(Supplementary information)

Health and ecological risk assessment and simulation of heavy metal-contaminated soil of Tehran landfill

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Table S1- The values of factors that used in the carcinogenic and non-carcinogenic risk assessment

Parameters	Symbol	Units	Children (1-6 years old)	Adults	Distribution	Reference
Heavy metal concentration	C_{soil}	mg/kg			Log-normal	This study
Ingestion rate	IngR	mg/day	24 ± 4	100 ± 1.7	Log-normal	[1-3]
Inhalation rate	InhR	m^3/day	7.6 ± 2.39	20 ± 1.27	Log-normal	[1,2]
Exposure frequency	EF	day/year	350 (180, 365)	350 (180, 365)	Triangular	[4,5]
Exposure duration	ED	year	6 ± 2.39	30 ± 2.74	Log-normal	[1,5]
Conversion factor	CF	kg/mg	1×10^{-6}	1×10^{-6}	Point	
Skin adherence factor	AF	mg/cm^2/day	0.2	0.07	Point	[1]
Dermal absorption factor	ABS	unitless	1.0×10^{-3}	1.0×10^{-3}	Point	[6]
Exposed skin area	SA	cm^2	2800 ± 1171	5700 ± 440	Log-normal	[1]
Particle emission factor	PEF	m^3/kg	1.36×10^9	1.36×10^9	Point	[1]
Average body weight	BW	kg	15 ± 1.5	70 ± 10.71	Log-normal	[6,7]
Average time	$AT_{non-cancer}$	day	ED × 365 = 8760	ED × 365 = 8760	Point	[23]
	AT_{cancer}	day	70 × 365 = 25500	70 × 365 = 25500	Point	[23]

Table S2- The values for SF (kg-day/mg) and R_fD (mg/kg/day) in health risk calculation through different exposure routes [19, 8, 9]

Factors	Heavy metals								
	Zn	Cu	Fe	Co	Ni	As	Cr	Pb	Cd
RfD_{ing}	0.3	4.0×10^{-2}	0.70	4.3×10^{-2}	2.0×10^{-2}	3.0×10^{-4}	3.0×10^{-3}	3.5×10^{-3}	1.0×10^{-3}
RfD_{inh}	0.3	4.0×10^{-2}	2.2×10^{-4}	5.7×10^{-6}	2.0×10^{-2}	3.0×10^{-4}	2.9×10^{-5}	3.5×10^{-3}	1.0×10^{-3}
RfD_{der}	0.3	4.0×10^{-2}	4.5×10^{-2}	1.6×10^{-2}	8.0×10^{-4}	3.0×10^{-4}	6.0×10^{-5}	5.3×10^{-4}	1×10^{-5}
SF_{ing}	----	----	----	----	1.7	1.5	0.5	8.5×10^{-3}	0.38
SF_{inh}	----	----	----	----	0.9	15.1	42.0	4.2×10^{-2}	6.3
SF_{der}	----	----	----	----	42.5	1.5	2.0	8.5×10^{-3}	0.38

Table S3- The concentration of heavy metals (mg/kg) in different sampling points in each season

