

Assessment of soil trace metal contamination of an uncontrolled landfill and its vicinity: the case of the city of 'Targuist' (Northern Morocco)

K. Andaloussi^{(a)*}; H. Achtak^(b); C. Nakhcha^(c); K. Haboubi^(d); M. Stitou^(a)

^(a) Laboratory of Water and Environmental Studies & Analysis, Department of Chemistry, Faculty of Sciences, Tetouan, Morocco

^(b) Department of Biology, Environment and Health Research Team, Faculty of Polydisciplinary, Safi, Morocco

^(c) Department of Geology, Faculty of Polydisciplinary, Safi, Morocco

^(d) Laboratory of Engineering Sciences and Applications, National School of Applied Science, Al Hoceima, Morocco

Abstract

This study aims to assess, for the first time, soil Trace Metal Elements (TME) contamination level in an uncontrolled landfill and its vicinity of 'Targuist' (town in northern Morocco). Soil samples were collected at two depths (20 and 40cm) from 16 sampling sites. Samples were characterized for their physicochemical parameters (pH, electrical conductivity (EC), organic matter (OM) and total organic carbon (TOC)) and for their TME (copper (Cu), zinc (Zn), cadmium (Cd) and chromium (Cr)) using atomic absorption spectroscopy (ASS). The results show no significant differences between soils sampled at 20cm or 40cm depths regarding the tested parameters. While significant differences between sampling sites In landfill and Out landfill is observed particularly regarding pH, CaCO₃, TOC, and Cd. Overall, our results show that soil physicochemical properties follow a spatial variability with decreasing values moving away from the landfill. Regarding TME soil contents, our results show contamination levels in most of the sampling sites of the study area. Furthermore, the total TME concentrations in soils vary according to the type of the studied metal and to the sampling site. Zn, Cu and Cd show significant positive correlations with pH. However, Cd has no correlation with any other trace elements or soil physicochemical properties. Meanwhile, Cr shows a significant negative correlation with Zn and Cu. OM, TOC, CaCO₃ and EC are strongly and positively correlated. These results are well illustrated in the outcomes of the Principal Components Analysis and Hierarchical Cluster Analysis.

* Corresponding author:

kandaloussi@uae.ac.ma

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1. Introduction

Recently, Morocco has experienced noticeable economic, demographic and urban growth, leading to a constant increase in solid waste. For a population of 36 million, Morocco produces more than 6 million tonne of household/industrial solid waste per year [1]. The elimination of waste by dumping in landfill remains the most popular method given its simplicity. However, this method has serious consequences both on public health and the environment as well as on the country's economic potential, namely tourism and the attractiveness of investments[2]. To mitigate the various associated risks of this issue, Morocco has undertaken a series of strategic actions to reform the household waste management sector to meet adequate sanitary and environmental conditions. These actions include the implementation of Law 28-00 and its implementing decrees, as well as the development of the National Household Waste Program (PNDM), which aims to upgrade the management of household waste until 2022. Despite these efforts, the country still has more than 220 landfills, often classified as illegal/uncontrolled, compared to only around 20 controlled landfills[3]. The town of Targuist has an uncontrolled landfill (Fig. 1), which receives mixed waste (household waste, inert waste, hospital waste) without prior sorting [4]. Landfill is responsible for direct input of trace metals into the soil and nearby environment [5]. Several studies have highlighted the contamination of landfills and their surroundings by trace metals [6];[7];[8];[9]. In fact, trace metals elements are not degradable by natural chemical or biological processes; hence, their accumulation persists in the environment for long periods[10]. This accumulation can easily reach toxic levels for human[11]. The mobility and bioavailability of trace elements are generally governed by soil physicochemical prevailing conditions such as pH, ionic exchange capacity (or EC) and organic matter content[12]. Soil occupies a central place in the exchanges balance of matter[13]. Soil contamination by trace elements increases the risk of their transfer along the food chain [14]. Trace elements are distributed in soils in various forms, including in exchangeable forms between clays and organic matter, as well as in the form of complexes associated with organic molecules. They can be included in crystalline phases or directly adsorbed on particles of oxides or hydroxides of iron, aluminum and manganese, and they can be retained in the remains of a living organism. A high pH limits the solubility and bioavailability of all ionic molecules in soil [33] cited by [15]; [9]. The ionic strength of the medium increases the solubility of trace elements [16]; [17]. High OM are common features among landfills in Morocco. OM of soil, by its large specific surface, contributes to the fixation of trace elements by complexation or by chemisorption. [33]. Soil flora (microorganisms) can contribute to the fixation as well as the mobility of trace elements by producing acidic forms for instances [18]. CaCO_3 exerts a chemical effect soil pH and thus reducing trace elements solubility. Thanks to the Ca^{2+} ions, CaCO_3 contributes to the formation and the stability of the clay-humic complex, hence increasing the cation exchange capacity of the substrate. Like all cationic metals, the behavior of Cd in soil is strongly influenced by pH[19]. Copper is a chalcophilic element, which is found associated with sulphides, along with lead, cadmium and zinc. In calcareous soils, as the case of Targuist landfill soil, the specific adsorption of Cu to CaCO_3 surfaces – with alkaline pH- can control copper concentrations in soil solution [20]. Zn is considered to be very mobile. However, Zn can easily adsorbed by organic and inorganic soil constituents[21]. As a cationic metal, the adsorption of Zn increases with pH [20]. For these reasons, the objective of this study is to describe the physicochemical characteristics of the studied landfill soil, and to determine its total concentration of some trace metals namely; Cadmium (Cd), Chromium (Cr), Copper (Cu), and Zinc (Zn).

2. Materials and methods

2.1. Presentation of the study area

The uncontrolled landfill is located about 1.5 km southeast of the town of Targuist (Eastern Rif of Morocco), about 500m north of the N8 national road (Figure 1). The altitude of the landfill varies between 1007 and 1013m and extends over an area of 1209m². A wadi flows in a thalweg located 170m south of the landfill in an easterly direction and a small canyon originates south of the landfill and continues southeast toward the wadi. The site currently receives around 19 tonne/day of mixed waste including household waste, inert waste and medical waste without any pre-treatment. Dumping is the only way to manage mixed waste at the landfill. This situation is complex and represents a real threat to the health of the population and the quality of the surrounding environment.

