

# Assessment of heavy metal contamination risk in soils of landfill of Bizerte (Tunisia) with a focus on application of pollution indicators

Abdelwaheb Aydi<sup>1</sup>

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**Abstract** The aim of this work was to assess the pollution status of metals in soils of Bizerte landfill (northeastern of Tunisia) using pollution indicators. For this purpose, soils samples from five excavations were collected and characterized for metal content (Pb, Cu, Cr, Zn, Ni and Cd). The results of the geo-accumulation index ( $I_{geo}$ ) revealed that the most of the soils samples could be considered as unpolluted (Class 1) for Cr, Cu, Zn, Pb and Ni, while the values of Cd demonstrated to have moderate contamination (Class 2) based on  $I_{geo}$  values. The results of the contamination factor (CF) also demonstrated low contamination levels for Ni, Pb, Zn, and Cu and moderate contamination levels for Cr and Cd. The values of pollution load index (PLI) were found to be low in all the studied samples and varied between 0.16 and 0.7, indicating that the studied stations in Bizerte landfill are in low pollution status considering the total of the studied metals.

**Keywords** Landfill · Heavy metals · Geo-accumulation index · Factor contamination · Pollution load index

## Introduction

Among environmental pollutants, heavy metals are of particular concern due to their toxicity, wide source, non-biodegradable properties, and their ability to accumulate for long period of time (Dong et al. 2011). Heavy metal pollution is an irreversible process in soil, once heavy

metals enter the soil, they are difficult to extract or dilute from the soil environment, are hazardous to organisms and they influence soil ecosystem structure and function (Zhou and Song 2004). These micropollutants can affect the ecosystems through bio-accumulation and bio-magnification processes at different levels of the food chain (Manahan 2000). Heavy metal pollution of soil is a major environmental problem in the last few decades owing to the rapid increase in urbanization and industrialization (Purushotham et al. 2012). Therefore, the fate of heavy metals in landfill has recently been the subject of extensive discussion (Jain et al. 2005; Marzougui and Ben Mammou 2006; Kasassi et al. 2008; Vandana et al. 2011; Kanmani and Gandhimathi 2013). Indeed, various studies have demonstrated that surrounding areas from landfill are greatly contaminated by metals; therefore, the evaluation of metal distribution in neighboring landfill is useful to assess pollution in the environment. The main objectives of the current study are as follows: (a) to determine the levels and distribution of cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), chromium (Cr) and nickel (Ni) in soils of landfill of Bizerte and their comparison with international soils quality criteria in landfill and (b) to assess the pollution status as well as the possible influence of anthropogenic activities.

## Materials and methods

### Site description

The Bizerte landfill is situated in the northeastern part of Tunisia and receives a total generated quantity of MSW of 275 tons/day. First opened in 2007, the site has an expected service life of 20 years. The composition of Bizerte City

✉ Abdelwaheb Aydi  
abdelwaheb\_2000@yahoo.fr

<sup>1</sup> Department of Earth Sciences, Faculty Science of Bizerte, University of Carthage, Jarzouna 7021, Bizerte, Tunisia

showed an organic fraction (54.4 %; composed mainly of food waste), followed by textiles (13.7 %), fines (11.2 %), plastics, leather and rubber (8.5 %), papers–cardboard (7.5 %), metals (3.3 %) and glass (1.4 %) (Chantou et al. 2013). The average moisture content of the waste received in the landfill is around 64 % on wet mass (Chantou et al. 2013).

After the placement of each 2-m layer of waste, the waste layer is covered by a 30-cm sand layer. An approximately 1.8-m-thick soil layer is used as a final cover above the waste layer.

The average leachate collected with high-density polyethylene pipes (diameter 160 mm) and stocked in three storage basins was about 60 m<sup>3</sup>/day, which is transferred to the main wastewater treatment plant for further treatment (Turki et al. 2014).