	Area	Sampling point	As	Cd	Cr	Mn	Ni	Pb	Zn	Cu	Fe	Co	Al
Autumn		1	5.8	0.25	68.5	1150	17.0	32.0	119.0	52.5	41100	15.0	69250
		2	3.5	1.1	127.0	1400	30.5	55.0	253.0	113.5	31100	19.0	70350
		3	12.0	0.24	90.0	1170	33.5	29.0	155.0	27.5	28950	10.5	50050
		4	5.0	0.24	70.5	810	19.5	25.0	47.5	24.5	29750	11.5	68600
		5	3.5	0.33	69.0	1050	30.5	30.0	58.5	34.0	42600	21.5	71000
	Landfill	6	5.5	0.5	128.0	950	37.5	150.0	355.5	224.5	41250	11.0	58950
		7	6.0	0.5	75.0	1115	29.0	27.0	106.5	52.0	44950	22.5	73300
		8	7.5	0.24	79.0	910	30.5	89.0	158.5	133.0	31000	11.0	62400
		9	6.5	0.35	53.0	840	22.0	29.0	89.5	23.0	26650	10.0	60450
		10	7.5	0.45	65.0	810	26.5	25.0	64.0	35.5	30300	9.0	58850
		11	6.0	0.5	112.0	840	47.0	111.5	352.5	226.0	36750	9.5	56900
	Residential	12	7.6	0.32	90.0	905	51.0	29.0	275.0	39.5	32050	12.5	65450
Winter		1	6.2	0.8	73.0	1097	25.0	39.0	114.0	64.0	44774	18.0	71293
		2	3.9	1.2	131.0	1388	36.0	61.0	297.0	132.0	31137	23.0	72125
		3	14	0.27	85.0	1129	39.0	33.0	134.0	40.0	31461	12.0	49213
		4	5.3	0.23	65.0	868	22.0	20.0	66.0	45.0	37909	15.0	66192
		5	3.8	0.27	64.0	1074	26.0	27.0	71.0	57.0	43202	18.0	73501
	Landfill	6	5.1	0.40	130.0	969	40.0	166.0	375.0	241.0	43134	16.0	60104
		7	5.1	0.23	72.0	1128	24.0	32.0	76.0	56.0	46848	19.0	74494
		8	7.0	0.31	78.0	880	35.0	78.0	213.0	112.0	33998	13.0	64714
		9	7.7	0.26	57.0	828	28.0	34.0	97.0	40.0	28309	11.0	61534
		10	6.4	0.25	62.0	800	29.0	29.0	78.0	39.0	32971	13.0	60528
		11	5.6	0.39	115.0	878	43.0	117.0	408.0	206.0	37891	13.0	58710
	Residential	12	8.0	0.27	81.0	940	49.0	34.0	85.0	35.0	34743	16.0	66843
Spring		1	8.0	0.27	69.0	1066	25.0	20.0	80.0	64.0	48285	18.0	72330
		2	9.2	0.22	46.0	1170	21.0	15.0	63.0	62.0	41874	16.0	69629
		3	9.8	0.23	74.0	778	41.0	20.0	92.0	48.0	33499	13.0	61778
		4	9.4	0.23	58.0	750	22.0	13.0	61.0	47.0	36290	13.0	61832
		5	4.9	0.24	62.0	1003	24.0	21.0	75.0	61.0	42734	16.0	71154
	Landfill	6	6.9	0.36	167.0	989	65.0	104.0	291.0	193.0	47160	17.0	63975
		7	17.6	0.28	69.0	1093	32.0	19.0	88.0	56.0	34405	13.0	59397
		8	12.0	0.26	68.0	813	35.0	29.0	107.0	76.0	32297	13.0	63116
		9	4.6	0.23	59.0	984	26.0	13.0	67.0	64.0	44748	17.0	73907
		10	14.5	0.23	63.0	728	38.0	19.0	77.0	41.0	29113	11.0	57373
		11	10.8	0.23	56.0	872	22.0	14.0	65.0	51.0	41819	15.0	67486
	Residential	12	15.1	0.25	69.0	733	42.0	19.0	71.0	38.0	30773	13.0	57661
Summer		1	4.3	0.37	79.0	1289	31.0	38.0	123.0	66.0	50242	17.0	78860
		2	4.3	0.90	85.0	1054	23.0	47.0	216.0	101.0	38808	14.0	67955
		3	7.8	0.29	81.0	1310	35.0	27.0	79.0	53.0	44464	15.0	71664
		4	3.6	0.27	55.0	996	22.0	16.0	62.0	51.0	38941	13.0	65229
		5	3.7	0.28	74.0	1172	24.0	25.0	68.0	58.0	46341	15.0	74916
	Landfill	6	3.9	0.27	85.0	1251	29.0	26.0	81.0	59.0	53911	18.0	80127
		7	5.0	0.28	81.0	1141	28.0	22.0	71.0	49.0	45279	16.0	72401
		8	4.2	0.33	85.0	920	33.0	51.0	160.0	153.0	33864	11.0	66751
		9	6.5	0.27	215.0	916	31.0	39.0	109.0	83.0	30998	10.0	63447
		10	4.2	0.28	72.0	856	33.0	34.0	90.0	60.0	29786	10.0	62276
		11	6.3	0.29	68.0	1003	23.0	18.0	78.0	56.0	43260	15.0	73720
	Residential	12	6.8	0.29	66.0	925	39.0	24.0	73.0	40.0	32583	12.0	62036
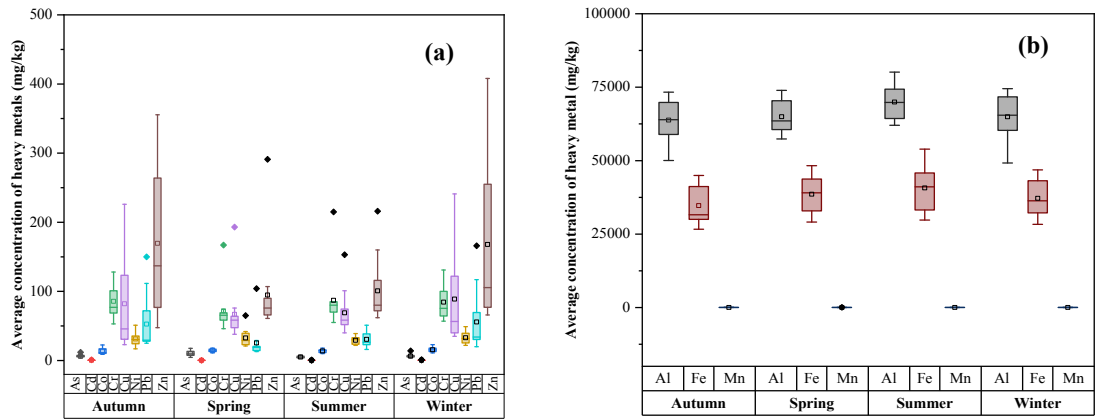
Fig. S1. Heavy metals concentrations (mg/kg) in each season

