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ORIGINAL PAPER

Development of soil pollution risk index in the vicinity of a waste dam in Chadormalu iron ore mine

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Abstract

Soil pollution caused by anthropogenic activities or natural factors results in reduced quality of environment. Fourteen elements, including Ti, Al, Fe, Cr, V, Pb, As, Sc, Zn, Cu, Co, Mn, Ca and Mo, in 20 soil samples and a wildflower called Anabasis Setifera on the tailing pond of Chadormalu iron ore in Iran were assessed. Metals were measured using inductively coupled plasma mass spectrometry (ICP-MS). Enrichment factor and contamination factor were employed to assess the ecological risk. C_f^i value within the range of 1.00–1.12 indicates the mean contamination of the soil, and E_r^i value within the range of 1–10 represents the low ecological risk of the elements in the soil. Transfer factor (Tr_i) was also used to calculate the transfer of heavy metals from soil to plant. Tr_i value within the range of 1.63–29.01 shows that the plant induces the transfer of contaminants from soil. The order of the transferred elements in terms of amount is as: Co > Ti > Cr > Al > Mn > Fe > Ca > V>Cu > Pb > Zn > As > Mo > Sc. Geo-accumulation (I_{geo}) and pollution indices have showed some weaknesses in assessing the high values of the elements. Therefore, in this study, a new index as level of pollution, Ln (LP), was developed to evaluate the contamination of soil by various concentrations of the elements. Based on I_{geo} and I_{POLL}, the pollutants fall within the class of 0 which indicates no pollution. The Ln (LP) index calculated as 0.069–1.166 shows that the studied elements, except for cobalt, had no pollution.

Keywords Contamination factors · Ecological risk · Heavy metals · Soil pollution · Iron ore mine

Introduction

To maintain the soil ecological balance, the concentration of heavy metals such as Cr, Ni, Cd, Cu, Pb and As must be low. However, the concentration of these elements is increasing with the increase in anthropogenic activities (Arenas-Lago et al. 2013). Soil is a natural dynamic body essential for human life, and it should be taken into account due to its high potential for absorbing heavy and toxic metals (Blaser et al. 2000; Vesali Naseh et al. 2012). In recent decades, the soil pollution by heavy metals caused by industrialization and urbanization has received special attention (Belis et al. 2013; Liu et al. 2014; Huang et al. 2015; Wang et al. 2015). Heavy metals pollution in urban areas stems from different sources such as industrial activities, power stations, mines, fossil fuels combustion and wastes disposal (Krishna and Govil 2007; Wei and Yang 2010). In mining areas, the disposal of non-recyclable mineral wastes produced from mineral ore concentrates is responsible for soil contamination. Concentration of heavy metals in soil increases the potential of risk and adverse effects in soil ecosystems (Cui et al. 2004; Li et al. 2009a, b). Different enrichment calculation methods are used to assess the heavy metals pollution in soil (Farsad et al. 2011). Some of these methods are enrichment factor (EF), contamination factor, geo-accumulation index, pollution index (I_{POLL}) and level of pollution Ln (LP). EF indicates the enrichment of soil contamination compared to the pre-industrial soil in the same environment (Dias et al. 2014).

Chadormalu iron ore mine is located at the center of Iran, 180 km northeast of Yazd and 85 km north of Bafgh, with

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five production lines and annual capacity of 9 million tons of steel production through direct reduction method. The solid wastes area of Chadormalu contains heavy metals in an area of 2546 km^2 6 km away from Chadormalu iron ore processing unit with a population of 4197 people. The population density in the mine is 1.65 per km^2 (Fig. 1). Saghand village and Bahabad county, with distances of 40 km and 60 km, are the nearest and furthest residential places to the mine, respectively. Population densities in these areas are 15.8 and 3.37, respectively. The annual average wind speed is 52 km/h, and the annual average rain and snowfall is 107 mm in the area. The amount of heavy metals in solid wastes and their contamination were assessed in this study. The wind disperses the solid waste particles in the surrounding area, and a wide area of solid wastes actually provides an inactive ecosystem. The ways of preventing the dispersion of particles containing heavy metals, reducing the amount of heavy metals and providing a sustainable desert ecosystem have been considered in this study.

Materials and methods

Study area and sampling

Water is recovered for reuse from slurry-like mineral wastes from the ponds located at the southeast of Chadormalu. The remaining solids are dried over time. In order to create an ecological stable equilibrium, 25-cm-thick soil was poured on solid wastes to let the local winds disperse the seeds to grow wildflowers. The purpose of this study was to investigate the amount of waste material contaminants transferred into the soil and the role of wildflower in reducing soil contamination and also to assess the effects of anthropogenic and natural factors on soil contamination.

