Typology, composition and characterization of urban solid waste in the industrial area of Bobo-Dioulasso, Burkina Faso

ABSTRACT

Aim : This study is to make a typology and characterize this urban solid waste in the industrial area of Bobo-Dioulasso (Burkina Faso)

Methodology : Systematic sampling of thirteen landfills identified by on-site observation carried out taking into account the density and heterogeneity of the waste. The waste typology is made taking into account the categories, origins, composition and hazardous nature of the waste. The characterization is carried out through the evaluation of the physico-chemical parameters and the contents of heavy metals contained in the waste.

Result : The results reveal several categories of waste, namely fine waste (26.58%), plastics (20.72%), glasses (13.86%) and textiles (11.38%) which account for 72.54% of waste. The other categories (putrescible, paper/cardboard, unclassified fuels, metals, unclassified incombustible and hazardous waste) account for 27.46%. The density of the waste is 6.34 kg/m². Household and industrial waste are present at 71.47% and 23.92% respectively on average. The D13 landfill contains 100% industrial waste. Agricultural waste (2.21%) and medical waste (0.43%) remain low compared to other types of waste. Organic waste predominates in the majority of landfills with an overall average of 60.93%. However, glassware (13.38%) and metal scrap (1.36%) are less present. Composable waste is 56.21%, semi-inert (18.73%) and inert (37.66). Non-hazardous waste predominates in landfills with an average of 71.63%, although potentially hazardous waste reaches high levels (50.70%). The measured parameters indicate waste with a low acid pH (6.50) and an organic matter of up to 68.84%, indicating a high degree of heterogeneity. In addition, some dumps have high concentrations of heavy metals, such as cadmium (24.60 mg/Kg), chromium (123.98 mg/Kg), copper (451.58 mg/Kg), mercury (68.93 mg/Kg), lead (158.57 mg/Kg) and zinc (62939.41 mg/Kg).

Conclusion : results should serve as a basis for local authorities to take decisions to raise awareness and prevent health and environmental risks arising from the landfill.

Key words : Waste, Dumping, Heavy metals, Industrial zone, Bobo-Dioulasso

I. INTRODUCTION

Inadequate waste management in major cities in developing countries is a major challenge. Waste disposal methods, which are often inefficient and unregulated, exist, including practices such as open incineration, uncontrolled deposits in shallow areas, streets, land reserves, stream banks and pipelines (Compaoré et *al*. 2010; Biaou et *al*. 2019). According to Zaafour et *al*. (2019), these practices expose populations to significant risks, especially since waste from domestic, economic or industrial activities causes multiple nuisances, posing a threat to human and animal health and to the ecological balance. In many sub-Saharan African countries, including Burkina Faso, waste disposal sites often take the form of uncontrolled landfills (Biaou et *al*. 2019). These unregulated sites receive various types of waste without prior treatment, thus increasing the risks of environmental pollution and health problems due to their uncontrolled accessibility (Zmirou et *al*., 2003). These landfills are accessible to the public and exposed to the weather, which promotes the dissolution of pollutants, thus amplifying their impact on soil, water and air. Moreover, the waste accumulated by these sites is often recovered to be used as fertilizer in urban areas, despite their high potential for heavy metal pollution (Biaou et *al*., 2019; Ibrahim et *al*., 2020). The Bobo-Dioulasso industrial zone in particular is a source of concern for heavy metals as it has an uncontrolled landfill. These elements, which are often present in waste such as batteries, electronic equipment and other industrial materials, are frequently used in urban agriculture without precautionary measures, contributing to the spread of persistent pollutants and their harmful effects on ecosystems and human health (Zmirou et *al*., 2003). In view of these challenges, an in-depth study is needed to identify the nature and characterize the solid urban waste of the Bobo-Dioulasso industrial zone. This study aims to (i) make a typology of waste in the industrial zone, (ii) carry out a qualitative characterization of the waste taking into account its origin, composition, degradation potential and dangerousness, (iii) determine the physico-chemical characteristics and the contents of heavy metals in waste. This will enable us to identify potential risks (ecological, health and environmental risks) and threats to the environment and to the population, with the aim of establishing tools for assistance and decision-making for proper waste management in the Bobo-Dioulasso industrial zone.

II. MATERIALS AND METHODS

2.1.Presentation of the study area

The town of Bobo-Dioulasso, located 365 km southwest of Ouagadougou, is the economic capital of Burkina Faso. It is the second largest city in the country and covers an area of 1805 km² and is located between 4°18' west longitude and 11°10' north latitude. Its climate is of the Sudano-Sahelian type, characterized by an alternation between a long dry season period from November to May and a shorter rainy season from June to October, marked by spatio-temporal variability in precipitation. The dominant soils are tropical ferruginous soils. The city is between the 900 and 1100 mm isohyetes with annual precipitation and temperature averages of 2027.15 mm and 27.8°C respectively. The geographic coordinates of the study area (Fig.1) are 4°19’34.9” W and 11°07’43.7” N.