Table S4- Descriptive statistics of soil heavy metals concentrations (mg/kg) in all sampling point

for four seasons

Element	Min	Max	Mean	Median	S.D	CV %	Background	World soil
As	3.9	3.9	6.8	6.7	2.6	38.3	6.1	6.0[*]
Cr	62.1	62.1	82.7	77.0	20.3	24.6	23.4	70.0[*]
Cd	0.24	0.24	0.36	0.29	0.12	32.9	0.34	0.35[*]
Cu	41.9	41.9	38.9	52.9	29.3	75.2	13.6	30.0[*]
Ni	21.4	21.4	30.3	29.9	5.7	18.9	11.3	50.0[*]
Pb	18.5	18.5	42.5	28.0	19.4	45.7	10.2	35.0[*]
Co	10.7	10.7	14.5	13.2	2.5	17.3	8.01	8.0[*]
Zn	59.1	59.1	133.9	112.0	52.2	38.9	31.6	90.0[*]
Mn	856.0	856.0	1005.4	969.0	98.1	9.7	792.9	1000.0[*]
Al	58176.3	58176.3	66178.0	65148.9	5106.6	7.7	65000.0	71000.0[*]
Fe	30542.5	30542.5	38276.2	35726.1	4363.7	11.4	24492.0	40000.0[*]

[*] Average values of world soils [10]

Table S5- The results for heavy metal normality test in different sampling points