The soil and plant were taken from 20 different points and combined together. A total of 12 compound samples of soil and 12 compound samples of plant were obtained. Soil samples were dried in a dryer at 40 °C for 36 h (Mollazadeh et al. 2013).

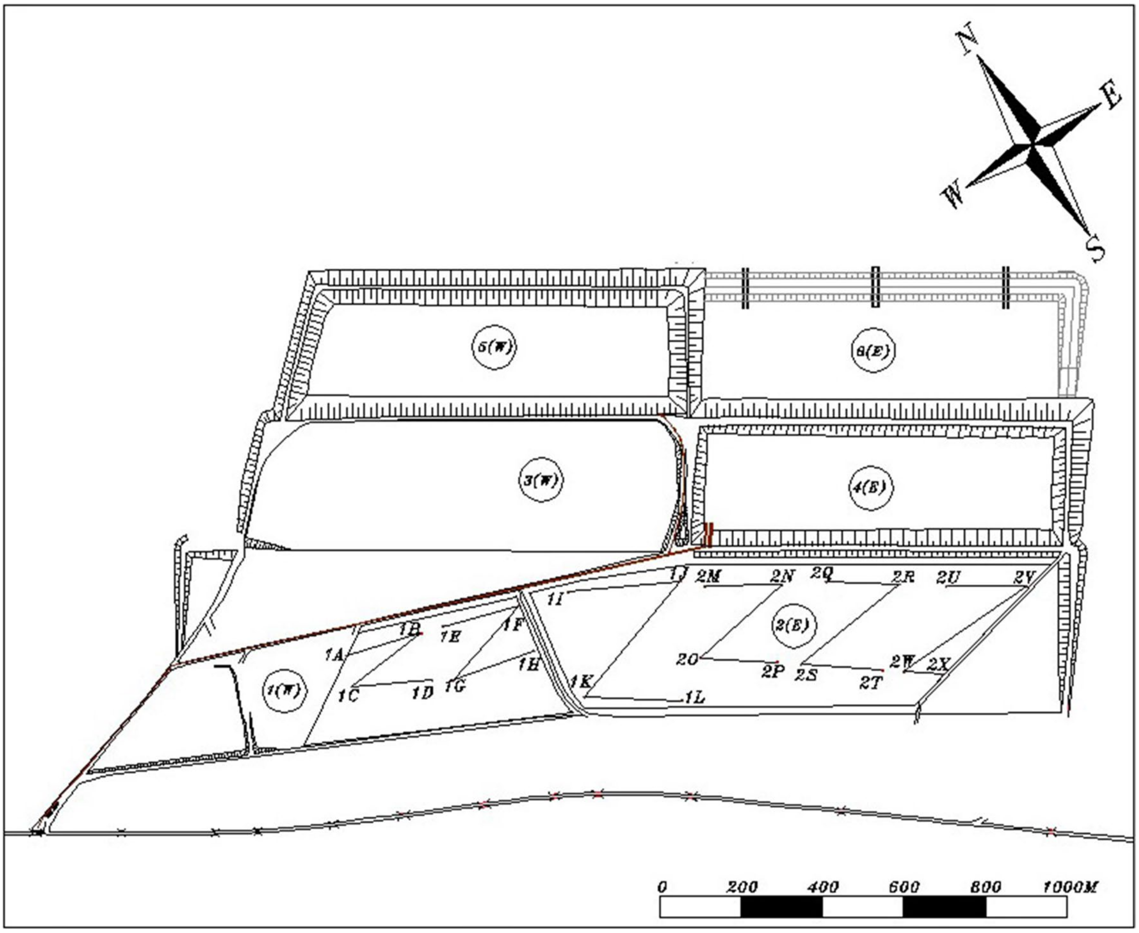

Fig. 1 Soil and plant sampling locations at Chadormalu Tail Basin

Measurement of soil physicochemical properties

The particle size distribution of the samples was measured by sieve analysis. Using sieves and ASTM, soil particles were classified into slime (< 300 mic), sand (> 300 mic) and gravel (> 2 mm). Slime and plant roots were micronized by disk mill. Soil pH was measured in a solution with the soil/water ratio of 1:5. The suspension was left standing for a while and then its pH was measured by a pH meter. For organic matters in soil samples, the samples were heated in a muffle furnace at 450 °C for 4 h (Glasby and Szefer 1998) and then the loss on ignition (LOI) was measured. Moreover, the analytical grade laboratory chemicals were used to analyze the samples and the deionized water (conductivity ≤ 4 µs/cm) was employed to prepare solutions. About 2 g of soil samples and powdered plant roots were dissolved in 5 ml of normal hydrochloric acid (0.53 N) in a clean glass container, and the obtained mixture was digested using microwave digestion system. Finally, the extracted solutions were filtered through syringe filter (DISMIC–25HP PTFE, pore size = 0.45 µm) (Toyo Roshi Kaisha, Ltd, Tokyo, Japan) and stored in 50-ml polypropylene pipes (Nalgene New York) (Arenas-Lago et al. 2014).

