Pb	Cr	Zn
ERL_a	8.20	34.0	29.90	46.70	81	150
ERM_b	70.00	270.0	51.60	218.0	370	410
PEL_c	41.60	108.0	42.80	112.0	160	271
This study	26.54	45.78	34.25	72.86	51.58	71.36
	(12-40)	(29-92)	(21-52.4)	(18-347)	(27-114)	(10-177)

a Effect range low (NOAA).
b Effect range medium (NOAA).
d Probable effects level (Environment Canada).

levels indicated that the average concentrations of arsenic, copper, nickel, and lead exceeded the Effect Range Low (ERL) threshold. Additionally, the concentrations of lead and nickel at some points exceeded the Probable Effects Level (PEL) (Table 11).

The Mean ERM index values for the landfills at Kashal Azadsara, Kisom, Nazoksara, and Amirkiaser were 0.221, 0.590, 0.019, and 0.316, respectively. For the combined sampling points in each region (landfill and downstream/upstream points), the values were 0.218, 0.439, 0.003, and 0.285, respectively. Based on the Mean ERM index, the probabilities of toxicity for mean ERM coefficients >1.5, 0.51–1.5, 0.11–0.5, and <0.1 are 76%, 49%, 21%, and 9%, respectively (Jamshidi and Bastami, 2016). Therefore, according to the results, the Kisom landfill has a 49% probability of pollution, while other studied points have a 21% probability of heavy metal pollution.

Many problems can arise from the presence of arsenic and lead contamination in these soils. Lead and arsenic accumulate in the body causing different toxicity in organisms and humans. Their toxic effects are such that they damage the living body and prevent it from functioning properly. Lead toxicity inhibits seed germination, plant growth, and yield. Lead interferes with root nutrient uptake, change plasma membrane permeability, and disrupts chloroplast structure, resulting in alters in respiration and transpiration. Lead produces ROS, activates antioxidants,

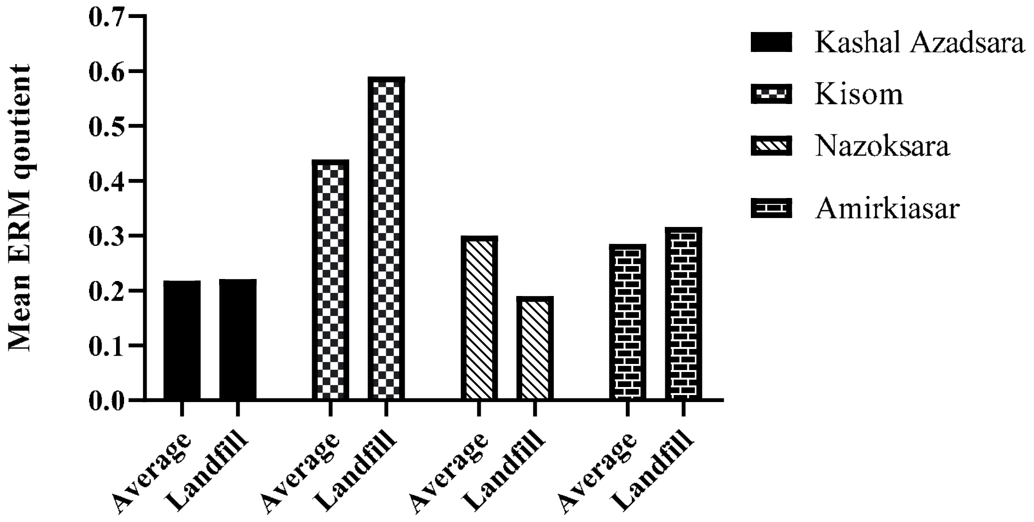

Fig. 3. Mean ERM quotient in the soil samples of Astaneh landfills

and disrupts photosynthesis, water balance, mineral balance, and hormonal status (Collin et al., 2022). Exposure of plants to arsenic leads to accumulation of reactive oxygen species (ROS), damages cell membranes, and significantly affects many plant metabolic processes, including the availability of essential nutrients, photosynthesis, carbohydrate, lipid, protein, and sulfur metabolism (Zhang et al., 2021).