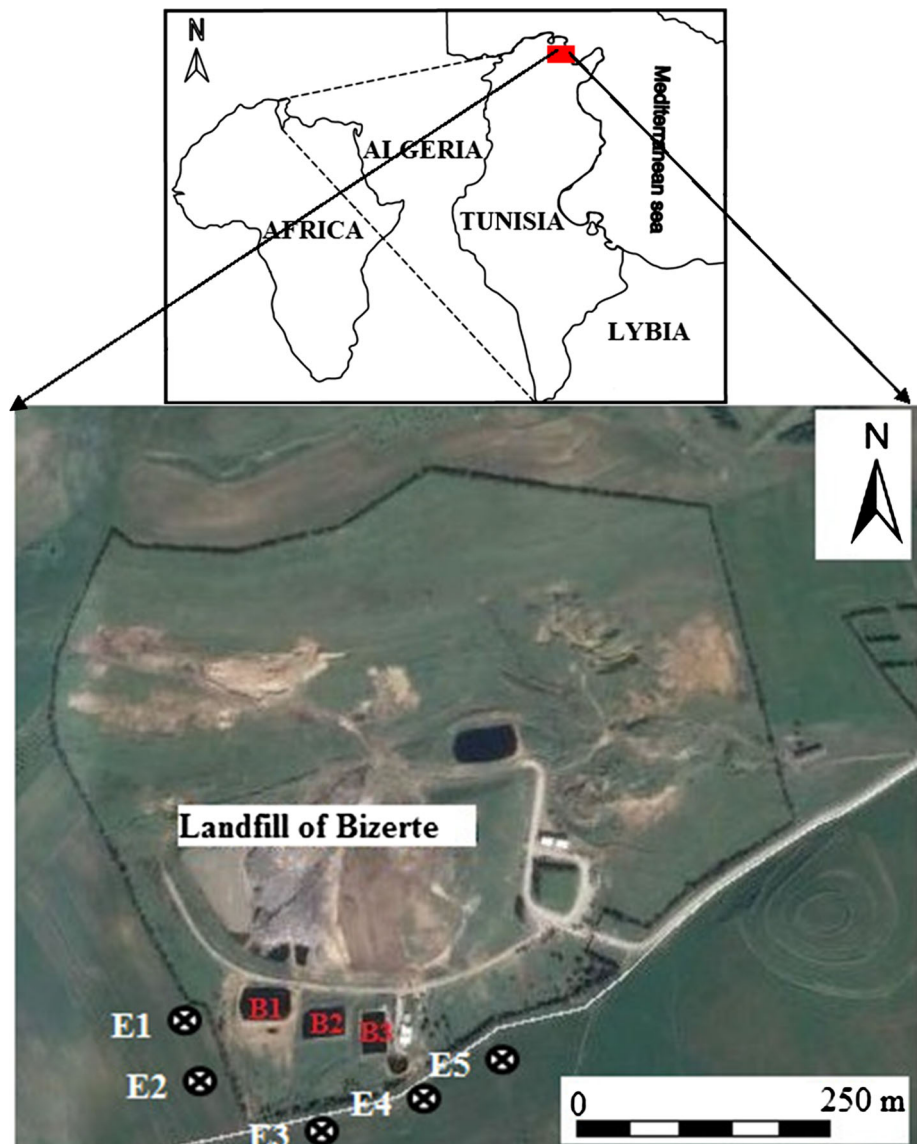
The soil stratigraphy of Bizerte landfill consists of clay intercalated with sand clay or marl. This impermeable clay

layer plays an important role in protecting the underlying confined aquifer from leachate infiltration.

### Sampling and analysis

For the purpose of the present investigation, five excavations (termed E1–E5) have been undertaken using a digger around the leachate storage basins for sampling purposes, in August 2014 (Fig. 1). Soil samples were collected at every 0.5-m interval (3 m depth from top surface). Thirty samples of soil were collected and stored in glass jars at 4 °C before being air-dried at room temperature (25 °C) and sieved through a 2-mm mesh. The soil samples were leached according to the NF 12457 methodology; heavy metals were estimated. Aliquots of soil samples were digested in HF–NO<sub>3</sub>–HClO<sub>4</sub> and stored at 4 °C prior to chemical analysis.

**Fig. 1** Localization of excavations points



Duplicate leachate samples were collected from 1 m depth at the three storage basins in August 2014 ( $T = 25\text{ }^\circ\text{C}$ ) (Fig. 1). Samples were stored at  $4\text{ }^\circ\text{C}$  before analysis.

The electrical conductivity (EC) and pH were measured by using a multi-parameter conductimeter (WTW Windaus LF 538) and a pH meter (WTW Windaus pH 538 with combine electrode) for leachate samples.

Chemical oxygen demand (COD) was measured following the MA-315 COD-1.0 (Centre d’expertise en analyse environnementale du QUEBEC 2003) and the biochemical oxygen demand ( $\text{BOD}_5$ ) was measured by using a BOD meter [BSB-controller Model 620 T (WTW)] for leachate samples.