2.2. Sampling

The assessment of trace metals contamination level in soil of the study area was based on characterizing the physicochemical parameters and quantifying the trace metals content of 16 selected sampling sites located within and surrounding the landfill (Figure 2). The lack of leachate recovery system in the landfill allows its infiltration and run off to surrounding land. Sampling sites are selected on the basis of their immediate exposure to leachate. In addition, we made sure that the sampling sites were selected according to natural runoff drain. Before any sampling, stones, waste and flora were eliminated from aboveground of each site, then sampling was carried out at two different levels/depth: at 20 cm (0-20cm) depth and at 40 cm (20-40cm) depth. To ensure sampling reliability, a 1m² quadrat was used. A manual auger with 20 cm high was introduced at the level of the four vertices and in the center of the quadrat. Soils of the same depth were mixed and then the quartering method was applied to obtain homogeneous and representative samples. The resulting samples were stored in an airtight clean plastic bag, labeled and packed in the freezer until the day of analysis

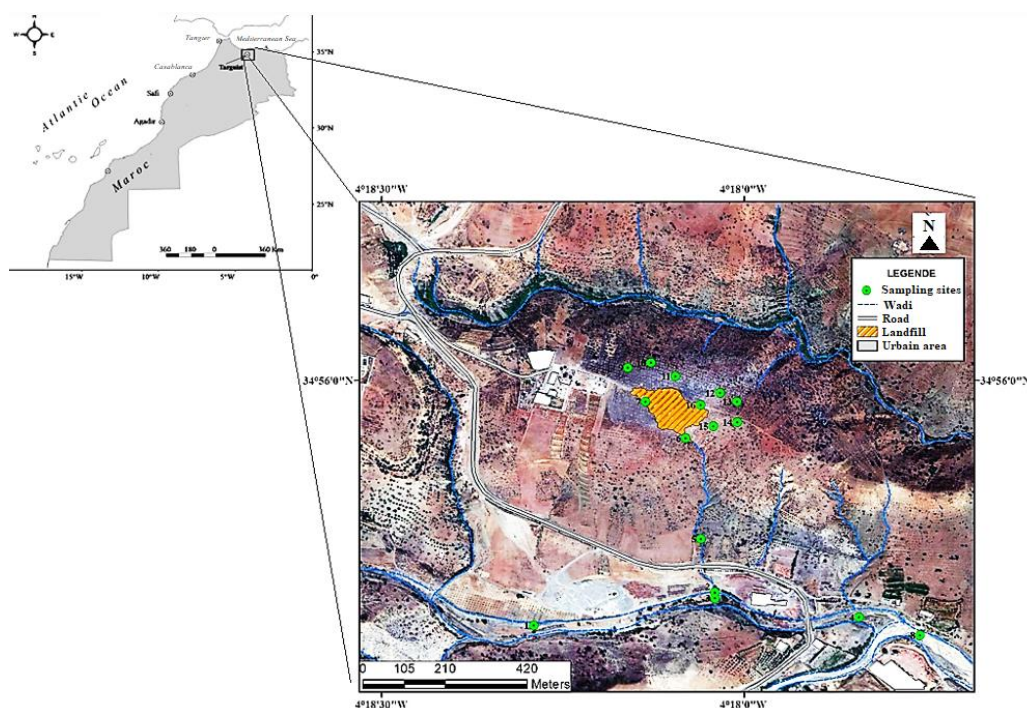


Figure 1. Geographical location of the study area and soil sampling sites.

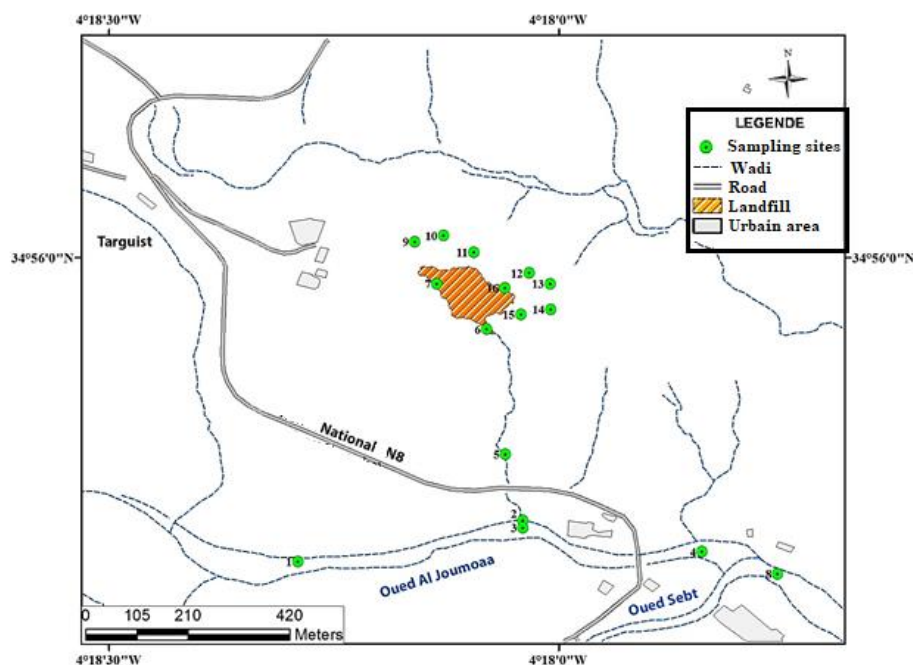


Figure 2. Geographical location of soil sampling sites.

2.3. Physicochemical characterization

The physicochemical characterization of soil samples was carried out at the Polydisciplinary Faculty of Safi (Morocco) within the laboratory of the "Environment and Health" research team. **pH** To measure pH, a suspension of soil (1g) with 2.5ml of distilled water was prepared, stirred for 30 min (AFNOR X 31-103), and decanted for 2h. The pH measurements were made using a multi-parameter (phenomenal ® MU 6100 L, VWR International, Vienna, Austria) previously calibrated (pH = 4; pH = 10 then pH = 7).

Electrical conductivity (EC)

To measure EC, soil solution (1g / 5ml) was prepared, stirred for 30 min and decanted for 1 hour (NFT 90-031, 1977). The electrical conductivity measurements were made using a multi-parameter (phenomenal ® MU 6100 L, VWR International, Vienna, Austria).