Livestock and poultry in the region are exposed to heavy metals. Cattle are particularly at risk due to their dietary habits. Exposure to lead and arsenic can cause various disorders and excessive oxidative stress due to free radical production (Tahir and Alkheraije, 2023). Exposure to lead causes clinical pathologic changes due to increased toxicity in the endocrine system and in the kidneys (Famurewa et al., 2022). Starving cows will eat anything, and they are very likely to ingest items containing lead. It accumulates in the kidneys, liver, and other tissues and acts like calcium in the body (Das, 2023; Souza-Arroyo et al., 2022). Poisoned cows typically show matted hair, malnutrition, emaciation, fetal abnormalities, muscle loss, and moderate anemia (Tahir, and Alkheraije, 2023; Cuomo et al., 2022). Symptoms of arsenic poisoning in cattle include severe gastrointestinal inflammation, nervous system symptoms, weight loss, mucosal lesions, disease, loss of appetite, conjunctivitis, and decreased milk production (Rajawat et al., 2022; Upadhyay et al., 2023). Human exposure to arsenic is associated with a variety vascular disease and also increases the risk of tumors of the liver, lung, kidney, and bladder (Gupta et al., 2022). Lead bioaccumulates and biomagnifies in the human, affecting the reproductive, renal, nervous, skeletal, hematopoietic, and cardiovascular systems (Collin et al., 2022). To reduce the concentration of heavy metals and their transfer into food, strategies such as waste management, preventing leachate from entering the soil and surrounding areas, avoiding the cultivation of fruit-bearing plants, preventing livestock grazing in contaminated soils, and using biological methods (especially phytoremediation) can be employed. A primary method to minimize leachate formation is to reduce water input into waste disposal sites. The main approach to achieve this goal is installing covers that minimize infiltration and divert some rainfall as run off)Serdarevic, 2018(. In the context of waste management and reducing its production in urban areas, the following points can be highlighted:

1. Reusable Containers: Instead of buying drinks in single-use plastic bottles, choose reusable containers. 2. **Product Reuse**: Reusing products reduces waste and provides an opportunity for financial savings by conserving resources and preserving natural resources for future use. 3. **Invest in Recycled Materials**: Invest in products made from recycled materials to help improve the environment. 4. **Greener Cleaners**: Use greener and more natural cleaners like vinegar and baking soda, which reduce the waste generated by numerous cleaning products and are better for the environment. 5. **Composting**: Organic waste, such as yard waste and food scraps, constitutes between 25% and 50% of total waste. 6. P**ublic Awareness**: Increase public awareness about the benefits of reducing waste production and increasing recycling. **7. Personal Influence**: Believe that individual behavior can serve as a model for others in the community.

CONCLUSION

In conclusion, the study highlights significant concerns regarding heavy metal contamination in the soils of landfills located in Astaneh, northern Iran. The findings reveal that elements such as arsenic and lead exceed permissible standards at all sampling points, indicating potential environmental and ecological risks. While some elements like iron, chromium, and nickel showed low contamination levels, others, including copper and cobalt, were classified as moderate pollutants in certain areas. The geo-accumulation index further confirmed that lead and arsenic posed moderate to high pollution risks in specific locations. These results emphasize the acute demand for effective waste management approaches and soil remediation plans to mitigate the negative impacts of heavy metal contamination on the environment and public health.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Abrahim, G. M. S., & Parker, R. J. (2008). Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environmental monitoring and assessment,. 136 (1); 227-238.

Ashrafi, S. M. , Mollashahi, M. and Ravanbakhsh, H. (2022). Investigating the effects of Urban Landfill on soil and plant biodiversity of Zarandin forest. Journal of Environmental Science Studies., *7*(2); 5024-5031.

Beinabaj, S. M. H., Heydariyan, H., Aleii, H. M., & Hosseinzadeh, A. (2023). Concentration of heavy metals in leachate, soil, and plants in Tehran's landfill: Investigation of the effect of landfill age on the intensity of pollution. Heliyon., 9 (1).