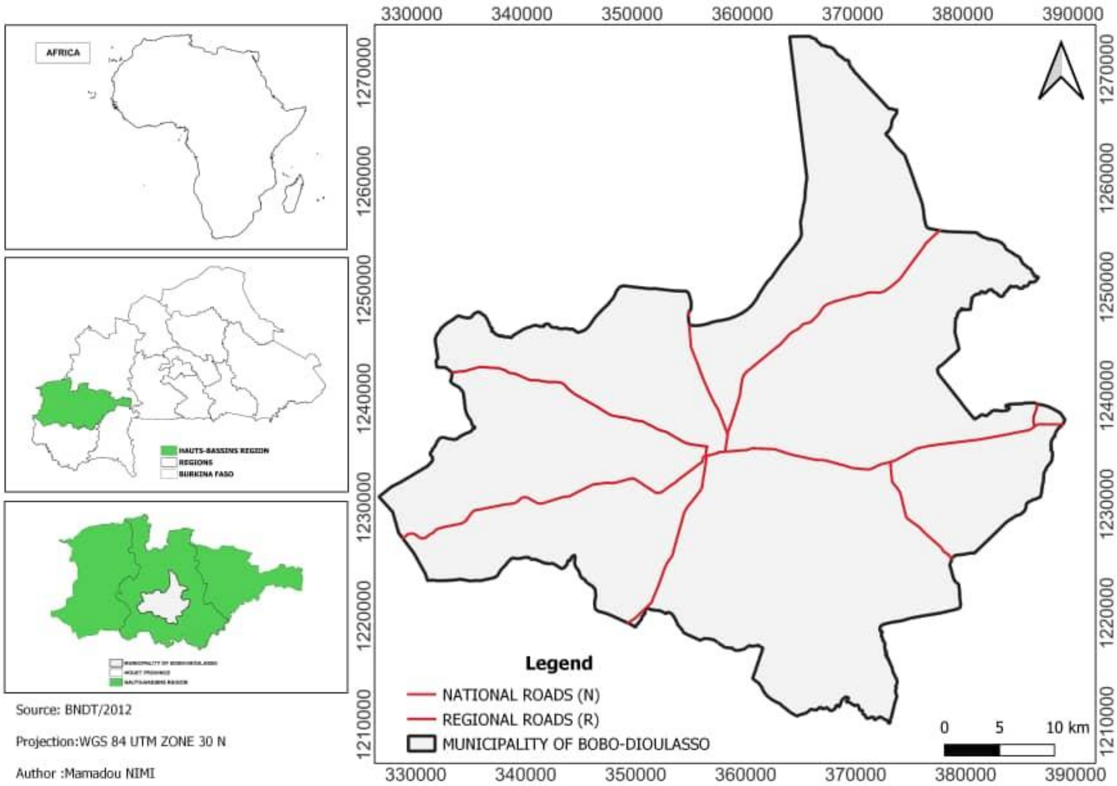

Fig. 1: Geographical location of the study area

2.2.Identification of waste dumps

Visual prospecting of the site was carried out in order to observe and analyze the physical environment. Thirteen (13) landfills in the industrial zone were subsequently selected taking into account the density and heterogeneity of the waste. Fig. (2) shows the location of the various dumps in the industrial zone.

Fig. 2 : Location of waste dumps

2.3.Sampling of waste

On each dump, composite samples were produced with three (3) waste samples taken from within 3 squares (1m×1m) defined along the diagonal of the dump (Fig. 3). A total of 13 composites samples were collected. For the quantitative characterization, the sampling concerned the fine part of the waste cleared of coarse elements. The samples were then placed in labeled polyethylene bags and sachets and sent to the Laboratories Department of the Regional Directorate of the Bureau of Mining and Geology of Burkina Faso (BUMIGEB) for analysis.

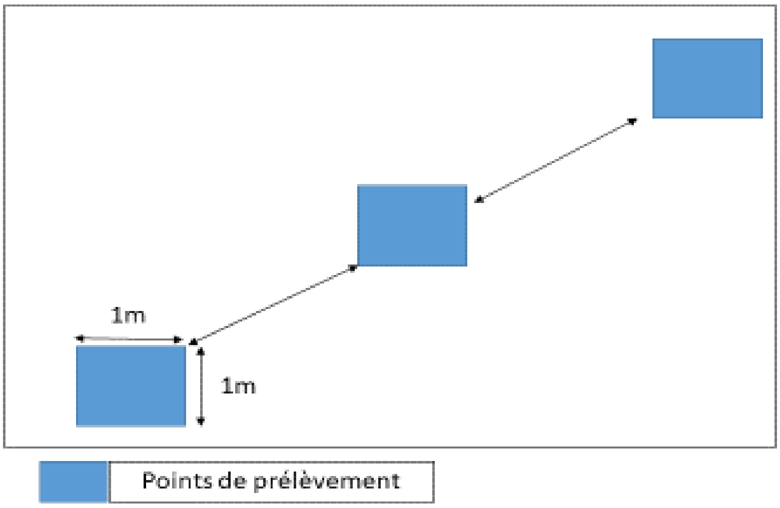

Fig. 3 : Waste sampling device

2.4.Analysis of waste samples

2.4.1. Typology and qualitative characterization

The waste samples packed in the bags, once in the laboratory, were manually sorted and weighed using an electronic SARTORIUS type E 5500S-F2 balance. Thus, waste has been characterized according to several criteria: the main categories (Putrestibles, Paper/Cardboard, Textiles, Plastics, Unclassified Fuels, Glasses, Metals, Unclassified Infuels, Hazardous Waste and Fine), origin, composition, degradability and dangerousness (Aloueimine, 2006).

2.4.2. Analysis of heavy metals

For the determination of heavy metal concentrations in the fine waste, the samples were first dried in the open air in the absence of dust, crushed with a porcelain mortar and sieved at 125 µm with a nylon mesh sieve. Reflux mineralization on a heating plate was carried out with a 3 g test sample to which were added 2 drops of 30-volume hydrogen peroxide, 5 ml of 69% nitric acid (HNO3), 5 ml of 40% fluoridric acid (HF) and 15 ml of 37% hydrochloric acid (HCl). Analysis of heavy metal contents shall be carried out by atomic absorption spectrometry. The device used is an Agilent Varian SpectrAA-240 FS.

2.4.3. Analysis of physico-chemical parameters

Analyzes included pHeau, Total Carbon (C), Total Nitrogen (N-total), Total Potassium (K-total), Total Phosphorus (P-total), Cationic Exchange Capacity (CEC), Electrical Conductivity (CE), Organic Matter (MO), Calcium (Ca), Magnesium (Mg), Manganese (MnO) and Iron (FeO) Oxide.