Instrumental analysis and quality control

Inductively coupled plasma mass spectrometry (ICP-MS-HP4500) was used to determine heavy metals contents in soil and plant. In order to prepare the calibration curve, 10 ppb solution of Y, Ce, Tl and Li was used. The calibration range for all the elements was 0.1 to 50.0 ppb, and this level was used for all of them. The mother solution (100 ppm) was from Merck and Chem Lab Companies. These solutions covered a wide range of metals. The results of heavy metals analysis in soil and plant are provided in Table 1.

Data calculation

Enrichment factors (EF)

The enrichment factor (EF) is a tool for differentiating between the heavy metals from anthropogenic activities and those from natural source. The concentration of immobile element in the sample and the reference sample was used in calculating EF. Knowing that Sc and Al are often considered to be immobile in soil, Al was considered immobile in this study. EF is calculated using Eq. 1:

$$\mathrm{EF} = \left(C_{\mathrm{M}}/C_{\mathrm{Al}}\right)\mathrm{Sample}/\left(C_{\mathrm{M}}/C_{\mathrm{Al}}\right)\mathrm{STD} \quad (1)$$

where $(C_{\mathrm{M}}/C_{\mathrm{Al}})$ sample is the ratio of heavy metals concentration (C_{M}) to aluminum concentration in soil and $(C_{\mathrm{M}}/C_{\mathrm{Al}})$ STD is the same ratio in the pre-industrial or standard sample.

The EF value of 1 for all samples places them in a non-contaminated range. EF values of < 2, 2–4, 4–16, 16–32 and > 32, respectively, indicate no contamination, low contamination, moderate contamination, high contamination and very high contamination (Table 2).

Contamination factor (C_f^i)

Contamination factor (C_f^i) is the ratio between the metal content in soil (Cm) and the standard concentration levels as suggested by Hakanson (1980) and can be calculated by Eq. 2.

$$\left(C_{\mathrm{STD}}\right)C_f^i = \frac{\mathrm{Cm}}{\mathrm{CSTD}} \quad (2)$$

The degree of contamination is classified as: low contamination ($C_f^i < 1$), moderate contamination (1–3), considerable contamination (3–6) and very high contamination ($C_f^i \geq 6$) (Rashed 2010) (Table 3).

Transfer factor (TF)

Transfer factor indicates the movement of contaminant from the soil to the plant as presented by Eq. 3.

$$\mathrm{TF} = \frac{C_{\mathrm{M}}}{C_{\mathrm{P}}} \quad (3)$$

where C_{M} is the concentration of metal in soil and C_{P} is the concentration of metal in plant.

Geo-accumulation Index (I_{geo})

I_{geo} is used to assess the metal contaminant in sediments and soils by comparing the analyzed concentration of metals with pre-industrial levels. I_{geo} proposed by Muller (1969) is calculated using Eq. 4.

$$I_{\mathrm{geo}} = \mathrm{Log}_2 \frac{\mathrm{Cm}}{1.5C_{\mathrm{STD}}} \quad (4)$$

where C_{M} and C_{STD} are the concentrations of metal in current and pre-industrial soil samples, respectively, factor 1.5 is used to eliminate possible variations in reference values and to eliminate anthropogenic effects. The geo-accumulation index (I_{geo}) was defined as: $I_{\mathrm{geo}} \leq 0.42$ (unpolluted), $0.42 < I_{\mathrm{geo}} \leq 1.42$ (less polluted), $1.42 < I_{\mathrm{geo}} \leq 3.42$ (moderately polluted), $3.42 < I_{\mathrm{geo}} \leq 4.42$ (strongly polluted) and $I_{\mathrm{geo}} > 4.42$ (extremely polluted). The geo-accumulation index (I_{geo}) is classified into 6 classes (Table 4).