Heavy metals (Fe, Pb, Cu, Cr, Zn, Ni, Cd and Mn) concentrations were determined using an Atomic Absorption Spectrometer Perkin-Elmer Analyst 200.

**Contamination assessment and data analysis**

*Geo-accumulation index*

The geo-accumulation index ( $I_{\text{geo}}$ ) introduced by Muller (1969) is used to assess metal pollution in soils. The index of geoaccumulation enables the assessment of contamination by comparing the current with background levels, and it could also be applied to assess the contamination of different environments. The following equation denotes the calculation of the index:

$$I_{\text{geo}} = \text{Log}_2 \left( \frac{C_n}{1.5B_n} \right), \tag{1}$$

where  $C_n$  is the measured concentration of the examined metal  $n$ ,  $B_n$  is the geochemical background concentration value (average crust) of the element  $n$ , and 1.5 is the background matrix correction factor that is included to correct possible background value variations due to lithogenic effects. According to Muller (1969), the  $I_{\text{geo}}$  for a metal is classified as follows: uncontaminated ( $I_{\text{geo}} \leq 0$ ) (Class 0); uncontaminated to moderately contaminated ( $0 < I_{\text{geo}} \leq 1$ ) (Class 1); moderately contaminated ( $1 < I_{\text{geo}} \leq 2$ ) (Class 2); moderately to heavily contaminated ( $2 < I_{\text{geo}} \leq 3$ ) (Class 3); heavily contaminated ( $3 < I_{\text{geo}} \leq 4$ ) (Class 4); heavily to extremely contaminated ( $4 < I_{\text{geo}} \leq 5$ ) (Class 5); and extremely contaminated ( $I_{\text{geo}} \geq 5$ ) (Class 6).

*Contamination factor*

The contamination factor (CF) is used to describe the contamination of a given toxic substance in the environment. In the version originally suggested by Hakanson (1980), the assessment of contamination was conducted through reference of the elemental concentrations to

preindustrial levels (Hakanson 1980). This parameter is expressed as:

$$\text{CF}_{\text{metal}} = \frac{C_{\text{metal}}}{C_{\text{background}}}, \tag{2}$$

where  $C_{\text{metal}}$  = metal concentration in soil sample;  $C_{\text{background}}$  = background value of that metal. The following criteria are used to describe the values of the contamination factor:  $\text{CF}_{\text{metal}} < 1$ , low contamination factor;  $1 \leq \text{CF}_{\text{metal}} < 3$ , moderate contamination factors;  $3 \leq \text{CF}_{\text{metal}} < 6$ , considerable contamination factors; and  $\text{CF}_{\text{metal}} \geq 6$ , very high contamination factor (Ghannem et al. 2014).

*Pollution load index*

The pollution load index (PLI) was proposed by Tomlinson et al. (1980) for detecting pollution which permits a comparison of pollution levels between sites and at different times. The PLI was obtained as a concentration factor of each heavy metal with respect to the background value. This parameter is expressed as:

$$\text{PLI} = \sqrt[n]{\text{CF}_1 \times \text{CF}_2 \times \dots \times \text{CF}_n}, \tag{3}$$

where CF is the contamination factor;  $n$ , number of metals. The pollution load index can be classified as no pollution ( $\text{PLI} < 1$ ), moderate pollution ( $1 < \text{PLI} < 2$ ), heavy pollution ( $2 < \text{PLI} < 3$ ), and extremely heavy pollution ( $3 < \text{PLI}$ ) (Zarei et al. 2014).

*Statistical analysis*

Correlation matrix and multivariate statistical analysis including principal component analysis (PCA) were

**Table 1** Physico-chemical characteristics of Bizerte leachate landfill

Parameters	Range	NT 106 002 <sup>a</sup>
pH	7.93–8.15	6.5–9
Electric conductivity (ms/cm)	32.5–45.8	NA
COD (mg O <sub>2</sub> /L)	16,200–18,113	1000
BOD5 (mg O <sub>2</sub> /L)	3500–4850	400
BOD5/COD	0.22–0.26	0.4
Fe (mg/L)	6.85–12.62	5
Cr (mg/L)	1.45–1.64	0.5
Zn (mg/L)	0.34–0.75	5
Cu (mg/L)	0.16–0.37	1
Cd (mg/L)	0.01–0.04	0.1
Ni (mg/L)	0.25–0.36	2
Pb (mg/L)	0.15–0.25	1
Mn (mg/L)	0.1–0.15	1

NA not available

<sup>a</sup> Norm for the wastewater drained to public sewer, Tunisia

performed using the XLSTAT statistical software package in order to evaluate associations among the investigated variables in the samples and to identify the most common pollution sources.