The pHeau measurement is made by the electronic method using a glass electrode pH meter in a suspension with water in a soil/solution ratio of 1/2.5 (1 g of soil per 2.5 ml of water) according to the AFNOR NF ISO 10-390 standard. The same solution is used to measure electrical conductivity using a conductivity meter (HI9829 Multiparameter). The total carbon was determined by oxidation under hot conditions (135° C. for 1 h) in an acid medium with potassium dichromate according to standard NF ISO 14-235. The determination of N-total was carried out by mineralization and distillation through the Kjeldahl method according to the AFNOR ISO 11-261 standard. For P-total, soil samples were first mineralized hot with a H2SO4-SeH2O2 mixture. Subsequently, the P-total was determined in the mineralizates using an automatic colorimeter SKALAR (Segmented flow analyzer, model SAN plus 4000-02, Skalar Hollande). K-total was determined using a flame photometer (JENCONS. PFP 7, Jenway LTD, Felsted, England). The cation exchange capacity (CEC) is measured by adding 2 ml of the silver nitrate solution mixed with thiol to vials containing 1 g of sieve and stirring for 2 hours. The solution is subsequently centrifuged and the concentrations of the different cations are read by an atomic absorption spectrometer. Total carbon is determined by the Walkley and Black (1934) method based on oxidation of carbon by potassium dichromate ($K_2Cr_2O_7$) in an acidic medium. Major elements such as Fe, Mn, K, Ca, Mg and Na are determined in the samples using the SAA spectrometer.

2.5.Analyzes of data

The resulting data were entered and processed with the Microsoft Excel 2016 spreadsheet and the statistical analysis was performed with the R version 4.3 software. The data were normalized by the Shapiro-Wilk test, and the homogeneity of the variances with the Levene test. Thereafter, the normal data undergoes an ANOVA at the significance level of 5%. When the conditions of the parametric tests are not complied with, the Kruskal-Wallis test is applied. For groups with significant differences, means are compared with Tukey's Honest Significant Difference (HSD) for parametric analyzes and Dunn's for non-parametric analyzes.

III. RESULTS

3.1. Qualitative characterization of waste from landfills in the industrial zone

3.1.1. Waste composition by category

Fig. (4) shows the different categories of waste identified on the dumps. The dumps analyzed reveal significant variations in the distribution of waste types, with a predominance of certain categories. The fines represent a significant proportion, in particular at D01 with 40.09%, D08 with 45.01% and D13 with 39.59%. Plastics are also very present, particularly at D02 with 25.65%, D05 with 29.41% and D10 with 36.55%. Putrescible waste stands out at D06 where it reaches 40.40% and at D12 with a proportion of 26.82%. On the other hand, hazardous waste is almost non-existent, while non-classified non-fuel remains largely unrepresented in all landfills. These results illustrate a strong presence of dominant categories such as fines, plastics and putrescible. This distribution demonstrates the heterogeneity of the waste compositions between the different sites studied.

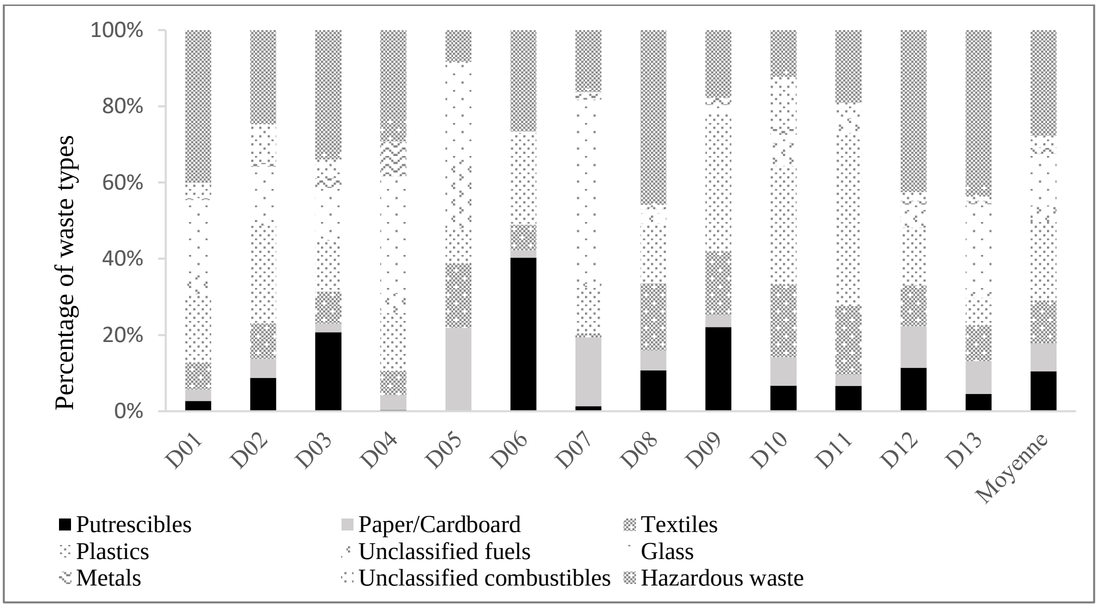

Fig. 4: Breakdown of waste by category, based on landfill site

3.1.2. The density of waste on landfills

Fig. (5) shows the distribution of the waste according to its density in g/m^2 for the various dumps (D01 to D13) as well as their average. The values indicate significant variations in waste densities between landfills. The D04 has the highest density, reaching 7668.23 g/m^2, and is statistically distinct from other dumps. D01 and D03 have relatively high densities of 5419.03 g/m^2 and 4817.66 g/m^2, respectively. In contrast, the lowest densities are observed at D10 (3316.63 g/m^2) and D11 (3112.32 g/m^2). The overall average density is 6366.19 g/m^2, reflecting a significant disparity between landfills.