Table 1 Metal contents in soils and plants from Tail Basin

Sampling station		Al %	As mg/kg	Ca %	CO mg/kg	Cr mg/kg	Cu mg/kg	Fe %	Mn mg/kg	Mo mg/kg	Pb mg/kg	Sc mg/kg	Ti mg/kg	V mg/kg	Zn mg/kg	LOI %	PH
1	Soil	5.4132	8.9	6.9545	20.0	169	42	4.8803	841	2.1	19	15.1	4893	163	50	10.05	8.23
	Plant	0.4522	2.508	0.5497	0.358	4.175	6	0.3421	60	1.563	22.476	11.757	110	16.640	15.849	–	–
2	Soil	5.2721	13.1	6.8092	18.9	200	37	5.6591	794	1.8	20	14.7	4724	187	63	10.96	8.21
	Plant	0.3871	0.653	0.2973	0.100	10.838	4	0.3483	58	0.875	0.050	14.530	239	18.208	8.075	–	–
3	Soil	5.2589	21.7	6.9594	21.3	180	40	5.0118	862	2.1	15	15.5	5183	166	50	11.31	8.39
	Plant	0.6020	23.723	0.7459	0.835	5.902	7	0.5885	85	4.769	10.874	11.605	149	27.623	15.331	–	–
4	Soil	5.2488	14.9	7.0290	21.7	189	39	5.0832	880	2.1	16	15.4	5035	170	55	11.96	8.40
	Plant	0.5087	10.649	1.1496	0.883	6.576	7	0.5277	89	1.382	2.785	14.174	173	25.361	17.712	–	–
5	Soil	5.3229	13.6	7.3180	22.8	198	41	5.4597	887	3.0	18	15.4	4971	184	46	12.02	8.41
	Plant	0.3301	17.421	1.0864	1.211	5.141	7	0.5419	90	2.933	0.050	12.878	155	26.938	15.464	–	–
6	Soil	5.4615	9.6	6.9602	18.2	204	33	3.9544	805	1.5	19	13.5	4642	125	55	10.38	8.08
	Plant	0.2649	8.355	0.5970	0.100	6.093	5	0.1659	55	1.829	0.051	14.543	61	13.492	8.861	–	–
7	Soil	5.3246	12.2	6.4283	18.4	220	35	3.8564	799	2.5	14	13.9	4493	123	61	12.46	8.53
	Plant	1.0658	0.100	0.8432	0.884	36.808	11	1.5601	152	1.173	2.337	14.683	693	63.438	26.206	–	–
8	Soil	5.2167	13.9	6.9891	25.2	213	47	5.5032	957	2.6	21	14.0	4684	181	59	11.20	8.42
	Plant	0.5414	14.086	1.5225	1.627	14.804	7	0.8598	168	2.740	0.050	13.606	323	39.649	24.223	–	–
9	Soil	5.2387	13.5	6.9722	20.8	226	37	4.4166	858	3.6	19	13.7	4642	141	50	11.89	8.51
	Plant	0.2544	3.895	0.4629	0.505	15.164	7	0.4114	42	1.169	5.156	16.919	61	18.098	9.678	–	–
10	Soil	5.4512	12.5	6.9416	18.8	187	34	3.8657	806	3.1	15	14.1	4642	123	55	12.35	8.50
	Plant	0.3339	5.367	1.1058	0.135	15.574	7	0.1447	82	2.846	0.050	18.255	102	12.658	16.740	–	–
11	Soil	5.2769	11.0	6.5863	24.7	187	47	5.5270	896	4.8	18	14.4	4494	183	56	13.68	8.46
	Plant	0.4599	7.639	0.2318	1.121	7.283	4	0.1734	26	2.709	9.074	22.561	66	10.058	8.483	–	–
12	Soil	5.5707	8.9	6.3602	18.5	211	35	3.7434	779	3.1	16	14.4	4753	119	57	11.59	8.27
	Plant	0.6033	0.100	0.9559	0.846	6.931	6	0.4053	109	4.821	0.853	18.758	178	20.792	16.027	–	–
Min	Soil	5.2167	8.9	6.3602	18.2	169	33	3.7434	779	1.5	14	13.5	4493	119	46	10.05	8.08
	Plant	0.2544	0.100	0.2318	0.100	4.175	4	0.1447	26	0.875	0.050	11.605	61	10.058	8.075	–	–
Max	Soil	5.5707	21.7	7.3180	25.2	226	47	5.6591	957	4.8	21	15.5	5183	187	63	13.68	8.53
	Plant	1.0658	23.723	1.5225	1.627	36.808	11	1.5601	168	4.821	22.476	22.561	693	63.438	26.206	–	–
Mean	Soil	5.3169	13.2	6.90435	21.0	198	39	4.8379	853.182	2.7	17.6364	14.5	4763.91	159	55	11.66	8.38
	Plant	0.4728	8.581	0.7811	0.705	11.669	7	0.5149	82	2.181	4.814	15.046	194	24.742	15.147	–	–
STD	Soil	0.111	3.443	0.272	2.444	17.015	4.699	0.741	52.875	0.905	2.236	0.704	214.814	27.258	5.011	0.978	0.140
	Plant	0.219	7.464	0.386	0.486	9.039	1.834	0.390	42.197	1.334	6.776	3.216	175.594	14.734	5.870	–	–