## Results and discussion

### Physico-chemical characteristics of leachate landfill

The data in Table 1 showed the physico-chemical properties of the studied leachate. All the collected leachate

samples were dark-colored and alkaline with pH range of 7.93–8.15. This may be attributed to the decrease in the concentration of free volatile acids due to anaerobic decomposition, as fatty acids can be partially ionized and contribute to higher pH values (Kanmani and Gandhimathi 2013). The relatively high value of electrical conductivity (32.5–45.8 ms/cm) indicates the presence of dissolved inorganic materials in the samples.

All samples were characterized with high COD values and low and low BOD<sub>5</sub>. The range of COD varies from 16,200 to 18,113 mg O<sub>2</sub>/L and the BOD ranges between 3500 and 4850 mg/L. The COD value is much higher than

**Table 2** Comparison of metal concentration in Bizerte landfill with similar studies in the world and relevant standards (mg/kg dry weight)

Station	Sample	Depth (m)	Pb	Cu	Cr	Zn	Ni	Cd
E1	S1.1	0.5	3.7	1.3	90.8	49.9	29.2	1.2
	S1.2	1	7.6	1.5	102.3	59	31.9	1.1
	S1.3	1.5	13.2	1.5	85.7	71.7	35.	1.1
	S1.4	2	12.1	1.6	100.9	76.7	39	0.9
	S1.5	2.5	10.7	1.6	91.8	76.8	29.7	1
	S1.6	3	7.2	1.7	92.9	68.3	34.1	1.1
E2	S2.1	0.5	8.2	1	67.2	20.9	19.8	0.8
	S2.2	1	7.8	1	72.5	23.2	20.6	1
	S2.3	1.5	7.8	1.3	79.3	28.5	21.1	0.9
	S2.4	2	4.8	1.4	76.4	41.9	24.5	0.9
	S2.5	2.5	2.5	1.4	75.8	45.5	24.3	1
	S2.6	3	6.5	1.4	91.2	41.3	25.7	1.1
E3	S3.1	0.5	5.3	1.3	64.5	28.1	20.8	0.7
	S3.2	1	6.8	1.4	90.5	37.6	31.8	0.6
	S3.3	1.5	8.8	1.4	83.8	53.8	31.7	0.5
	S3.4	2	7.2	1.2	73.1	48.4	28	0.9
	S3.5	2.5	4.8	1.2	81.8	30.1	24.7	0.7
	S3.6	3	7.5	1.6	109.9	57.3	33	1.2
E4	S4.1	0.5	6.2	0.4	36.9	33.6	11.3	0.3
	S4.2	1	3.7	0.1	34.4	40.2	10	0.3
	S4.3	1.5	3.5	1	76.2	41.6	22.8	0.4
	S4.4	2	6.6	1.3	90.9	47.1	25.9	0.5
	S4.5	2.5	6.2	1.4	104.2	49.4	27.2	0.7
	S4.6	3	7.6	1.6	94.1	48.6	33.5	1
E5	S5.1	0.5	3.4	0.7	42.5	9.7	4.7	0.7
	S5.2	1	3.7	0.6	45.5	10.2	5.2	0.6
	S5.3	1.5	5.2	0.5	47.5	11.6	6.6	0.5
	S5.4	2	4	0.7	51	13.8	8.8	0.5
	S5.5	2.5	1.8	0.7	46.8	15.4	10.4	0.5
	S5.6	3	2.8	0.5	50.4	7.6	4.6	0.3
Range			1.8–13.2	0.1–1.7	34.4–109.9	7.6–76.8	4.6–39	0.3–1.2
Ivoirian landfill <sup>a</sup>			10.3–1500	20–369.7	27.7–125	18.6–1163.7	–	1–11.5
Greek landfill <sup>b</sup>			3–93	8–356	4–172	6–344	6–64	0.5–19
Morocco landfill <sup>c</sup>			62–656	1–11.5	52–76	63–68	47–62	–
European norm			50–300	50–140	50–100	150–300	30–75	1–3
AFNOR			100	100	150	300	50	2

<sup>a</sup> Kouame et al. (2006)

<sup>b</sup> Kasassi et al. (2008)

<sup>c</sup> Nhari et al. (2014)

that of domestic wastewater and it is higher than the Tunisian Standards for discharge in public sewer (NT 106 002: COD = 1000 mg/L and BOD5 = 400 mg/L), therefore discharge into the sewer is not permitted. It is commonly known that organics in leachate are characterized by different biodegradability. A measure of biodegradability is BOD5/COD ratio (Zayen et al. 2010). The BOD5/COD ratio (0.22–0.26) indicated a mature landfill.