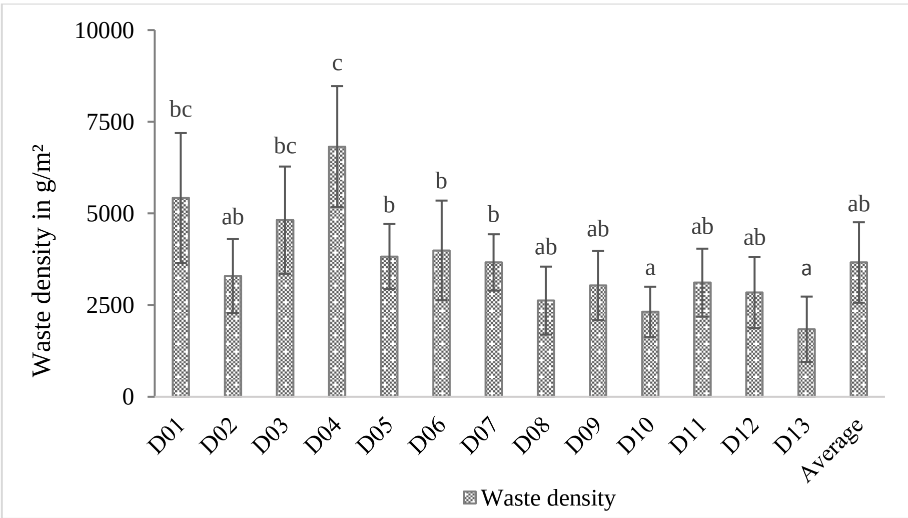

Fig. 5: Distribution of waste density by dump site

3.1.3. Composition of waste by origin

Fig. (6) shows the percentage distribution of waste types, i.e. household, industrial, agricultural and medical, for dumps D01 to D13, as well as the overall average. Household waste predominates in almost all landfills, with proportions ranging from 14.34% for D04 to 100% for D06, D08, D09 and D12, and an overall average of 71.47%. Industrial waste appears in some dumps, reaching a maximum of 100% for D13 and contributing to an overall average of 23.92%. Agricultural waste, which is much less widely represented, is present only in landfills D01, D02, D03, D10 and D11 with respective proportions of 4.61%, 8.64%, 1.91%, 7.55% and 6.14% for an overall average of 2.21%. Medical waste, almost non-existent, appears only in the D03 and D04 dumps, with proportions of 5.44% and 0.09%, and an average contribution of only 0.43%. These results show a dominance of household waste in all landfills, followed by a limited contribution of industrial waste, while agricultural and medical waste remains negligible.

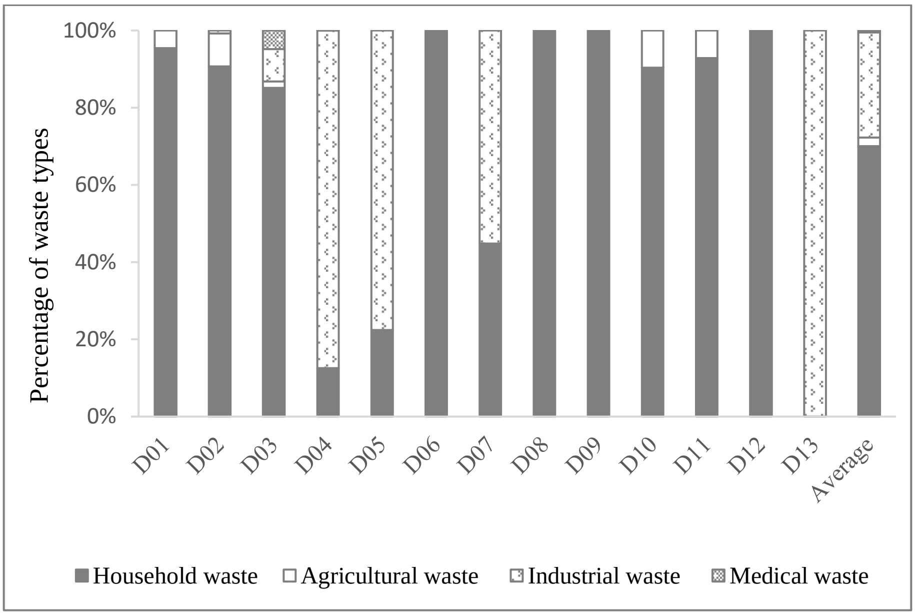

Fig. 6: Breakdown of waste by origin, based on landfill dumps

3.1.4. Distribution by composition

Fig. (7) shows the percentage distribution of the types of waste, namely organic, plastic, metal, glassware and ash, in the dumps D01 to D13, as well as the general average. Organic waste predominates in the majority of landfills, accounting for between 46.44% for D07 and 76.94% for D03, with an overall average of 60.93%. Plastics account for a significant share, reaching a maximum of 36.94% in the D04 and an overall average of 30.48%. Ash also contributes significantly, accounting for up to 29.89% in the D02 and an average of 27.04%. Glassware, although less frequent, appears mostly in the D07 with 29.80%, and their overall average is 13.38%. Metal waste, the least represented, does not exceed 7.84% in the D04 and has an overall average of 1.36%. These data reveal a predominance of organic waste in all landfills, followed by a significant presence of plastics and ash, while glassworks and metal waste remain marginally present.

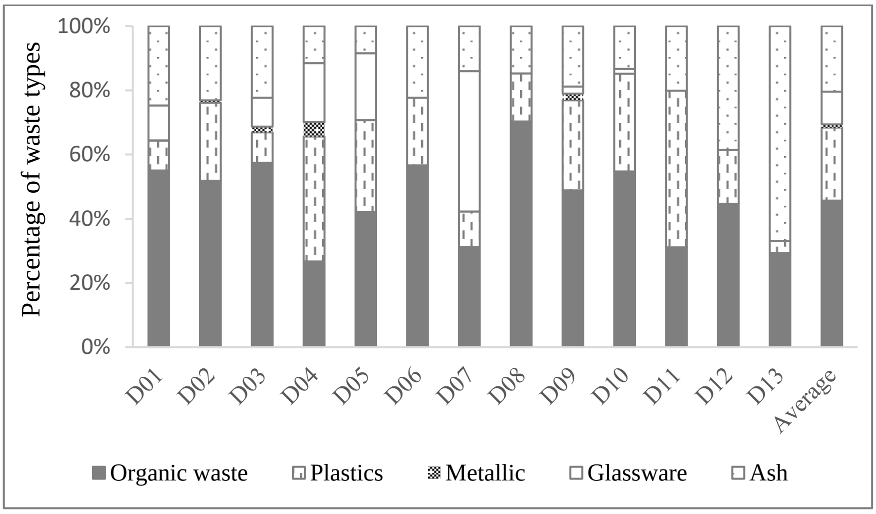

Fig. 7: Breakdown of waste by composition, based on landfill dumps

3.1.5. Breakdown by degradability

Fig. (8) shows the percentage distribution of the compostable, inert and semi-inert waste in the dumps D01 to D13 as well as the general average. Compostable waste is the most predominant, accounting for between 34.14% for D07 and 77.56% for D03, with an overall average of 56.21%. Semi-inert waste, although less frequent, peaks in D12 with 95.95% and is zero in landfills D02, D06, D08, D11 and D12, while its overall average is 18.73%. Inert waste has a maximum proportion of 63.10% in D11 and an overall average of 37.66%. These data show a predominance of compostable waste in all landfills, followed by a lower but not negligible presence of inert and semi-inert waste.