Table 2 Terminologies for contamination classes on single and integrated indices

Indices	Unpolluted	Low polluted	Moderately polluted	Strongly polluted	Extremely polluted
Ln(LP)	<1	1–2	2–4	4–6	>6
I_{POLL}	<0.42	0.42–1.42	1.42–3.42	3.42–4.42	>4.42
EF	<2	2–4	4–16	16–32	>32
I_{geo}	<0.42	0.42–1.42	1.42–3.42	3.42–4.42	>4.42
mcd	<1.5	1.5–2	2–4	4–22	>22

Table 3 Hakanson contamination classes

Factor	Low polluted	Moderately polluted	Considerable	Very high
C_f	<1	1–3	3–6	≥ 6

Pollution index (I_{POLL})

I_{POLL} index indicates the degree of metal contamination which can be calculated by Eq. 5 (Karbassi et al. 2008).

$$I_{\text{POLL}} = \text{Log}_2 \frac{\text{Cm}}{1.5C_{\text{STD}}} \tag{5}$$

where C_{M} and C_{STD} are the concentrations of metal in current and pre-industrial soil samples, respectively. Classification of I_{POLL} is the same as that of I_{geo}.

Modified contamination degree (mcd)

Modified contamination degree (mcd) is a modified form of the Hankanson equation for calculating the overall degree of contamination at a given site. Contamination degree is the final index for estimating soil contamination in terms of the presence of various elements and can be calculated by Eq. 6.

$$\text{mcd} = \frac{\sum_{i=1}^{n} C_f^i}{n} \tag{6}$$

where C_f^i is the contamination factor for each element and n is the total number of the analyzed elements. Modified contamination degree is classified as: $\text{mcd} < 1.5$ (no contamination), $1.5 \leq \text{mcd} < 2$ (low contamination), $2 \leq \text{mcd} < 4$ (moderate contamination), $4 \leq \text{mcd} < 22$ (high contamination) and $\text{mcd} \geq 22$ (extreme contamination).

Pollution level (LP)

Considering the specific characteristics of the soil samples taken from the iron ore tailing pond, C_f^i, I_{geo}, I_{POLL} and mcd cannot provide reliable results because of their restricted range and high concentrations of elements. Therefore, it was decided to develop an index based on math principles and simulation using the data obtained from TF and I_{POLL} to be applicable to all types of soil from other mines and to similar projects, with the capability to assess high concentrations of contamination. The new index was named level of pollution, Ln (LP), and it was presented as an equation in Neperian logarithm form (Eq. 7):

$$\text{Ln (LP)} = 0.0519 \times \text{TF} + 0.6931 \times I_{\text{POLL}} - 0.163 \tag{7}$$

Classification of pollution level (LP) is: $\text{Ln (LP)} < 1$ (no contamination), $1 \leq \text{Ln (LP)} < 2$ (low contamination), $4 \leq \text{Ln (LP)} < 6$ (high contamination) and $\text{Ln (LP)} > 6$ (extreme contamination).

Statistical analysis

The data were analyzed using SPSS 2014 (SPSS, ASA), and cluster analysis was used for soil and plant separately and in compound. In this study, cluster analysis has been widely used to analyze the data and the relationship between the metal contents of soil and plant.

Results and discussion

Metal contents in soil and plant samples are provided. The LOI range in soil samples is in the range of 10% to 13%. Some studies indicated that the organic content in the soils from Iran was less than 5% (Saeedi and Karbassi 2006). Therefore, the high value of organic contents in the soil can be attributed to the high level of BOD (Saeedi and Karbassi 2006; Karbassi et al. 2008; Parvaresh et al. 2011; Mollazadeh et al. 2013). High concentration of Ca (about 6%) can be related to the presence

Table 4 Muller contamination classes

Class 0	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
$I_{\text{geo}} \leq 0$	$0 < I_{\text{geo}} \leq 1$	$1 < I_{\text{geo}} \leq 2$	$2 < I_{\text{geo}} \leq 3$	$3 < I_{\text{geo}} \leq 4$	$4 < I_{\text{geo}} \leq 5$	$I_{\text{geo}} > 5$

of lime in the soil. The percentile of anthropogenic and natural metal contents has been shown in Table 5.