Organic matter (OM)

The level of organic matter is obtained after burning a mass of sample previously dried at 105°C (mass initial - M_i), in a muffle furnace at 650°C for 6 hours (mass final - M_f). The organic matter content is calculated according to the following expression (NF U 44-160):

$$OM \text{ in } \% \text{ of } DM = \frac{M_i - M_f}{M_i} \times 100 \quad (1)$$

With OM: Organic matter; DM : dried matter; M_i : Initial mass; M_f : final mass

After calcination at 650 °C, the combustion of organic material is complete. The content of total organic carbon (TOC) is calculated from the rate of organic matter according to the following formula:

$$TOC (\%) = \frac{OM(\%)}{1,72} \quad (2)$$

With 1,72 is the conversion factor according to Howard, 1965 and Denis Baize 2012, based on the idea that carbon represent 58% of OM

Quantification of total content of trace-metal elements (TME)

Based on previous work, our choice was privileged on the analysis of Cd, Cr, Cu and Zn by atomic absorption spectroscopy (AAS). Samples intended for trace metal analysis are pre-sieved using a 2mm mesh and finely ground. A mass of 0.5 g of our sample was subjected to liquid mineralization in an acidic medium (4 mL of hydrofluoric acid, 2 mL of a mixture of hydrochloric acid (37%) and nitric acid (67%)) at 120 °C for 4 hours in accordance with the methodology indicated by [22]. The mineralized sample was taken up in 25 mL of bi-distilled water to determine trace metallic elements using a spectrophotometer of flame atomic absorption (AI 1200, Aurora Instruments Limited, Canada).

2.4. Statistical analyzes

The data were statistically described, then a correlation matrix coupled with the ascending hierarchical classification (AHC) and the principal component analysis (PCA) were presented in order to highlight the intensity of the relationship between the physico-chemical parameters and the trace metal elements.

3. Results and discussion

3.1. Physicochemical characteristics of the samples analyzed

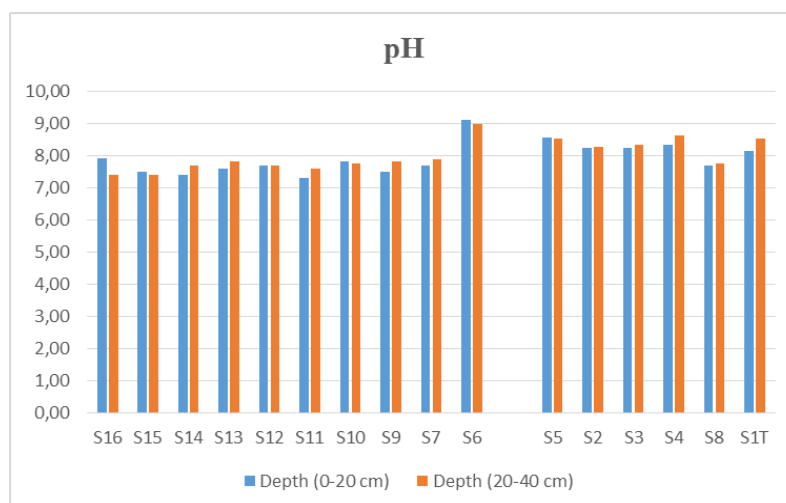


Figure 3: pH of soil samples in landfill (S16-S6) and off landfill (S5-S1T) of 16 sampling sites at two depths (20cm & 40cm).

Table 1. Averages concentration of physicochemical parameters with *p* value of *t*-Test for 20 cm & 40 cm depths

N = 16	Depth	Means \pm SE	P value of t-test
pH	20cm	7.915 \pm 0.120	0.614
	40cm	8.001 \pm 0.117	
CE	20cm	457.450 \pm 176.373	0.981
	40cm	463.768 \pm 191.407	
MO	20cm	9.832 \pm 0.934	0.938
	40cm	9.729 \pm 0.921	
CaCO ₃	20cm	11.993 \pm 1.023	0.973

TOC	40cm	12.039±0.854	0.933
	20cm	5.687±0.522	
	40cm	5.625±0.523	

The pH of our soil samples is overall basic ($\text{pH} > 7$), with a maximum value of 9.1 recorded for site 6 and a minimum value of 7.3 for site 11 (Figure 3). pH values show a slight tendency to increase off landfill (8.266 ± 0.084 versus 7.773 ± 0.103), but no significant difference between 20 & 40cm depths (7.915 ± 0.120 versus 8.001 ± 0.117) (Tables 1 & 2).

In our work, the pH values measured in the landfill of Targuist are similar to those documented in the landfills of Beni Mellal [8] and Tangier [15].

Table 2. Averages of concentration of physicochemical parameters for In & Off landfill sampling sites, with p value of t-Test (* significant difference at 0.05 level)

N (in)= 20 N(out)= 12	In/Out	Means \pm SE	P value of t-test
pH*	In Landfill	7.773 ± 0.103	0.003
	Off landfill	8.266 ± 0.084	
EC	In Landfill	584.010 ± 200.766	0.121
	Off landfill	254.941 ± 31.401	
OM*	In Landfill	11.771 ± 0.688	<0.001
	Off landfill	6.463 ± 0.405	
CaCO ₃ *	In Landfill	14.094 ± 0.671	<0.001
	Off landfill	8.552 ± 0.432	
TOC*	In Landfill	6.750 ± 0.389	<0.001
	Off landfill	3.833 ± 0.270	

Electrical conductivity (EC)

The electrical conductivity is the capacity of the soil solution, by means of respective ions, to conduct electric current [23], so it gives us information on the salinity of the soil based on the classification of [35]. The average values of EC (Figure 4) of different sites varies between $457.45 \pm 176.37 \mu\text{s/cm}$ for 20cm depth (EC_{20}) and $463.76 \pm 191.40 \mu\text{s/cm}$ for EC_{40} . Generally, there is no significant differences between EC_{20} and EC_{40} (Table 1). In addition, site 7 shows the highest EC values for both depths. Overall, there is no significant differences between sites In ($584.010 \pm 200.766 \mu\text{s/cm}$) and Out ($254.941 \pm 31.401 \mu\text{s/cm}$) of landfill (Table 2). The EC results, and according to the classification of [35], indicate that the landfill soil is unsalted to slightly salty (Table 3). The strong EC recorded at site 7 is believed to be due to the phenomenon of mineralization, which occurs following the burning of the waste rich in OM, in addition to the stagnation of the leachate. According to [24], EC is a very good indicator of the diffusion of possible leach products from a mass of a waste. The values of EC are very low compared to those recorded in Tangier and Beni Mellal landfills. Thus, we can expect a significant immobilization of TME in Targuist landfill.