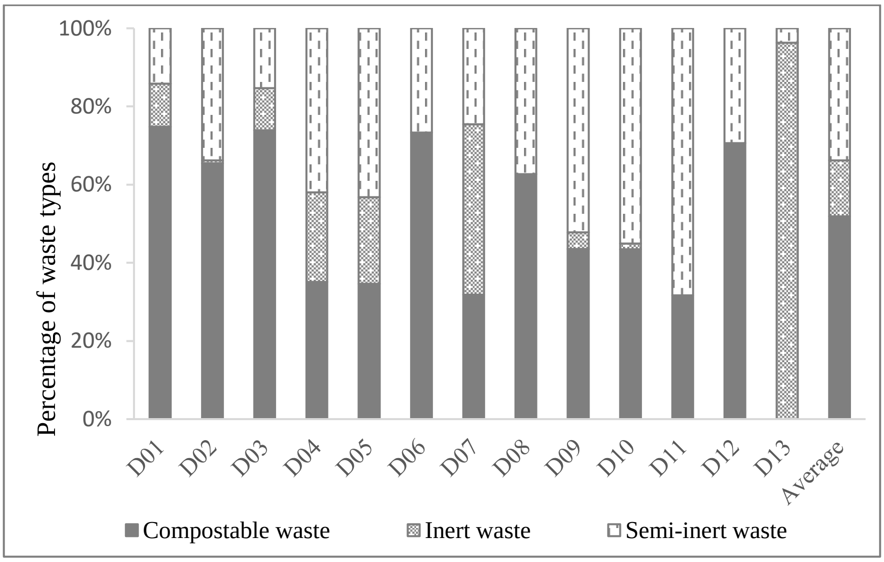

Fig. 8: Breakdown of waste by degradability according to landfill dumps

3.1.6. Distribution by Hazard

Fig. (9) shows the percentage distribution of the types of waste (non-hazardous, potentially hazardous and ultimately hazardous) in the different types of dumps (D01 to D13) and an overall average. Non-hazardous waste predominates in all categories, with an average of 71.63%. Potentially hazardous waste is a significant part of some landfills, including D07 (50.70%) and D04 (46.19%). Ultimately hazardous waste is a minority and only observed in D03 (16.50%) and D04 (7.67%).

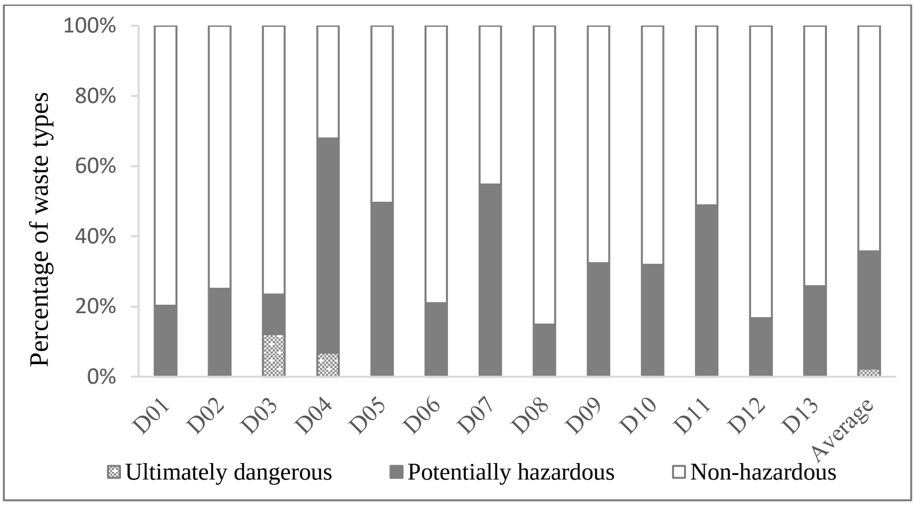

Fig. 9: Breakdown of hazardous waste by dump site

3.2. Quantitative characterization of waste from landfills in the industrial zone

3.2.1. Assessment of the heavy metal content of waste

The average content of heavy metals in the waste samples analyzed is presented in Table (1). Three metals, Cd, Hg and Zn respectively with mean concentrations of 5.28 mg/kg, 5.81 mg/kg and 7973.31 mg/kg remain above the limit values according to AFNOR U44-051. Zn is the metal with the highest average content (7973.31 mg/kg), while As is the element with the lowest average concentration in waste (0.70 mg/kg). Furthermore, apart from As, Ni and Pb, the remainder of the heavy metals analyzed, Cd, Cr, Cu, Hg and Zn, have respective maximums contents of 24.60 mg/kg, 123.98 mg/kg, 451.58 mg/kg, 68.93 mg/kg, 62939.41 mg/kg, which are also greater than the limit values according to AFNOR U44-051.