Percentile of lithogenous portion

Ti (100%) > Al (99.95%) > Fe (99.93%) > Cr (99.89%) > V (99.88%) > Sc (99.85%) > Zn (99.77%) > Cu (99.54%) > Co (99.28%) > Mn (98.80%) > Ca (97.14%) > Mo (89.19%)

Percentile of anthropogenic portion

Mo (10.81%) > Ca (2.86%) > Mn (1.20%) > Co (0.72%) > Cu (0.46%) > Zn (0.23%) > Sc (0.15%) > V (0.12%) > Cr (0.11%) > Fe (0.07%) > Al (0.05%) > Ti (0%)

This chemical partitioning shows that MO and Ca are derived from anthropogenic sources. Some studies show that about 10% of each metal component can be originated from anthropogenic source (10% of the total metal content is representative of the anthropogenic portion) (Saeedi and Karbassi 2006; Karbassi et al. 2008). Therefore, in this study, the anthropogenic portions of Mo, Ca, Mn and Al are considered to be normal. The calculated indices values for metals are shown in Table 6. The restricted range of I_{POLL}, I_{geo} and EF made them inappropriate to be used for the analysis of the data obtained in this study. The plant root absorbed water, minerals and food. TF values in Table 7 show the importance of plant in absorbing heavy metals from soil. They also showed no anthropogenic pollution, implying that the pollution was naturally formed with no intervention of human activities.

Cluster analysis identified a positive correlation among the metal components in soil samples (Fig. 2). Most of this correlation is related to Fe, Co, Cr, Pb, Al, Sc and Ca. Fe, Co and Cr, Pb portions also have the same behavior.

Table 5 Percentile of lithogenous and anthropogenic portion of metals in soil from Tail Basin

	Station/fraction	%													
		Al	As	Ca	CO	Cr	Cu	Fe	Mn	Mo	Pb	Sc	Ti	V	Zn
1	Lithogenous	99.95	99.06	97.22	99.30	99.90	99.61	99.94	98.75	75.76	99.71	99.84	100.00	99.85	99.67
	Anthropogenic	0.05	0.94	2.78	0.70	0.10	0.39	0.06	1.25	24.24	0.29	0.16	0.00	0.15	0.33
2	Lithogenous	99.95	99.51	97.09	99.33	99.93	99.67	99.95	98.80	93.33	99.77	99.85	100.00	99.91	99.79
	Anthropogenic	0.051	0.49	2.91	0.67	0.07	0.33	0.05	1.20	6.67	0.23	0.15	0.00	0.09	0.21
3	Lithogenous	99.95	99.66	97.18	99.37	99.91	99.60	99.94	98.85	96.65	99.75	99.84	100.00	99.89	99.79
	Anthropogenic	0.05	0.34	2.82	0.63	0.09	0.40	0.06	1.15	3.35	0.25	0.16	0.00	0.11	0.21
4	Lithogenous	99.94	99.65	97.14	99.32	99.89	99.52	99.93	98.74	96.90	99.79	99.82	100.00	99.89	99.80
	Anthropogenic	0.06	0.35	2.86	0.68	0.11	0.48	0.07	1.26	3.10	0.21	0.18	0.00	0.11	0.20
5	Lithogenous	99.95	99.58	97.47	99.46	99.91	99.53	99.94	98.86	94.27	99.83	99.85	100.00	99.91	99.82
	Anthropogenic	0.05	0.42	2.53	0.54	0.09	0.47	0.06	1.14	5.73	0.17	0.15	0.00	0.09	0.18
6	Lithogenous	99.95	99.62	97.03	99.28	99.89	99.56	99.94	98.82	95.56	99.77	99.89	100.00	99.90	99.79
	Anthropogenic	0.05	0.38	2.97	0.72	0.11	0.44	0.06	1.18	4.44	0.23	0.11	0.00	0.10	0.21
7	Lithogenous	99.94	99.53	96.82	99.14	99.84	99.57	99.92	98.75	74.92	99.62	99.84	100.00	99.83	99.75
	Anthropogenic	0.06	0.47	3.18	0.86	0.16	0.43	0.08	1.25	25.08	0.39	0.16	0.00	0.17	0.25
8	Lithogenous	99.95	99.35	97.21	99.37	99.92	99.43	99.94	98.79	75.88	99.81	99.85	100.00	99.91	99.77
	Anthropogenic	0.05	0.65	2.79	0.63	0.08	0.57	0.06	1.21	24.12	0.19	0.15	0.00	0.09	0.23
9	Lithogenous	99.95	99.33	97.15	99.24	99.92	99.27	99.92	98.73	82.58	99.79	99.85	100.00	99.89	99.73
	Anthropogenic	0.05	0.67	2.85	0.76	0.08	0.73	0.08	1.27	17.42	0.21	0.15	0.00	0.11	0.27
10	Lithogenous	99.96	98.97	97.25	99.01	99.89	99.16	99.93	98.95	97.07	99.70	99.80	100.00	99.84	99.77
	Anthropogenic	0.04	1.03	2.75	0.99	0.11	0.84	0.07	1.05	2.93	0.30	0.20	0.00	0.16	0.23
11	Lithogenous	99.95	99.62	97.35	99.41	99.83	99.78	99.92	98.67	97.88	99.78	99.87	100.00	99.90	99.79
	Anthropogenic	0.05	0.38	2.65	0.59	0.17	0.22	0.08	1.33	2.13	0.22	0.13	0.00	0.10	0.21
12	Lithogenous	99.95	99.92	96.81	99.15	99.84	99.73	99.93	98.83	89.52	99.71	99.86	100.00	99.84	99.79
	Anthropogenic	0.05	0.08	3.19	0.85	0.16	0.27	0.07	1.17	10.48	0.29	0.14	0.00	0.16	0.21
Mean	Lithogenous	99.95	99.48	97.14	99.28	99.89	99.54	99.93	98.80	89.19	99.75	99.85	100.00	99.88	99.77
	Anthropogenic	0.05	0.52	2.86	0.72	0.11	0.46	0.07	1.20	10.81	0.25	0.15	0.00	0.12	0.23