Collin, S., Baskar, A., Geevarghese, D. M., Ali, M. N. V. S., Bahubali, P., Choudhary, R., ... & Swamiappan, S. (2022). Bioaccumulation of lead (Pb) and its effects in plants: A review. Journal of Hazardous Materials Letters., 3; 100064

Cuomo, D., Foster, M. J., & Threadgill, D. (2022). Systemic review of genetic and epigenetic factors underlying differential toxicity to environmental lead (Pb) exposure. Environmental Science and Pollution Research., 29 (24); 35583-35598.

Das, A. (2023). Nanotheranostics: the toxicological implications. In Design and Applications of Theranostic Nanomedicines (pp. 369-394). Woodhead Publishing.

de Souza, V. B., Hollas, C. E., Bortoli, M., Manosso, F. C., & de Souza, D. Z. (2023). Heavy metal contamination in soils of a decommissioned landfill southern Brazil: Ecological and health risk assessment. Chemosphere., 339; 139689.

Du, C., & Li, Z. (2023). Contamination and health risks of heavy metals in the soil of a historical landfill in northern China. Chemosphere., 313; 137349.

Esmaeilzadeh, M., Karbassi, A., & Moattar, F. (2016). Heavy metals in sediments and their bioaccumulation in Phragmites australis in the Anzali wetland of Iran. Chinese journal of oceanology and limnology., 34; 810-820.

Famurewa, A. C., Renu, K., Eladl, M. A., Chakraborty, R., Myakala, H., El-Sherbiny, M., … & Gopalakrishnan, A. V. (2022). Hesperidin and hesperetin against heavy metal toxicity: Insight on the molecular mechanism of mitigation. Biomedicine & Pharmacotherapy., 149; 112914.

Gupta, A., Dubey, P., Kumar, M., Roy, A., Sharma, D., Khan, M. M., ... & Hasanuzzaman, M. (2022). Consequences of arsenic contamination on plants and mycoremediation-mediated arsenic stress tolerance for sustainable agriculture. Plants., 11 (23); 3220.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. Water research., 14(8); 975-1001.

Hashmi, M. Z., Khan, S., Kavil, Y. N., Alelyani, S. S., Al Sehemi, A. G., Hasnain, A., ... & Ahmed, Z. (2024). Spatial distribution and health risks assessment of heavy metals in e-waste dumping sites from Pakistan. Environmental Geochemistry and Health., 46(8); 279.

Harikumar, P. S., Nasir, U. P., & Rahman, M. M. (2009). Distribution of heavy metals in the core sediments of a tropical wetland system. International Journal of Environmental Science & Technology., *6*; 225-232.

Hou, S., Zheng, N., Tang, L., Ji, X., & Li, Y. (2019). Effect of soil pH and organicmatter content on heavy metals availability in maize (Zea mays L.) rhizospheric soil of non-ferrous metals smelting area. Environmental Monitoring and Assessment., 191(10); 634.

Jamshidi, S., & Bastami, K. D. (2016). Metal contamination and its ecological risk assessment in the surface sediments of Anzali wetland, Caspian Sea. Marine pollution bulletin., 113(1-2); 559-565.

Jayasundara, R. B. C. D., Udayagee, K. P. P., Karunarathna, A. K., Manage, P. M., Nugara, R. N., & Abhayapala, K. M. R. D. (2023). Permeable reactive barriers as an in situ groundwater remediation technique for open solid waste dumpsites: a review and prospect. Water, Air, & Soil Pollution., 234(1); 50.

Karimian, S., Shekoohiyan, S., & Moussavi, G. (2021). Health and ecological risk assessment and simulation of heavy metal-contaminated soil of Tehran landfill. RSC advances., *11*(14); 8080-8095.

Long, E. R., Macdonald, D. D., Smith, S. L., & Calder, F. D. (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental management., 19; 81-97.