Landfill leachate sampled from Bizerte landfill seems to be highly loaded by ions and heavy metals (Table 1). Heavy metal concentrations showed the following order: Fe > Cr > Cu > Zn > Pb > Ni > Mn > Cd. The high level of Fe indicates the dumping of steel scrap in the landfill. The average concentrations of Zn, Cu, Cd, Pb, Ni and Mn were well below the Tunisian regulations for discharge in a public sewer, whereas Fe and Cr exceeded the permissible limits of Tunisian regulations. Generally, the metallic load of studied leachate corresponded to a typical composition of leachate generated by urban landfill nationally and internationally (Table 1).

**Site lithology**

The physical properties (soil profile) of the in situ soil for each of the five excavations (E1–E5) are as follows:

E1 (37°16'04"N/9°46'34"E, excavated 35 m away from the storage basins B1 at a depth of 3 m) showed topsoil and a layer of greenish compact clay (0.9 m) followed by another thin layer of brown clay (2 m).

E2 (37°16'44"N/9°46'36"E, distant of 75 m of the leachate basin storage B1 with a final depth of 3 m): after the topsoil, 0.6 m greyish clay was found, followed by greenish clay until the final excavations depth.

E3 (37°15'60"N/9°46'38"E, 100 m from the storage basin B2): with a final depth of 3 m, yellow clay was found down to 1.8 m, whereas greyish clay was located next and down to the final excavation depth.

E4 (37°16'02"N/9°46'41"E, 60 m from the storage basin B3 and 85 m from the storage basin B2): it consisted mainly of yellow compact clay (1.5 m), then brown clay sandy until 3 m depth.

E5 (37°16'08"N/9°42'84"E, 50 m from the storage basin B3): after the topsoil 2.3 m greyish clay compact clay was found. Then, yellow silty clay layer reached 0.6 m thick.

As for the distribution of the different heavy metals versus depth, it can be mentioned, first that the lowest concentrations are for Cd, Cu, Pb and Ni and the highest for Cr and Zn. Furthermore, heavy metal concentrations recorded in the clay sandy level were lower than those of the clay levels, confirming the retention of these compounds by clayey soils.

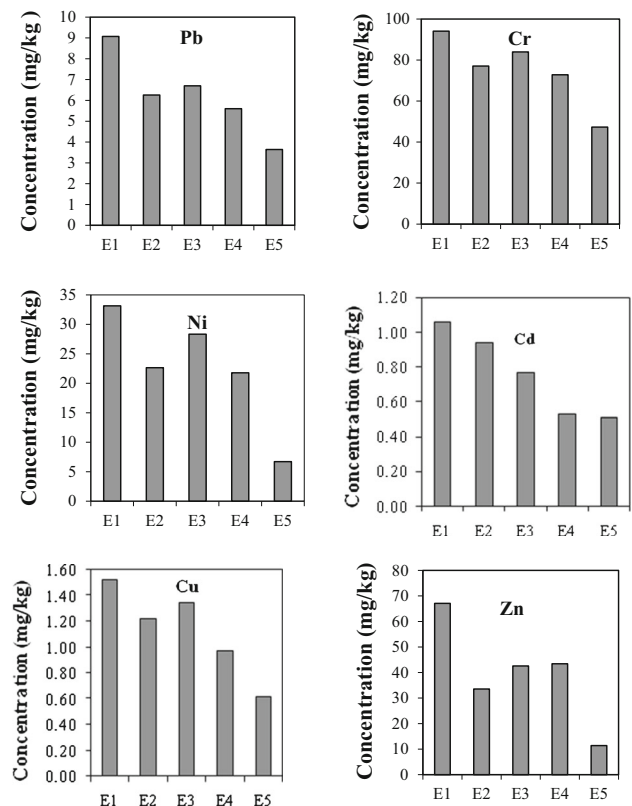
The average metal leaching values found in this study were also compared with values reported from other

studies. For almost all the samples, the heavy metals contents are close to, or even less than those measured values in the Greek, Morocco and the Ivoirian landfills (Kouame et al. 2006; Kasassi et al. 2008; Nhari et al. 2014).