Table 6 Pollution intensity in soils from Tail Basin

Station/index		%													
		Al	As	Ca	CO	Cr	Cu	Fe	Mn	Mo	Pb	Sc	Ti	V	Zn
Mean of 12 station	Ln (LP)	0.44	0.07	0.37	1.17	0.70	0.23	0.38	0.41	0.14	0.16	0.04	0.98	0.25	0.15
	I_{POLL}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	I_{geo}	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	EF	1.00	1.00	1.03	1.00	1.00	1.00	1.00	1.01	1.12	1.00	1.00	0.99	1.00	1.00

Table 7 Transfer factor in soils and plants from Tail Basin

Station/transfer factor		%													
		Al	As	Ca	CO	Cr	Cu	Fe	Mn	Mo	Pb	Sc	Ti	V	Zn
Mean of 12 station	TF	11.04	1.63	8.62	29.01	17.65	5.57	9.38	9.96	1.12	4.01	0.94	24.68	6.35	3.61

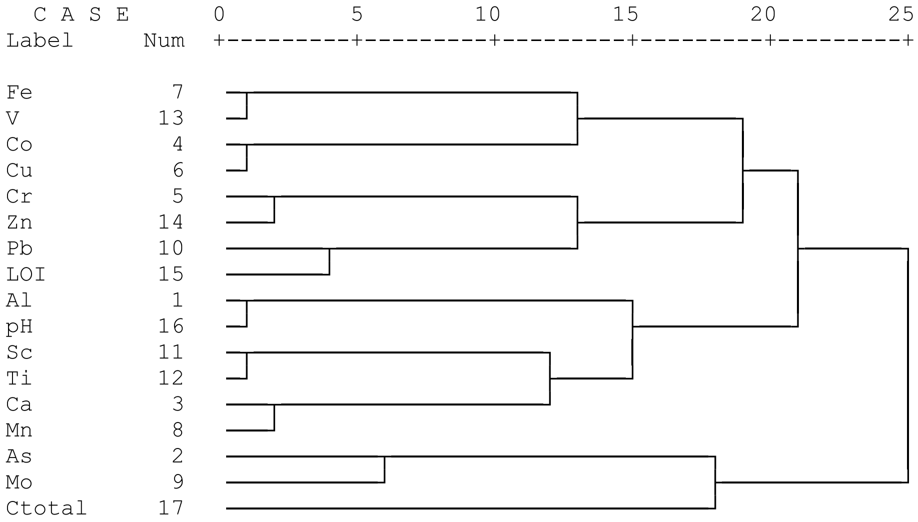

Fig. 2 Dendrogram of cluster analysis for soil of Tail Basin

Cluster analysis of soil and plant showed a positive correlation among Fe, Co, Al, Sc, Ti and As (Fig. 3). The interaction of these elements in soil and plant revealed the important role of plant in reducing the pollution. Cluster analysis also showed that Fe, Cr, Pb, Mo, Co, As, Mn and Al were interdependent in the plant (Fig. 4).