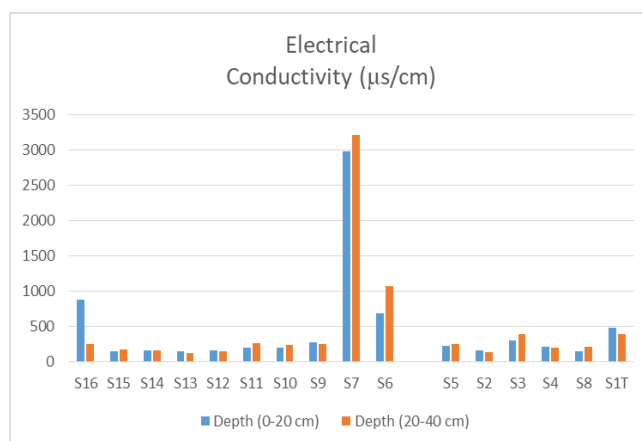


Figure 4: EC of soil samples taken at two depths

Table 3: Class of soil quality according to the scale of [35] Durand (1983)

CE (µs/cm)	Soil quality
0 to 500	Not salty
500 to 1000	Slightly salty
1000 to 2000	Salty
2000 to 4000	Very salty
over 4000	Extremely salty

Organic material

The content of organic matter (OM) in the soil samples (Figure 5) showed no significant differences between depths ($OM_{20}=9.832\pm0.934$ mg/kg; $OM_{40}=9.729\pm0.921$ mg/kg), while there is significant difference in OM content between sites in landfill (11.771 ± 0.688 mg/kg) and sites out of landfill (6.463 ± 0.405 mg/kg). This variability of values is close to that observed in Tangier landfill [9]. Thought, all in landfill sites show significant values of OM, the maximum value was recorded for site 7. This is due to the reception of the fermentable material, which constitutes the most important fraction in the physical composition of household waste [6]; [4]; [25]

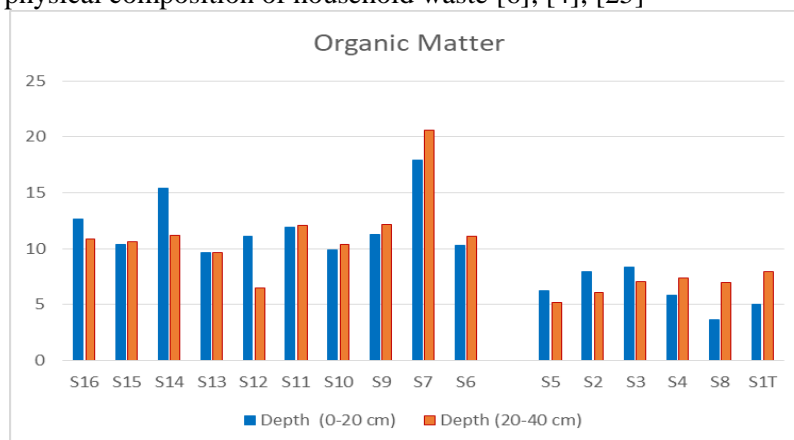


Figure 5: Percentage of organic matter (OM) in soil samples for both depths 0-20cm and 20-40 cm

Total organic carbon (TOC)

The TOC in sampled soil (Figure 6) follows the same trend as OM. The sites located in landfill, as well as the neighboring sites containing vegetation, show significant TOC contents, while the sites at the edges of the landfill and the wadi show relatively lower values. We noted as well the maximum value of TOC recorded for Site 7 (11.89%).

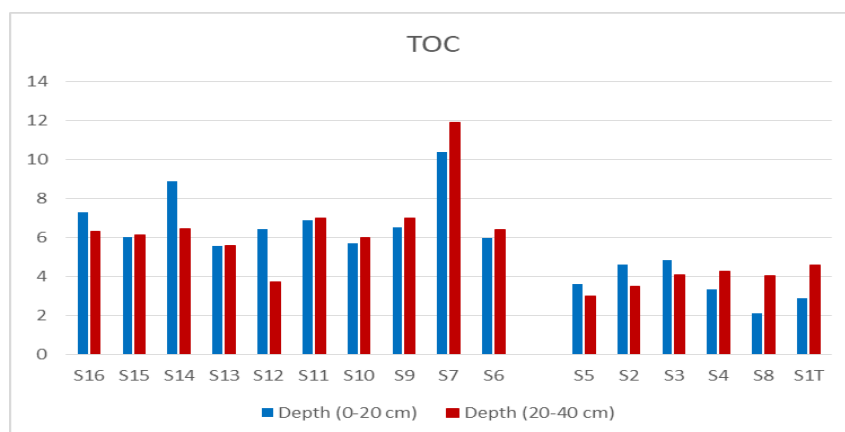


Figure 6: TOC percentage content of soil samples for both 20 and 40 cm depths

Calcium carbonate

A limestone soil can be recognized by its whitish color due to the large amount of chalk, generally comes from marine deposits, composed mainly of calcium carbonate (CaCO_3). All studied sites show values of CaCO_3 varying between 6 and 21% (Figure 7) with no significant difference between depths (Table 1). However, there is significant difference between sites in landfill (14.094 ± 0.671 mg/kg) and sites out of landfill (8.552 ± 0.432 mg/kg) (Table 2).

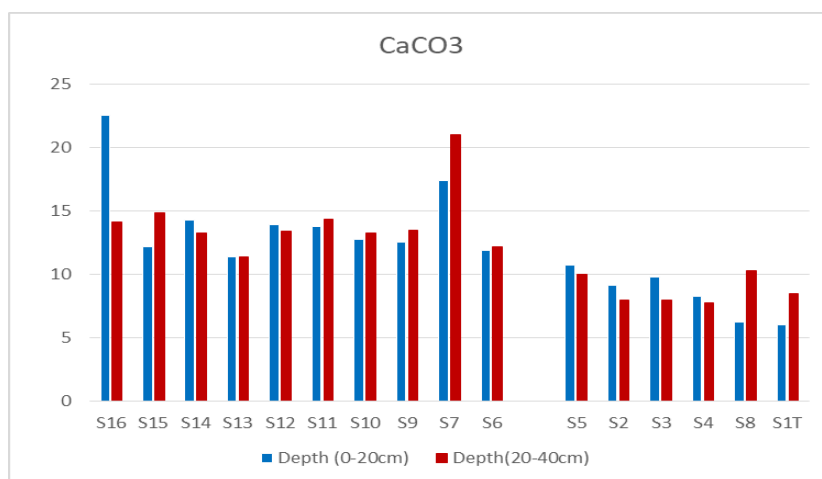


Figure 7: The average calcium carbonate content in different sites and at two depths

3.2. Trace Metal Elements content

Table 4. Averages concentration of TME with p value of t-Test for 20 cm & 40 cm depths

N = 16	Depth	Means \pm SE (mg/kg)	P value of t-test
Cd	20cm	1.542 \pm 0.139	0.669
	40cm	1.450 \pm 0.162	
Cr	20cm	45.100 \pm 4.595	0.999
	40cm	45.093 \pm 3.898	
Cu	20cm	45.431 \pm 12.865	0.772
	40cm	41.378 \pm 5.204	
Zn	20cm	137.106 \pm 20.303	0.749
	40cm	129.736 \pm 10.352	