Table 1: Level of concentrations in mg/kg of heavy metals in waste from landfills in the Bobo-Dioulasso industrial zone (n = 13)

Heavy metals (mg/Kg)	Min	Max	Average	SD	Mediane	NF U44-051
As	0.00	5.37	0.70	1.68	0.00	**18**
Cd	0.82	24.60	5.28	6.78	2.48	**3**
Cr	24.36	123.98	55.35	26.36	51.84	**120**
Cu	30.21	451.58	118.97	115.50	71.75	**300**
Hg	0.00	68.93	5.81	19.00	0.00	**2**
Ni	23.87	56.57	36.37	9.97	33.88	**60**
Pb	0.98	158.57	72.07	49.47	62.11	**180**
Zn	115.79	62939.41	7973.31	17645.57	742.26	**600**

SD : *Standard deviation*

3.2.2. Assessment of physicochemical parameters of waste

The results of the physico-chemical parameters analyzed are given in Table (2). The pHeau of the waste samples varied between 5.83 and 7.06, with an average of 6.50 ± 0.43, indicating mostly acidic to slightly basic conditions. The electrical conductivity has an average of 1033.54±639.43 uS/cm, with a wide variation (297 to 2690 uS/cm), reflecting significant differences in the content of dissolved salts. The organic matter exhibits values of between 5.63 and 68.84%, with an average of 22.26 ± 19.27%, and the C/N ratio ranges from 4.57 to 20.06, with an average of 13.13. The mean cation exchange capacity (CEC) is 11.57 ± 6.22 cmol/kg. Finally, the mean percentages of MnO_2 and FeO are respectively 309.74±159.21% and 32178.83±15144.73%.

Table 2: Physico-chemical parameters in waste from landfills (n = 13)

Parameters	Min	Max	Average	SD	Mediane
pHeau	5.83	7.06	6.50	0.43	6.58
CE (µS/cm)	297.00	2690.00	1033.54	639.43	800.00
C (%)	3.26	39.93	12.91	11.18	9.34
MO (%)	5.63	68.84	22.26	19.27	16.09
N-total (%)	0.33	1.99	0.95	0.50	0.86
C/N	4.57	20.06	13.13	5.04	15.17
P_total (mg/kg)	559.42	3030.63	1908.66	750.20	2055.04
K_total (mg/kg)	2142.78	10121.44	3943.93	2192.39	3312.88
CEC (cmole/kg)	4.55	29.60	11.57	6.22	10.50
Ca (%)	0.20	7.05	1.90	1.76	1.44
Mg (%)	0.19	0.80	0.39	0.16	0.37
Na (mg/kg)	138.88	4226.70	772.16	1149.40	401.79
MnO (%)	89.48	589.38	309.74	159.21	283.68
FeO (%)	4657.09	57017.15	32178.83	15144.73	28881.66

ET : *Standard deviation* ***CE :*** *electrical conductivity* ***C :*** *carbon* ***MO :*** *organic matter*
CEC : *cation exchange capacity* ***C/N*** *: carbon/nitrogen ratio*

3.3. Statistical analysis of data in waste from landfills in the industrial zone

3.3.1. Correlation between different parameters in waste

A perfect correlation (r=1, p< 0.05) is observed between MO and C. Moreover, N-t is strongly correlated (r=0.84) with these two parameters. P-t is significantly correlated with CE (r=0.6), C (r=0.57), MO (r=0.57) and N-t (r=0.71). The C/N ratio exhibits a strong correlation (r=0.68) with C and MO. K-t shows a significant correlation (r=0.55) with N-t. Ca is strongly correlated (r=0.84) with CEC. As for Mg, it exhibits a significant correlation with C (r=0.66), MO (r=0.66) and N-t (r=0.61). Na was significantly correlated with C (r=0.85), MO (r=0.85), N-t (r=0.75), C/N (r=0.52), CEC (r=0.73), and Ca (r=0.78). MnO shows a strong correlation with C (r=0.67), MO (r=0.67), N-t (r=0.48), C/N (r=0.65), Mg (r=0.60) and Na (r=0.52). Cr shows a significant positive correlation (r=0.52) with MnO. Cu also showed significant correlation with C (r=0.80), MO (r=0.80), N-t (r=0.64) and C/N (r=0.60). Moreover, Hg exhibits a strong correlation with C (r=0.78) and FeO (r=0.50). Ni exhibits a strong correlation with Mg (r=0.69), MnO (r=0.66), Cr (r=0.59) and Cu (r=0.67). Finally, Pb is strongly correlated with N-t (r=0.55), CEC (r=0.57), Ca (r=0.51), Na (r=0.54) and MnO (r=0.63).

Table 3: Pearson correlation matrix between the different parameters

Var	pH	CE	C	MO	N-t	C/N	P_t	K_t	CEC	Ca	Mg	Na	MnO	FeO	Cd	Cr	Cu	Hg	Ni	Pb	Zn
pH	1,00																				
CE	-0,12	1,00																			
C	0,45	0,43	1,00																		
MO	0,45	0,43	**1,00**	1,00																	
N-t	0,38	0,38	**0,84**	**0,84**	1,00																
C/N	0,25	0,31	**0,68**	**0,68**	0,21	1,00															
P_t	-0,02	**0,60**	**0,57**	**0,57**	**0,71**	0,07	1,00														
K_t	-0,01	0,25	0,29	0,29	**0,55**	-0,15	0,43	1,00													
CEC	0,26	0,38	0,44	0,44	0,35	0,44	0,20	0,06	1,00												
Ca	0,14	0,47	0,49	0,49	0,40	0,39	0,29	0,23	**0,84**	1,00											
Mg	0,06	0,42	**0,66**	**0,66**	**0,61**	0,44	0,46	0,39	-0,12	0,07	1,00										
Na	0,41	0,34	**0,85**	**0,85**	**0,75**	**0,52**	0,46	0,32	**0,73**	**0,78**	0,29	1,00									
MnO	0,08	-0,03	**0,67**	**0,67**	0,48	**0,65**	0,21	0,22	0,22	0,28	**0,60**	**0,52**	1,00								
FeO	-0,32	0,27	-0,35	-0,35	-0,38	0,03	-0,15	-0,10	0,26	0,18	-0,04	-0,26	-0,21	1,00							
Cd	-0,04	-0,12	0,06	0,06	-0,09	0,35	-0,14	-0,02	0,40	0,13	-0,22	0,14	0,46	-0,03	1,00						
Cr	-0,29	0,07	0,16	0,16	-0,03	0,32	0,29	0,12	0,01	0,18	0,30	0,13	**0,52**	0,31	0,21	1,00					
Cu	0,21	0,15	**0,80**	**0,80**	**0,64**	**0,60**	0,48	0,20	0,01	0,03	**0,73**	0,48	**0,84**	-0,42	0,24	0,40	1,00				
Hg	-0,19	**0,78**	0,01	0,01	-0,03	0,12	0,17	-0,17	0,22	0,11	0,13	-0,07	-0,40	**0,50**	-0,20	-0,19	-0,20	1,00			
Ni	0,02	0,16	0,43	0,43	0,22	0,47	0,24	0,33	-0,28	0,02	**0,69**	0,14	**0,66**	-0,20	0,12	**0,59**	**0,67**	-0,26	1,00		
Pb	0,18	0,02	0,46	0,46	**0,55**	0,22	0,34	0,10	**0,57**	**0,51**	0,20	**0,54**	**0,63**	0,02	0,39	0,27	0,42	-0,25	0,06	1,00	
Zn	-0,34	-0,22	-0,13	-0,13	0,20	-0,43	-0,02	0,01	-0,05	-0,08	0,08	-0,07	0,12	0,10	-0,13	-0,08	-0,02	-0,06	-0,33	0,47	1,00