Marinho, A. P. F. D., Nascimento, C. W. A. D., & Cunha, K. P. V. D. (2022). Soil degradation and Cu, Cr, Ni, Pb and Zn contamination in dumpsites of humid and semiarid tropical regions in northeastern Brazil. Environmental Monitoring and Assessment., 194(7); 459.

Martin, J.M., & Meybeck, M. (1979). Elemental Mass-Balance of Material Carried by Major World Rivers. Mar. Chem., 7 (3);178-206.

Muller, G. (1979). Heavy metals in the sediment of the Rhine-Changes seity. Umsch. Wiss. Tech.79;778-783.

Pandey, J. and Singh, R. (2017). Heavy metals in sediments of Ganga River: up- and downstream urban influences. Applied Water Science., 7(4); 1669–1678.

Peng, X., Jiang, Y., Chen, Z., Osman, A. I., Farghali, M., Rooney, D. W., & Yap, P. S. (2023). Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: a review. Environmental Chemistry Letters., 21 (2); 765-801.

Pu, Y., Sun, Q., Yang, J., Wang, H., Xu, X., Wang, J., & Zhan, M. (2024). Pollution characteristics and risk assessment of heavy metals in the soil of a municipal solid waste landfill site. Soil and Sediment Contamination: An International Journal., 1-18.

Rajawat, N. K., Bhardwaj, K., & Mathur, N. (2022). Risk of Parkinson disease associated with pesticide exposure and protection by probiotics. Materials Today: Proceedings, 69; A1-A11.

Rouhani, A., & Hejcman, M. (2024). A review of soil pollution around municipal solid waste landfills in Iran and comparable instances from other parts of the world. International Journal of Environmental Science and Technology., 1-18.

Saadatlu, E. A., Barzinpour, F., & Yaghoubi, S. (2022). A sustainable model for municipal solid waste system considering global warming potential impact: A case study. Computers & Industrial Engineering., 169; 108127.

Sanga, V. F., & Pius, C. F. (2024). Heavy metal contamination in soil and food crops and associated human health risks in the vicinity of Iringa Municipal dumpsite, Tanzania. Discover Environment., *2*(1); 104.

Serdarevic, A. (2018). Landfill leachate management—control and treatment. In Advanced Technologies, Systems, and Applications II: Proceedings of the International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies (IAT) (pp. 618-632). Springer International Publishing.

Shariati, S., Pourbabaee A.A., Alikhani, H.A. & Rezaei, K. (2019). Investigation of Heavy Metal Contamination in the Surface Sediments of Anzali Wetland in North of Iran. Pollution., 5 (1); 211-224.

Souza-Arroyo, V., Fabián, J. J., Bucio-Ortiz, L., Miranda-Labra, R. U., Gomez-Quiroz, L. E., & Gutiérrez-Ruiz, M. C. (2022). The mechanism of the cadmium-induced toxicity and cellular response in the liver. Toxicology., 480; 153339.

Tahir, I., & Alkheraije, K. A. (2023). A review of important heavy metals toxicity with special emphasis on nephrotoxicity and its management in cattle. Frontiers in Veterinary Science. 10; 1149720.

Wang, S., Han, Z., Wang, J., He, X., Zhou, Z., & Hu, X. (2022). Environmental risk assessment and factors influencing heavy metal concentrations in the soil of municipal solid waste landfills. Waste Management., 139; 330-340.

Upadhyay, K., Viramgami, A., Balachandar, R., Pagdhune, A., Shaikh, I., & Sivaperumal, P. (2023). Development and validation of Graphite Furnace Atomic Absorption Spectrometry method and its application for clinical evaluation of blood lead levels among occupationally exposed lead smelting plant workers. Analytical Sciences., 39 (4); 517-526.

Zhang, J., Hamza, A., Xie, Z., Hussain, S., Brestic, M., Tahir, M. A., ... & Shabala, S. (2021). Arsenic transport and interaction with plant metabolism: Clues for improving agricultural productivity and food safety. Environmental Pollution., 290; 117987.