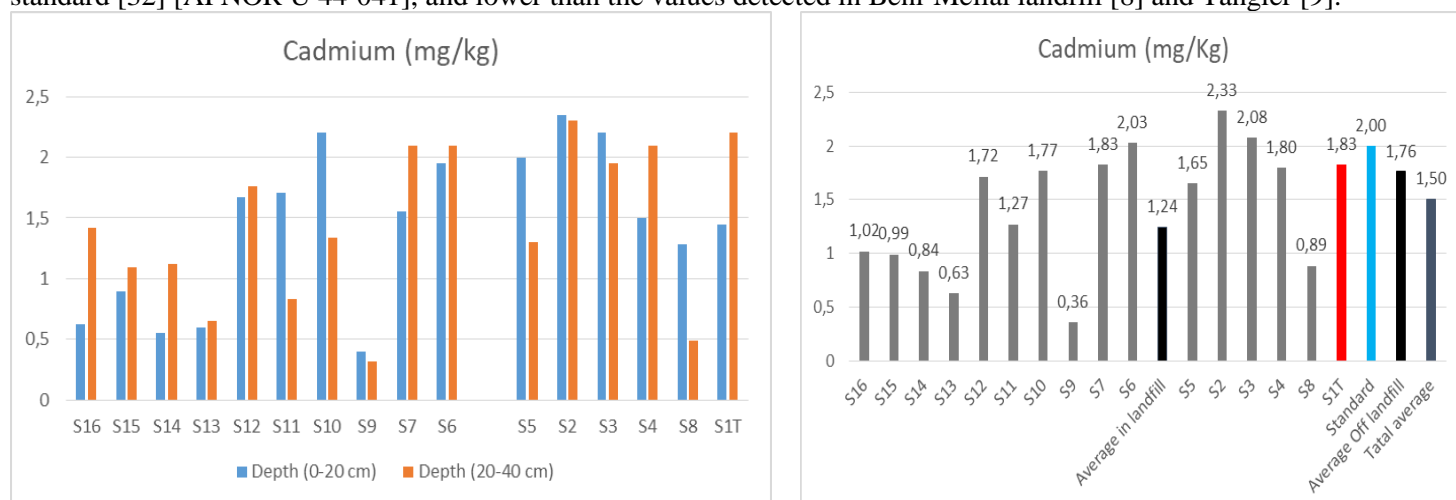
Table 5. Averages of TME concentrations In & off landfill sampling sites, with p value of t-Test

	N (in)= 20 N(out)= 12	In/Out	Means \pm SE	P value of t-test
Cd		In Landfill	1.338 \pm 0.128	0.051
		Off landfill	1.760 \pm 0.161	
Cr		In Landfill	46.351 \pm 3.594	0.607
		Off landfill	43.006 \pm 5.310	
Cu		In Landfill	43.772 \pm 11.008	0.946
		Off landfill	42.792 \pm 1.507	
Zn		In Landfill	134.713 \pm 17.961	0.885
		Off landfill	131.267 \pm 4.268	

The form in which a metal occurs in the soil depends on several factors such as its mineralogical composition, the conditions of salinity (EC), pH, oxidation-reduction, particle size and water content of the soil, the presence of ligands in solution and microorganisms [12]. All these factors can lead either to the solubility of metals or on the contrary their precipitation or their adsorption [26];[27]; [13].

Cadmium

The average concentrations of Cd in landfill (1.338 \pm 0.128 mg/kg) and out of landfill (1.760 \pm 0.161 mg/kg) are almost significant ($p=0.051$). Meanwhile, no significant difference was found between 20 cm (1.542 \pm 0.139 mg/kg) and 40 cm (1.450 \pm 0.162 mg/kg) depths (Table 4 ; 5). In fact, the deposit of mixed waste within the landfill in a random manner leads to a non-uniform degradation of this waste, thus a flow of trace metals varies from one site to another. However, the overall average concentration (1.5 mg/kg; Figure 8) remain below the limit value (2 mg/kg) defined by the standard [32] [AFNOR U 44-041], and lower than the values detected in Beni-Mellal landfill [8] and Tangier [9].

**Figure 8:** The average cadmium content within each site and at the level of the two depths

Sites with Cd above landfill average contain burnt and old waste as well as some vegetation, which allow bioaccumulation and could explain their high Cd content. The Cd content in sites S6 (2.03 mg/kg) slightly exceeds the standard for 40 cm depth, due to the almost permanent burning of the dumped waste. Furthermore, Cd content slightly exceeds the limit value defined by the standard [32] [AFNOR U 44-041] in S2 (2.33 mg/kg) and S3 (2.08 mg/kg), this is due to their location in a poor drainage area. In fact, site S2 is located in major bed of the wadi, while site S3 is

located in the minor bed of the wadi, which favors a stagnation of leachate runoff. Moreover, it can be due to the garb of the tires of the traffic passing by the national road N8. In fact, Cd contents in sites off the landfill correspond either to the concentration of the geochemical background, or to the release of this metal during the incineration of solid waste, which can be entrained towards the ground or it is due to the wear of the tires or another source of pollution[13]. It is wise to mention that during our field survey, we discovered downstream of S1T (far from the leachate runoff drain) located in the wadi, a place containing construction and demolition waste. The main potential sources of Cd in our study area include household garbage incineration, tire wear, batteries and pigments of household paints; cigarette butts[13] [28]. The average concentration of Cd detected does not exceed the standard and lower than that found by [8] and [9].

Chromium

The average concentrations of sampled soil in landfill is 46.351 ± 3.594 mg/kg and off landfill is 43.006 ± 5.310 . While the average concentration for 20 cm depth is 45.100 ± 4.595 and 45.093 ± 3.898 for 40 cm depth (Table 4; Figure 9). Overall, there was no significant differences in Cr soil content neither regarding depth nor in & off landfill. Yet, these values remain lower than the standard (150 mg/kg) recommended by [32] [AFNOR U 44-041]. Waste paint, as well as stainless steels, are the source of Cr pollution. Plastic packaging is a major contributor to Cr pollution. In fact, 30% of chromium found in similar landfills comes from plastic packaging[29]. In our study sites, daily, about 10.86% or 2.2T of plastic is dumped in Targuist landfill according to [4]. The average Cr concentration in our study area is lower than that found by [7]; [8] and [9].