Elements	Kolmogorov-Smirnov[a]	Shapiro-Wilk
	Sig.	Sig.
As	0.001	0.000
Cd	0.000	0.000
Cr	0.000	0.000
Cu	0.000	0.000
Co	0.004	0.046
Pb	0.000	0.000
Zn	0.000	0.000
Mn	0.000[*]	0.000
Fe	0.041	0.028
Ni	0.000[*]	0.003
Al	0.000[*]	0.000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table S6- The results for nonparametric test in different sampling points

Parameters	As	Cd	Cr	Cu	Co	Pb	Zn	Mn	Fe	Ni	Al
Mann-Whitney U	2.0	6.0	6.0	0.0	1.0	4.0	5.0	0.0	0.0	0.0	0.0
Wilcoxon W	12.0	16.0	16.0	10.0	11.0	14.0	15.0	10.0	10.0	10.0	10.0
Z	-1.0	0.0	0.0	-2.0	-2.0	-1.0	0.0	-2.0	-2.0	-2.0	-2.0
Asymp. Sig. (2-tailed)	0.000	0.000	0.000	0.020	0.042	0.000	0.000	0.021	0.021	0.020	0.021
Exact Sig. [2*(1-tailed Sig.)]	0.000[b]	0.000[b]	0.000[b]	0.029[b]	0.057[b]	0.000[b]	0.000[b]	0.029[b]	0.029[b]	0.029[b]	0.029[b]

a. Grouping Variable: points

b. Not corrected for ties.

Table S7- The results for Kruskal-Wallis test for different sampling points

Parameters	As	Cd	Cr	Cu	Co	Pb	Zn	Mn	Fe	Ni	Al
Chi-Square	20.0	11.0	19.0	30.0	26.0	16.0	24.0	32.0	29.0	28.0	20.0
Asymp. Sig.	0.038	0.000	0.052	0.001	0.006	0.000	0.009	0.001	0.002	0.003	0.044

a. Kruskal Wallis Test

b. Grouping Variable: points

Table S8- The results for heavy metal normality test in four seasons

Heavy metals	Season	Kolmogorov-Smirnov[a] Sig.	Shapiro-Wilk Sig.
As	Autumn	0.000	0.086
	Winter	0.000	0.007
	Spring	0.000*	0.000
	Summer	0.008	0.042
Cd	Autumn	0.009	0.001
	Winter	0.000	0.000
	Spring	0.000	0.002
	Summer	0.000	0.000
Cr	Autumn	0.000*	0.000
	Winter	0.052	0.021
	Spring	0.000	0.000
	Summer	0.000	0.000
Cu	Autumn	0.001	0.003
	Winter	0.003	0.004
	Spring	0.000	0.000
	Summer	0.006	0.003
Co	Autumn	0.029	0.015
	Winter	0.000*	0.000
	Spring	0.020	0.000
	Summer	0.000*	0.000
Pb	Autumn	0.000	0.001
	Winter	0.002	0.002
	Spring	0.000	0.000
	Summer	0.000	0.000
Zn	Autumn	0.000	0.082
	Winter	0.014	0.006
	Spring	0.000	0.000
	Summer	0.024	0.005
Mn	Autumn	0.000*	0.000
	Winter	0.000*	0.000
	Spring	0.000*	0.000
	Summer	0.000*	0.000
Fe	Autumn	0.041	0.000
	Winter	0.000*	0.000
	Spring	0.000*	0.000
	Summer	0.000*	0.000

Ni	Autumn	0.000*	0.000
	Winter	0.000*	0.000
	Spring	0.000	0.024
	Summer	0.000*	0.000
Al	Autumn	0.000*	0.000
	Winter	0.000*	0.000
	Spring	0.000*	0.000
	Summer	0.000*	0.000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table S9- The results for Mann-Whitney U test in four seasons

Parameters	As	Cd	Cr	Cu	Co	Pb	Zn	Mn	Fe	Ni	Al
Mann-Whitney U	50.0	59.0	68.0	52.0	58.0	45.0	51.0	47.0	37.0	71.0	38.0
Wilcoxon W	128.0	137.0	146.0	130.0	136.0	123.0	129.0	125.0	115.0	149.0	116.0
Z	-1.0	0.0	0.0	-1.0	0.0	-1.0	-1.0	-1.0	-2.0	-0.05	-1.0
Asymp. Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.000	0.050
Exact Sig. [2*(1-tailed Sig.)]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.045[b]	0.000[b]	0.052[b]

a. Grouping Variable: Season

b. Not corrected for ties.