For almost all the samples, the heavy metals contents are close to, or even less than the standard values proposed by the European norm for non-polluted soils (IEEP 2009), and for the French association of normalization (AFNOR 1996) (Table 2).

Heavy metals distribution among the five sites can be seen in Fig. 2. The mean concentrations (in mg/kg dry weight) of Pb, Cr, Cd, Cu, Zn and Ni from the five sites were, respectively, 9.07, 94.08, 1.06, 1.52, 67.08 and 33.15 from E1 and 6.26, 77.06, 0.94, 1.22, 33.55 and 22.65 from E2 and 6.7, 83.93, 0.77, 1.34, 42.56, 42.56 and 28.34 from E3 and 5.6, 72.78, 0.53, 0.97, 43.42 and 21.79 from E4 and 3.46, 47.28, 0.51, 0.61, 11.37 and 6.71 from E5.

Excavations E1 and E4 showed a decrease of heavy metals from a depth of 2 m to the bottom. This is probably due to the insulated clay being at a high level. It is also important to notice that the heavy metals recorded in excavation E4 (85 m to the storage basin B2) were higher than the excavation E3 (100 m to the storage basins B2), which proved that lateral migration of pollutants was less important than the vertical one.



**Fig. 2** Mean metal concentrations (mg/kg dry weight) in soils of each excavation

The concentrations of heavy metal in the studied soils samples followed the order of  $E1 > E3 > E2 > E4 > E5$  for Pb, Cr, Cu and Ni and  $E1 > E4 > E3 > E2 > E1$  for Zn (Fig. 2).

### Metal contamination levels

The  $I_{geo}$  values for selected metals at each sampling site are listed in Table 3. The results of the geo-accumulation index showed that the greater part of the samples could be considered as unpolluted for Cr, Cu, Zn, Pb and Ni. The contamination levels of these metals based on  $I_{geo}$  values were assessed to be uncontaminated ( $I_{geo} < 0$ ) (Class 0). According to  $I_{geo}$  values of Cd, soils can be considered as uncontaminated to moderately contaminated (Class 1) for E4 and E5, moderately contaminated (Class 2) for E1, E2 and E3.

The CF and PLI are widely used to evaluate the degree of heavy metal pollution in the soils (Bhuiyan et al. 2010).

The calculated CF and PLI for the studied metals in soils of Bizerte landfill are listed in Table 4. The CF values for Cd (3.81) and Cr (1.06) are relatively high in the samples studied, indicating that the Bizerte landfill soils are highly polluted by these two metals. The mean CF values for the metals in the study area follow the decreasing in order Ni (0.45) > Pb (0.39) > Zn (0.31) > Cu (0.04) and demonstrated low contamination levels. The PLI values calculated for each site are also shown in Table 4. The values of PLI were found to be low in all the studied samples and varied between 0.16 and 0.7, indicating that the studied stations in Bizerte landfill are in low pollution status considering the total of the studied metals.

Pearson correlation coefficient of the heavy metals and  $p$  values (probability of no correlation) for statistical hypothesis testing are listed in Table 5. The matrix shows the strength of the linear relationships between each pair of variables. Cr shows a marked positive correlation with Cu

**Table 3** Geo-accumulation index for concentration of metals soils of Bizerte landfill and its grading classification

Metal	Excavation	$I_{geo}$ range	Classification
Pb	E1	−2.72 to −0.87	Uncontaminated
	E2	−3.24 to −1.56	Uncontaminated
	E3	−2.34 to −1.44	Uncontaminated
	E4	−2.80 to −1.67	Uncontaminated
	E5	−3.78 to −2.22	Uncontaminated
Cr	E1	−0.31 to −0.06	Uncontaminated
	E2	−0.66 to −0.22	Uncontaminated
	E3	−0.72 to 0.05	Uncontaminated to moderately contaminated
	E4	−1.63 to −0.03	Uncontaminated
	E5	−1.33 to −1.06	Uncontaminated
Cd	E1	1.58 to 1.94	Moderately contaminated
	E2	1.49 to 1.81	Moderately contaminated
	E3	0.74 to 2.00	Moderately contaminated
	E4	0.14 to 1.74	From uncontaminated to moderately contaminated
	E5	0.32 to 1.22	From uncontaminated to moderately contaminated
Cu	E1	−5.16 to −4.86	Uncontaminated
	E2	−5.63 to −5.13	Uncontaminated
	E3	−5.32 to −4.94	Uncontaminated
	E4	−8.91 to −4.95	Uncontaminated
	E5	−6.61 to −6.07	Uncontaminated
Zn	E1	−1.93 to −1.31	Uncontaminated
	E2	−3.19 to −2.07	Uncontaminated
	E3	−2.76 to −1.73	Uncontaminated
	E4	−2.50 to −1.95	Uncontaminated
	E5	−4.64 to −3.63	Uncontaminated
Ni	E1	−1.36 to −0.94	Uncontaminated
	E2	−1.92 to −1.55	Uncontaminated
	E3	−1.85 to −1.18	Uncontaminated
	E4	−2.90 to −1.16	Uncontaminated
	E5	−4.02 to −2.85	Uncontaminated