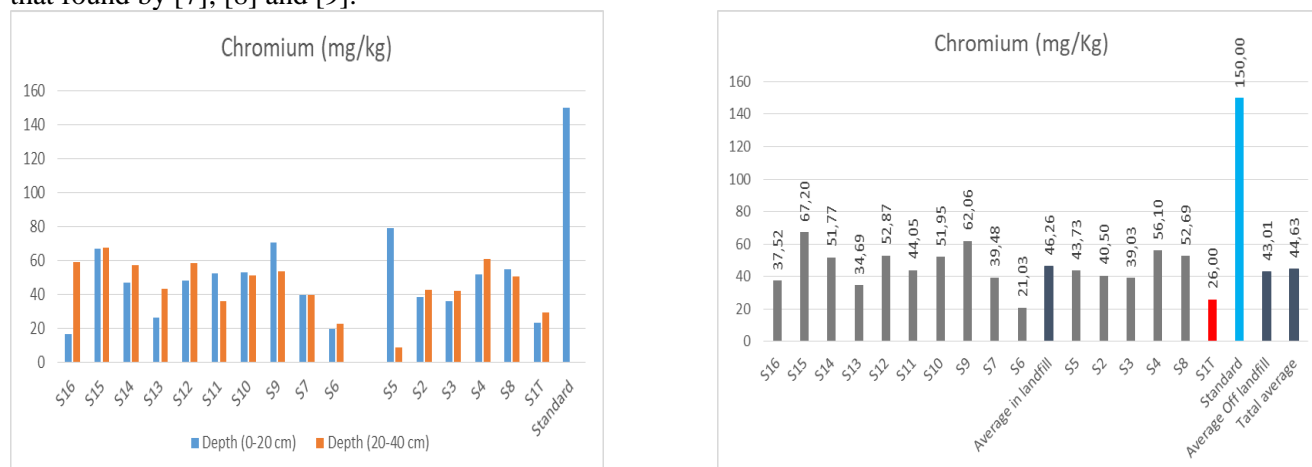


Figure 9: The average Chromium content within each site

Copper content

The average content of Cu in sampled soil show no significant differences between 20 cm depth (45.431 ± 12.865 mg/kg) and 40 cm depth (41.378 ± 5.204 mg/kg). Likewise, the average in landfill (43.772 ± 11.008 mg/kg) and off landfill (42.792 ± 1.507 mg/kg) show no significant differences according to t-Test (Table 4 & 5; Figure 10). These concentrations found in our study landfill remain lower than that found in the Béni Mellal landfill [8]. The high content which characterizes S6 has exceeded the standard [32] [AFNOR U 44-041] in the 0-20cm layer is because the leachate from the entire landfill and even the majority of the incinerated waste converge toward S6 site, which is located at the level of sloppy small canyon. Then, it drops by more than 75% at S5 site which is located further on the same small canyon. This may be due to the retention phenomenon of copper in alkaline pH (=9). Copper content in our study area remains lower than that mentioned by [8] and [7]. The main anthropogenic source of soil pollution by

copper is electronic and electrical construction waste as well as hospital waste and plumbing products (tubes and pipes) [13].

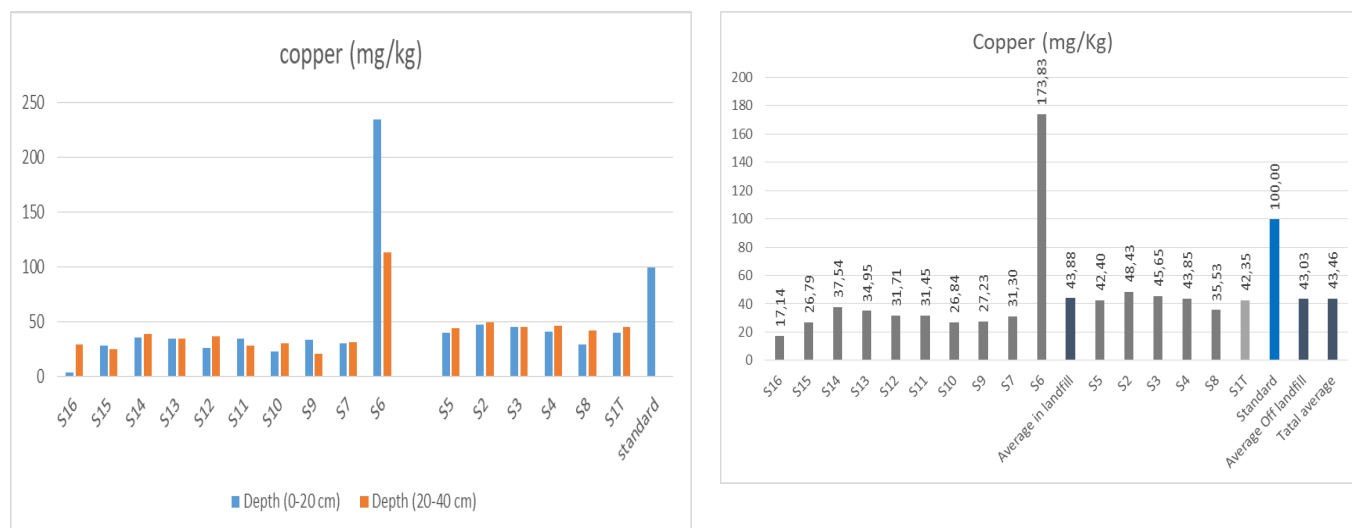


Figure 10: The average copper content at each site

Zinc

Our results show no significant differences in Zn content in our sampled soil for 20 cm (137.106 ± 20.303 mg/kg) and 40 cm (129.736 ± 10.352 mg/kg) depths. Similar result was found between in landfill (134.713 ± 17.961 mg/kg) and off landfill (131.267 ± 4.268 mg/kg) sampling sites (Table 4 & 5; Figure 11). These values do not exceed the standard [32] [AFNOR U 44-041]. The exceptionally high value at S6 site follows the same trend as that observed for Cu.

The average concentration of Zn is higher compared to that found by [7], but lower than values found by [9], which are exceeding the standard [32] [AFNOR U 44-041].