**Table S10-** The results for Kruskal-Wallis test for four seasons

Parameters	As	Cd	Cr	Cu	Co	Pb	Zn	Mn	Fe	Ni	Al
Chi-Square	14.0	12.0	6.0	1.0	4.0	16.0	5.0	5.0	5.0	0.0	5.0
Asymp. Sig.	0.002	0.006	0.072	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000

a. Kruskal Wallis Test

b. Grouping Variable: Season

Table S11- PCA rotated component matrix

Variable	PCA			Communality
	1	**2**	**3**	
As	-0.198	0.678	0.148	0.521
Cd	0.317	-0.055	-0.872	0.864
Cr	0.737	0.010	-0.277	0.620
Mn	0.049	-0.531	-0.371	0.721
Ni	0.648	0.282	-0.035	0.501
Pb	0.951	-0.050	0.035	0.908
Zn	0.928	0.045	-0.216	0.910
Cu	0.943	-0.139	0.002	0.908
Fe	0.017	-0.908	0.117	0.839
Co	-0.110	-0.705	-0.476	0.735
Al	-0.297	-0.870	-0.201	0.885
% Var	**0.351**	**0.266**	**0.148**	**0.765**
Cumulative %	**0.351**	**0.617**	**0.765**	
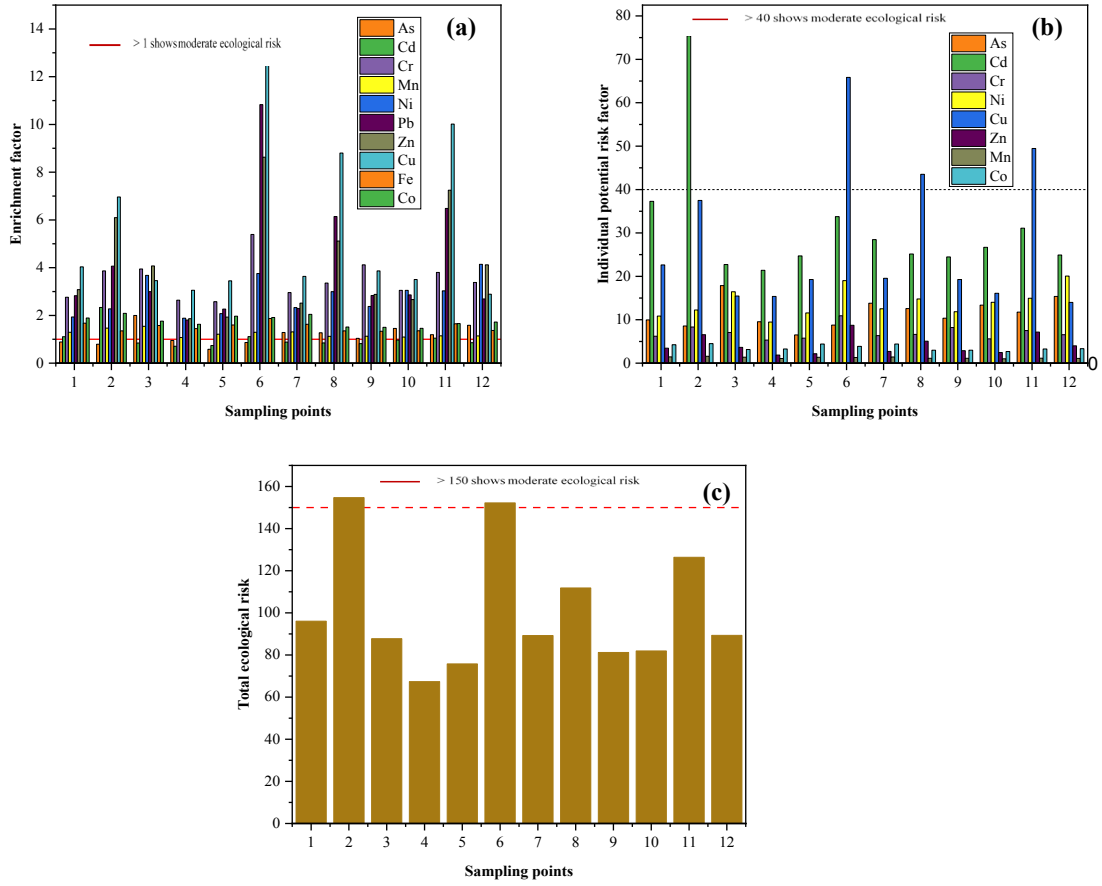
Fig. S2. The ecological risk indices, a) enrichment factor; b) individual potential risk factor; c)