**Table 4** Contamination factors (CF) and pollution load index (PLI) of soil heavy metals in the Bizerte landfill

Station	Sample	Depth (m)	Contamination factors (CF)						PLI
			Pb	Cu	Cr	Zn	Ni	Cd	
E1	S1.1	0.5	0.23	0.04	1.28	0.39	0.58	5.75	0.50
	S1.2	1	0.48	0.05	1.44	0.46	0.64	5.50	0.61
	S1.3	1.5	0.82	0.05	1.21	0.56	0.70	5.50	0.68
	S1.4	2	0.76	0.05	1.42	0.60	0.78	4.50	0.70
	S1.5	2.5	0.67	0.05	1.29	0.60	0.59	5.00	0.65
	S1.6	3	0.45	0.05	1.31	0.54	0.68	5.50	0.63
E2	S2.1	0.5	0.51	0.03	0.95	0.16	0.40	4.20	0.40
	S2.2	1	0.48	0.03	1.02	0.18	0.41	4.75	0.42
	S2.3	1.5	0.49	0.04	1.12	0.22	0.42	4.50	0.46
	S2.4	2	0.30	0.04	1.08	0.33	0.49	4.50	0.47
	S2.5	2.5	0.16	0.04	1.07	0.36	0.49	5.00	0.43
	S2.6	3	0.41	0.04	1.28	0.33	0.51	5.25	0.52
E3	S3.1	0.5	0.33	0.04	0.91	0.22	0.42	3.50	0.39
	S3.2	1	0.42	0.04	1.28	0.30	0.64	3.00	0.49
	S3.3	1.5	0.55	0.04	1.18	0.42	0.63	2.50	0.52
	S3.4	2	0.45	0.04	1.03	0.38	0.56	4.50	0.51
	S3.5	2.5	0.30	0.04	1.15	0.24	0.49	3.50	0.42
	S3.6	3	0.47	0.05	1.55	0.45	0.66	6.00	0.63
E4	S4.1	0.5	0.38	0.01	0.52	0.26	0.23	1.50	0.25
	S4.2	1	0.23	0.01	0.49	0.32	0.20	1.50	0.18
	S4.3	1.5	0.22	0.03	1.07	0.33	0.46	2.00	0.36
	S4.4	2	0.41	0.04	1.28	0.37	0.52	2.50	0.47
	S4.5	2.5	0.38	0.05	1.47	0.39	0.54	3.50	0.52
	S4.6	3	0.47	0.05	1.33	0.38	0.67	5.00	0.58
E5	S5.1	0.5	0.21	0.02	0.60	0.08	0.09	3.50	0.20
	S5.2	1	0.23	0.02	0.64	0.08	0.10	3.00	0.20
	S5.3	1.5	0.32	0.02	0.67	0.09	0.13	2.50	0.22
	S5.4	2	0.25	0.02	0.72	0.11	0.18	2.25	0.24
	S5.5	2.5	0.11	0.02	0.66	0.12	0.21	2.50	0.21
	S5.6	3	0.17	0.02	0.71	0.06	0.09	1.50	0.16
	Mean		0.39	0.04	1.06	0.31	0.45	3.81	0.43

**Table 5** Pearson’s correlation coefficients for Pb, Cu, Cr, Zn, Ni and Cd in the soil samples of Bizerte landfill

	Pb	Cu	Cr	Zn	Ni	Cd
Pb	1					
Cu	0.58	1				
Cr	0.56	0.93	1			
Zn	0.68	0.74	0.75	1		
Ni	0.80	0.92	0.91	0.88	1	
Cd	0.46	0.58	0.69	0.55	0.66	1