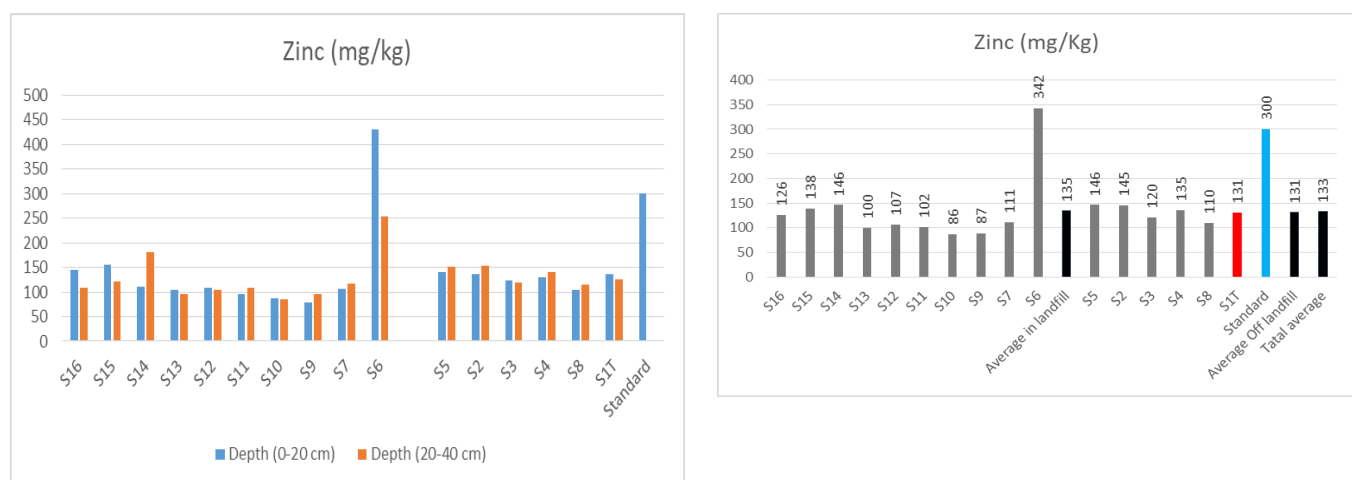


Figure 11: Average Zinc content within each site and on both depths

3.3. Relationship between different landfill soil physicochemical properties and trace metal pollution

A correlation matrix was produced to demonstrate the relationship between the trace metals content and the physicochemical characteristics of the soil. The results are shown in (Table 5). The closer the Pearson correlation coefficient between two elements is to (+1), the more they have the same tendency and vice versa [8].

The results of Pearson's correlation analysis (Table 5) show a positive and significant correlation between pH and Zn, Cu and Cd ($p < 0.01$). However, Cd is only correlated with the pH. With the exception of EC, pH is correlated with all parameters. In addition, pH reveals a negative and significant correlation with MO, COT. Moreover, we notice that Cr is negatively correlated with pH, Cu and Zn. These last two metals are highly correlated ($p < 0.01$). EC is highly correlated with MO, TOC, and CaCO₃. These last three are significantly correlated. This could be attributed to the fact that the dumped waste is both rich in organic matter including TOC, as well as in mineral elements. The correlation with CaCO₃ can be explained by the fact that the waste is distributed evenly on the substrate. The strong correlations allow us to say that these parameters evolve in the same way. On the other hand, the positive and significant correlations between different trace metals argue in favor of a similar source of pollution [30];[31]; [32].

Table 5: Pearson correlation matrix between trace metals and physicochemical parameters within the uncontrolled landfill of Targuist.

Pearson coefficient of correlation (r) N = 32		pH	EC	OM	CaCO ₃	TOC	Cd	Cr	Cu	Zn
pH	r	1	,065	-,367*	-,395*	-,361*	,557**	-,440*	,653**	,665**
	Sig.		,723	,039	,025	,042	,001	,012	,000	,000
EC	r		1	,692**	,559**	,682**	,183	-,252	,064	,084
	Sig.			,000	,001	,000	,316	,164	,728	,649
OM	r			1	,835**	,990**	-,143	-,026	-,063	-,043
	Sig.				,000	,000	,435	,886	,731	,817
CaCO ₃	r				1	,818**	-,203	-,042	-,177	-,063
	Sig.					,000	,264	,820	,331	,733
TOC	r					1	-,098	-,044	-,064	-,057
	Sig.						,595	,810	,729	,755
Cd	r						1	-,192	,299	,255
	Sig.							,292	,096	,159
Cr	r							1	-,354*	-,390*
	Sig.								,047	,027
Cu	r								1	,931**
	Sig.									,000
Zn	r									1
	Sig.									

*, Significance at 0.05 level; **, Significance at 0.01 level.

To in-depth the analysis and interpretation of these results, we relayed on the hierarchical ascending classification (HAC), and Principal Component Analysis (PCA).

Hierarchical Ascending Classification (HAC)

The ascending hierarchical classification (Figure 11) has identified four main groups; i) OM, TOC, CaCO₃ and EC; ii) Cu, Zn, pH and Cd; iii) Cr.

Principal component analysis (PCA)

The KMO (Kaiser-Meyer-Olkin) index with Bartlett's sphericity test ensure the validity of the PCA. Therefore, the two values are valid and significant ($KMO > 0.666$; $p < 0.001$). After varimax rotation, the PCA analysis presented two principal components and explaining a total variance of 71.85%. The projection of the studied parameters on the first two components revealed a group on positive side of component 1 (C1) made up of EC, OM, TOC, and CaCO₃. The second group is displayed on positive side of C2 and consisting of Zn, Cu, pH and Cd. While the third group is displayed on negative side of C2 and revolves around Cr (Figure 13).

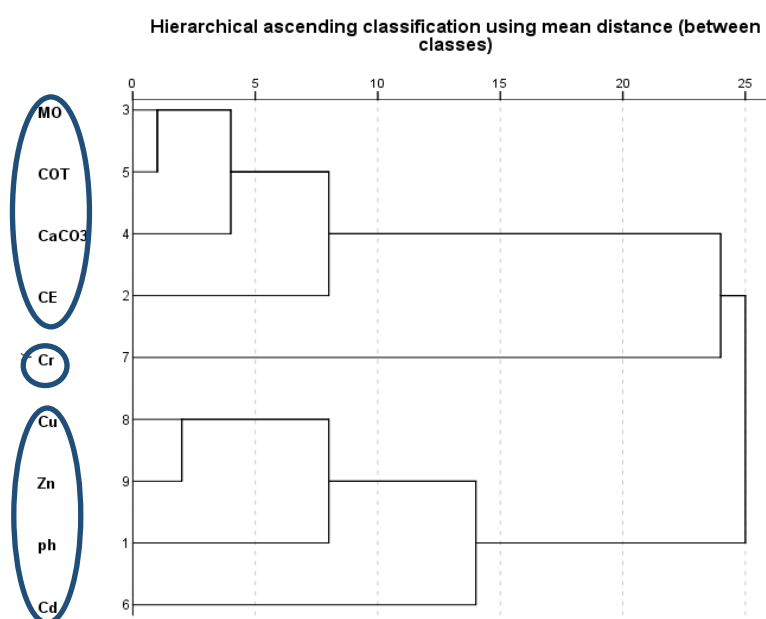


Figure 12: Hierarchical ascending classification between TME and physicochemical parameters