total ecological risk index

Table S12- Non-carcinogenic and carcinogenic health risk values from exposure routes in different landfill sampling points in four seasons

Sampling points	HQ			ILCR		
	Ingestion	Dermal	Inhalation	Ingestion	Dermal	Inhalation
1	1.3E-01	9.0E-03	4.9E-02	9.4E-05	7.5E-06	2.5E-07
2	1.1E-01	7.9E-03	3.8E-02	7.7E-05	5.7E-06	2.7E-07
3	1.2E-01	8.4E-03	4.3E-02	1.1E-04	8.5E-06	2.6E-07
4	1.0E-01	9.0E-03	3.8E-02	6.7E-05	5.3E-06	1.7E-07
5	1.2E-01	8.3E-03	4.5E-02	7.6E-05	5.9E-06	2.3E-07
6	1. 3E-01	9.6E-03	5.3E-02	9.0E-05	7.1E-06	2.7E-07
7	1.2E-01	8.4E-03	4.4E-02	8.8E-05	6.8E-06	2.6E-07
8	1.0E-01	7.3E-03	3.3E-02	1.0E-04	8.0E-06	2.7E-07
9	1.2E-01	1.1E-03	3.1E-02	1.3E-04	8.0E-06	6.7E-07
10	8.0E-02	6.6E-03	2.9E-02	9.7E-05	7.9E-06	2.3E-07
11	1.1E-01	7.7E-03	4.2E-02	7.4E-05	5.6E-06	2.2E-07
Average	1.1E-01	8.2E-03	4.0E-02	1.1E-04	9.3E-06	2.2E-07
Ingestion/dermal ratio	13.6			13.1		
Ingestion/inhalation ratio	2.8			322.0		

Table S13- The comparison of carcinogenic values through investigated heavy metals in children and adults

Group	CR values					ILCR
	As	Cd	Cr	Pb	Ni	
Adults	6.6E-06	5.1E-08	1.8E-05	1.1E-07	1.2E-04	1.4E-04
Children	1.1E-05	1.5E-07	4.6E-05	3.9E-07	6.0E-05	1.2E-04

Table S14- Statistical values of Monte Carlo simulation for HI and ILCR in adults and children

Groups	HQ				ILCR			
	Skewness	Kurtosis	Mean	Percentile 95%	Skewness	Kurtosis	Mean	Percentile 95%
Adults	0.38	3.1	1.4E-01	1.8E-01	0.55	3.1	1.4E-04	1.8E-04
Children	0.47	3.1	8.9E-01	1.1E+00	0.64	3.6	1.2E-04	1.5E-04

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