Significant values ( $p < 0.05$ ) are shown in bold

( $r = 0.93, p < 0.05$ ) and Pb ( $r = 0.56, p < 0.05$ ). Similarly, Ni shows strong positive correlation with Cu ( $r = 0.92, p < 0.05$ ), Cr ( $r = 0.91, p < 0.05$ ), Zn ( $r = 0.88, p < 0.05$ ) and Pb ( $r = 0.80, p < 0.05$ ). Cd also shows marked positive correlation with Cr ( $r = 0.69, p < 0.05$ ), Ni ( $r = 0.66, p < 0.05$ ) and weak positive

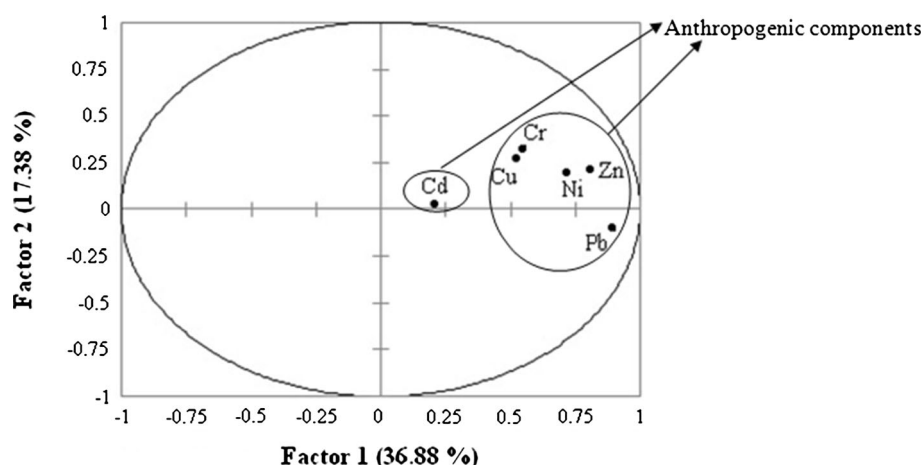
correlation with Cu ( $r = 0.58, p < 0.05$ ) and Pb ( $r = 0.46, p < 0.05$ ). These positive correlations indicate that the contents of heavy metals in the Bizerte landfill soils probably originated from the same pollutant sources.

The principal component analysis applied to all metal concentrations resulted essentially in three principal components. The threshold of significance considered for  $p < 0.05$  is equal to 0.325 after the student test ( $n = 30$ ). The significant correlations between selected parameters (variables) and the components represent approximately 54 % of the total variance. The contribution of the first, second and third PCs of the total variance are 36, 88 and 17.38 %, respectively.

Over the  $1 \times 2$  factorial plane (presenting the maximum of inertia), one can clearly show two distinct groups (Fig. 3):

The first group (G1) which is positively displayed over factor 1, is representative of Pb, Cu, Cr, Ni and Zn. These

**Fig. 3** Projection of variables (metal concentrations) in the (1 × 2) factorial plane



metals present among each other highly significant positive correlation coefficients. They may be discharged simultaneously and have a similar behavior. The presence of Zn and Pb in this group would suggest possible sources of industrial contamination in the vicinity (Ennouri et al. 2010). This finding could mean that these metals have a common anthropogenic source and have similar properties (Calace et al. 2005).

The second group (G2), which is positively displayed over axis 2, is articulated around Cd. This metal showed significant positive correlation coefficients, but they did not show any correlations with metals of the first group, implying that it is independent to the other metals. This clearly shows the possibility of different source to the other trace elements.

## Conclusion

Heavy metal concentrations (Pb, Cr, Cd, Cu, Zn and Ni) were examined in 30 soil samples from Bizerte landfill, northeastern part of Tunisia. This work aimed at analyzing the metal pollution status and identifying the correlations between these examined metals. The results of the geoaccumulation index ( $I_{geo}$ ) showed that the most of the soils samples could be considered as unpolluted (Class 1) for Cr, Cu, Zn, Pb and Ni, while the values of Cd demonstrated to have moderate contamination (Class 2) based on  $I_{geo}$  values. The results of the contamination factor (CF) also demonstrated low contamination levels for Ni, Pb, Zn, and Cu and moderate contamination levels for Cr and Cd. The values of pollution load index (PLI) were found to be low in all the studied samples, indicating that the studied excavations in Bizerte landfill are in low pollution status considering the total of the studied metals.

The statistical analysis of data by PCA showed that anthropogenic inputs derived from leachate are among the

contamination sources that directly impacted the soils of Bizerte landfill. Finally, these results can be used as an indicator in the identification of pollution sources for heavy metals, and can assist the decision-makers to evaluate the heavy metal pollution status in Tunisian landfills.

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