Bold : Significant correlation ($p<0.05$)

3.3.2. Principal Component Analysis

The analysis of the principal components (PCA) shows an extraction efficiency of between 62% and 99%. The main components CP1, CP2, CP3, CP4, CP5 and CP6 extracted from the waste samples after a Varimax rotation represent respectively 27%, 19%, 12%, 11%, 11% and 8% of the total variance estimated at 88% (Table 4). Principal component 1 (CP1) is the most dominant factor in wastes with very high positive loadings for physicochemical parameters such as organic matter (0.77), carbon (0.77), total N (0.0.53), C/N (0.71), Mg (0.83), MnO (0.84) as well as metals such as Cu (0.95) and Ni (0.76). CP2, the second most important determinant factor, shows high positive charges of CEC (0.98), Ca (0.87), Na (0.75), and Pb (0.64), followed by moderate positive charges of C/N (0.43), carbon (0.44), organic matter (0.44), and Cd (0.47). CP3 is represented significantly by positive charges of electrical conductivity (0.81) and Hg (0.95) and moderate charges of FeO (0.46). However, it is also marked by a moderate negative loading of Cd (-0.44) and MnO (-0.36). CP4 is positively dominated by total elements, namely N-total (0.57), P-total (0.67) and K-total (0.87). CP5 showed high positive loads of Cr (0.72) and FeO (0.65) but also high negative loads of pHeau (-0.72) and moderate negative loads of carbon (-0.37), N-total (-0.42) and MO (-0.37) were observed in this component. Finally, the less representative CP6 (8% of the total variance explained) illustrates a strong positive charge of heavy metals such as Zn (0.97) and Pb (0.56) as well as moderate negative charges of C/N (-0.37) and Ni (-0.37).

Table 4: Principal component loads of physicochemical parameters and heavy metals.

Variables	CP1	CP2	CP3	CP4	CP5	CP6	Communities
pHeau	0.16	0.26	-0.14	-0.07	**-0.72**	-0.23	**0.69**
CE	0.22	0.28	**0.81**	0.32	0.11	-0.18	**0.93**
C	**0.77**	0.44	0.13	0.25	-0.37	-0.03	**0.99**
MO	**0.77**	0.44	0.13	0.25	-0.37	-0.03	**0.99**
N-total	**0.53**	0.33	0.10	**0.57**	-0.42	0.29	**0.99**
C/N	**0.71**	0.43	0.14	-0.35	0.02	-0.37	**0.96**
P_total	0.37	0.18	0.30	**0.67**	-0.02	0.09	**0.72**
K_total	0.11	0.09	-0.11	**0.87**	0.07	-0.05	**0.79**
CEC	-0.03	**0.98**	0.17	-0.03	-0.05	0.02	**0.99**
Ca	0.06	**0.87**	0.16	0.24	0.05	-0.06	**0.85**
Mg	**0.83**	-0.15	0.29	0.30	0.04	0.11	**0.90**
Na	0.41	**0.75**	0.01	0.30	-0.33	-0.01	**0.92**
MnO	**0.84**	0.31	-0.36	0.01	0.17	0.13	**0.98**
FeO	-0.26	0.19	0.46	-0.20	**0.65**	0.07	**0.77**
Cd	0.14	0.47	-0.44	-0.29	0.28	-0.13	**0.62**
Cr	0.44	0.12	-0.16	0.13	**0.72**	-0.12	**0.79**
Cu	**0.95**	0.05	-0.13	0.12	-0.10	0.05	**0.95**
Hg	-0.09	0.06	**0.95**	-0.13	0.08	-0.03	**0.94**
Ni	**0.76**	-0.18	-0.18	0.23	0.28	-0.37	**0.91**
Pb	0.34	**0.64**	-0.24	0.06	0.07	**0.56**	**0.90**
Zn	-0.06	-0.06	-0.05	0.03	0.10	**0.97**	**0.97**
% variance	**27**	**19**	**12**	**11**	**11**	**8**	
% accumulate	**27**	**46**	**58**	**69**	**80**	**88**	

IV. DISCUSSION

4.1. Qualitative characterization of waste from landfills in the industrial zone

4.1.1. Waste composition by category

A detailed study shows that all landfills cover a wide variability of waste. It can be seen that on five of the dumps (D1, D3, D8, D12, D13), there is much more fine waste (32.24 to 45.01%), followed by four others (D2, D9, D10, D11) dominated by plastics with a variation in the ratio ranging from 25.81 to 45.63%. On the other hand, there is glass waste which dominates three dumps (D04, D05, D7) with a percentage by mass which varies from 24.29 to 47.98%, and a single dump (D6) where there are many more putrescible, that is to say 40.4%. This irregular distribution reflects the image of the landfill. Fine waste could come from several sources directly or indirectly linked to the advanced degradability of the different categories of waste (Ngnikam et *al*., 2017). The average levels of fine waste (26.58%) and plastics are in line with those of (Aloueimine, 2006) in Nouakchott (Mauritania). The work of Bah et *al*., (2021) had shown that in Faladié's household waste, 53.1% of fine waste was composed mainly of a mixture of soil, sand and ash. These results remain proportionally higher than those of ADEME, 2021b, which consisted of 30% putrescible waste, 4% plastic waste and 1% waste. However, this level of putrescible waste is comparable to the level found on D6. The results of the fine fraction obtained in the depots D1, D3, D8, D12 and D13 are comparable to those of Aloueimine, (2006). The plastic content obtained at dumps D2, D9, D10 and D11 is practically the same as for the works of Zaafour et *al*., (2019), as well as the textile content. These results are also similar to those found by Adamou et *al*., (2023) showing that in household waste, the fine parts followed by putrescible and plastics are the most represented. At the landfill in the industrial zone, putrescible are dominant only at the D6 level with an overall average of 10.53%. This low rate could be explained by the fact that this waste is food waste that can be eaten by stray animals at the landfill. These remains can also mix with fine waste and increase its volume (Ngnikam et *al*., 2017). The work of Biaou et *al*., (2019) also showed that household solid waste was rich in putrescible waste (31.6%) and fine elements (33.8%). Cheniti (2014) found in household waste, 46% putrescible waste, 15.10% textiles, 10.01% plastics, 5% paper and cardboard and 12% fine.