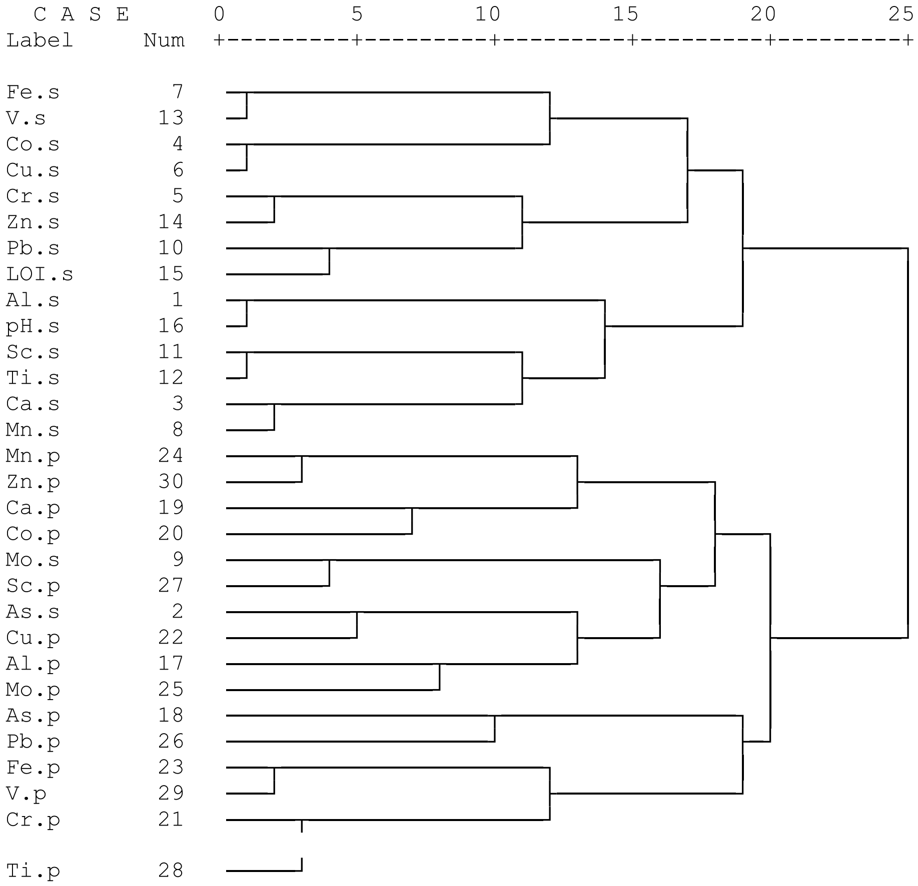

Fig. 3 Dendrogram of cluster analysis for soil and plant of Tail Basin

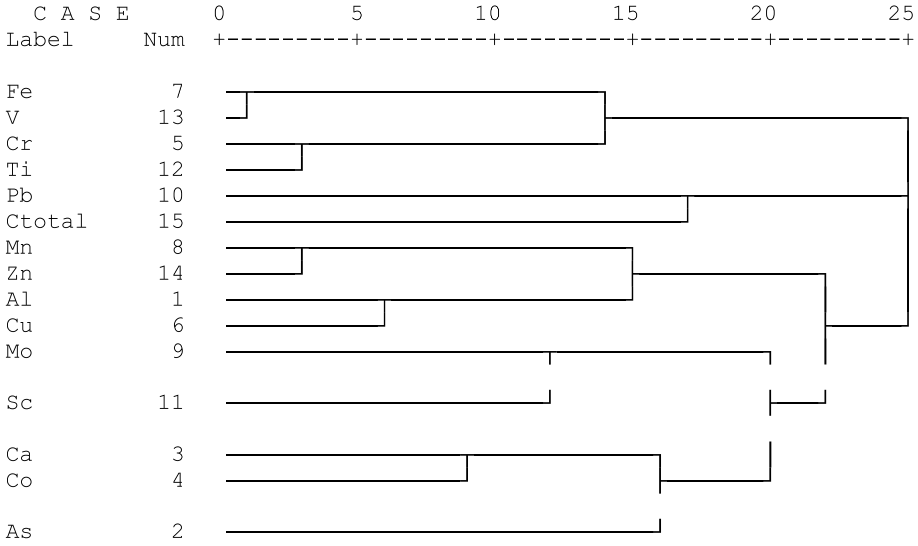

Fig. 4 Dendrogram of cluster analysis for plant of Tail Basin

Conclusion

Solid wastes from iron ore operations have resulted in vast areas of dried tailing ponds during the last two decades. The results of this study showed that pouring soil on these ponds and the growth of wildflowers on them prevented the spread of contamination. Plant played an important role in heavy metals uptake. Considering this restriction, all the data were placed in no pollution range. Therefore, a new index called Ln (Lp) was developed and used as a solution. The obtained results revealed that all the studied elements, except for cobalt with low pollution, were in the range of no pollution. For I_{geo}, I_{POLL} and EF indices, all the elements were in the range of no pollution. Modified degree of contamination also showed no contamination.

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