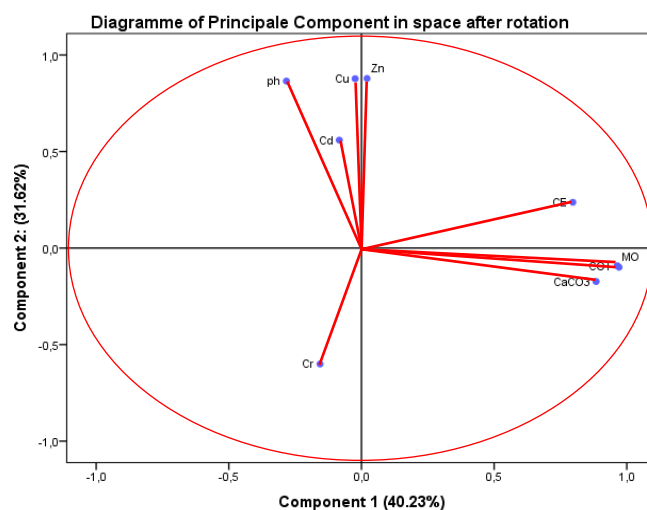


Figure 13: PCA representation of the studied variables (TME and physicochemical parameters) on the two principal components C1-C2.

The parameters of each group show significant correlations between them. The strong correlations between Zn, Cu and pH confirm that these elements may be governed by pH. It is wise to note that Cd is not correlated with Cu and Zn, thus it is not on the same projection plan, but somehow related to pH influence as a cation element. Chromium exhibits no positive correlation with metals or soil parameters, and it evolves in the opposite direction with pH, Zn and Cu indicating that this element has another source, which may be the value of the geochemical background. OM, TOC and CaCO₃ are strongly correlated with each other as well as with EC with no relations with studied TME.

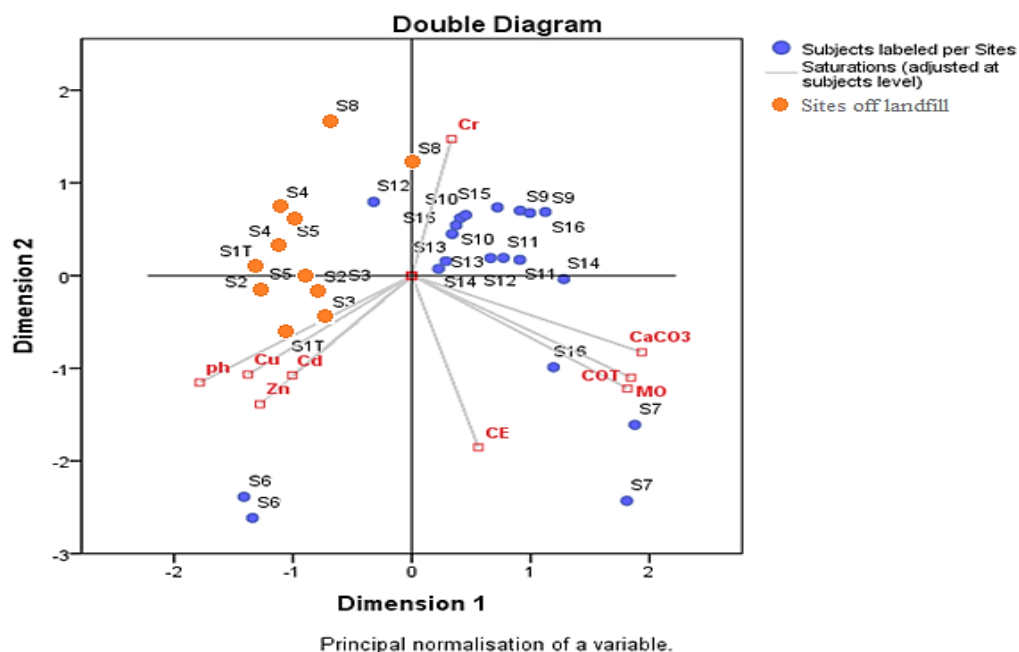


Figure 14: Simultaneous projection of the sampling sites and the TME on the D1-D2 plan

The simultaneous projection of the sampling sites and the studied parameters (Figure 14) allows elucidating the influence of unusual value of measured parameters recorded at each specific sites. It is wise to note that each sites is projected twice, indicating values measured at 20 cm and 40 cm depths. Thus, S6 recorded high value of pH, Cu and Zn. In addition, sites off landfill recorded higher pH and Cd values than sites in landfill. Hence, pH, Cu, Zn and Cd are located on the negative side of Dimension 1 (Figure 14) where most off landfill sites occur, but the weight of values recorded in S6 bring these parameters to the negative side of Dimension 2 as well. Similarly, S7 recorded unusual high values for OM, TOC, CaCO₃ and EC. In addition, S16 measured high value of CaCO₃. EC is projected near to Dimension 2 because S6 recorded high value of EC. This due to the stagnation of the leachate in S7 and S6, where the fermentable fraction of the waste is important. Finally, Cr is almost evenly distributed among in/off landfill sites, so it is positioned between them on the positive side of Dimension 2, and because it is negatively correlated with pH, Cu and Zn. Randomly, the uncontrolled landfill receives various types of waste that may contain one or more types of these metals at a time, or enriched by these metals simultaneously. Moreover, the sources diversity of metals in this study confirms that the landfill receives mixed wastes, which contain variety of metals [28] and provide smoke and dust caused by almost permanent burning of the dumped waste.

4. Conclusion

The aim of this work was to determine the total concentration of TME in the soil of the landfill and its surroundings as well as the extent of contamination and the possible origin of these harmful pollutants. The results obtained show that

the soil of the uncontrolled landfill in the town of Targuist and its surroundings is alkaline and unsalted at most of the sites. The high organic matter content is related to the nature of the dumped waste, which is a common feature among household landfills in Morocco. The average trace metals contents at all the sampling sites show acceptable levels for Cadmium, Chromium, Copper and Zinc. The significant correlations observed between the metallic elements Cu, Zn and Cd with pH suggest that this later govern these metals. Soil contamination in the study area by trace metals can lead on the one hand to their adsorption by plants and their bioaccumulation in the food chain, and on the other hand to the contamination of surface and ground water. At the end of this study, we conclude that the landfill and its surroundings are slightly contaminated. Strict monitoring must be put in place to mitigate the impact of the uncontrolled landfill on the components of the environment (water, air, soil, etc.). It is wise to take into account the accumulation of TME over the long term, especially since the proximity of a waterway is a real threat of runoff and contamination of the surrounding natural environments. It is necessary to consider further investigation of the studied landfill in order to assess the TME ecological toxicity and its impact on local population health.

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