4.1.2 Composition of waste by density

The density of waste in an uncontrolled landfill depends on several factors, including the type of waste (organic, plastic, etc.), its condition (compacted or not) and environmental conditions (Aïna et *al*., 2007). The density was determined by weighing the various waste masses taken from the dumps. It is variably varied and provides point-in-time and instantaneous information which does not allow to explain the variations on the different values obtained. The waste is much denser on the D04 dump (6823 g/m²) compared to the others, followed by the D01 (5419 g/m²), D03 (4817.67 g/m²) and D06 (63991.33 g/m²) dumps. The work of Aïna et *al*., (2007) had shown that the waste density at a landfill in Saaba, Burkina Faso ranged from 140 to 650 Kg/m^2. The general average of the densities (of 6366.19 g/m^2) indicates a considerable disparity between the dumps. At the time of the work of Aloueimine (2006), the average waste density in Nouakchott was 410 Kg/m^2.

4.1.3. Composition of waste by origin

At least 85.1% of household waste (D1, D2, D3, D6, D8, D9, D10, D11) and 55.16% of industrial waste (D4, D5, D7, D12) are found in most landfills. Similar results have been found in several localities in Africa. In Bembéréké and Nouakchott, solid waste was 99% (Ngahane, 2015) and 90% (Aloueimine, 2006) of household waste, respectively. This predominance of waste types in the study area could be explained by the location of the landfill, which is not far from the dwellings and accessible to all without control. Agricultural waste is present with a low rate at landfills D01 (4.59%), D02 (8.58%), D03 (1.66%), D10 (9.61%) and D11 (7.15%). As for medical waste, it is present only in two dumps D3 and D4 with low levels respectively with 4.82% and 0.05%. Industrial waste is said to come from industrial plants in the industrial zone, and medical waste is said to come mainly from health centers without incineration facilities.

4.1.4. Distribution by composition

Most dumps are composed primarily of organic, plastic, fine, glass and metal waste. Organic waste is the dominant component of landfills (D1, D2, D3, D5, D6, D8, D9 D10, D11) with a minimum content of 42.56%, followed by plastics with a minimum content of 38.85% on two landfills (D4, D11). These two types of waste make up on average 68.42% of the waste from all landfills. The high level of organic waste is believed to be due to the presence of putrescible waste, waste from green spaces and markets, and crop residues in household and agricultural waste. The results of Sané (2002) on solid waste from Abidjan showed comparable results with 50.9% of organic waste, mainly consisting of fermentable and vegetable waste. The work of Merzouki et *al*. (2011), in the examination of waste from the Fkih Bensaleh landfill, had also found a dominant fraction of organic matter at 77% in the waste package. Thus, in the Organization for European Cooperation and Economic Development (OECD) report (2008) 49% of Spain's solid waste consisted of organic waste. The ash and the glass are moderately representative in the dumps with 20.44% and 10.11% respectively. These different components of the waste reflect a heterogeneous face of the dumps in the industrial zone of the town of Bobo-Dioulasso. The majority of plastics and glass found in landfills are of industrial (agro-food industries), medical and household origin. Matejka et *al*. (2001) found similar results on solid urban waste (DUS) in Guinea with 22.8% of plastics. The OECD report also found 12% glasses in DUS in Germany and Luxembourg. However Ezz (2003) found a lower rate of 2% for plastics and 3% for glasses on DUS in Egypt, household waste from Yaoundé was poorly represented in glasses (1.7%) and metals (0.8%) (Ngnikam et *al*., 2017). Merzouki et *al*. (2015) evaluated metals (1.8%) and glasses (0.9%) at the Fkih Ben Salah landfill. The 20.44% of fine (ash) comes from household waste and the permanent burning of garbage (Wang et *al*., 2023) at landfills. The total fraction of fine waste remains relatively comparable to that obtained from other cities in African countries, including 33.8% Fkih Ben Salah (Biaou et *al*., 2019) and 37% in Bamako (Adamou et *al*., 2023). However, in Annaba, Cheniti et *al*. (2013) found 12% of household waste. Heavy metals represent a low average level of 1.04%. This result corroborates that of Yé (2007) on the average composition of the rubbish bins of the town of Bobo-Dioulasso in metals which was 1.1%. This low level is thought to be due to the recovery of certain materials containing metals (iron, copper, zinc, etc.) for possible recovery (recycling, reuse, etc.) (Naïma et *al*., 2012). The results of Zaafour et *al*. (2019) corroborate by saying that the majority of the waste consists of metals and plastics respectively at 29% and 30% because the waste is varied in nature and beneficial to waste pickers, who dig into the waste to recover everything they find important (Naïma et *al*., 2012; Zaafour et *al*., 2019). In sum, the landfill has a very high potential for material recovery (ADEME, 2021b) or 89.9% of the total waste composition; 23.8% of the waste (plastic, metal) could contribute to material recovery and 66.1% (organic, ash) to organic recovery (Bah et *al*., 2021; Naïma et *al*., 2012; Zaafour et *al*., 2019).

4.1.5. Breakdown by degradability

Composed of various wastes, the industrial zone dumps have an average content of 51.92% of compostable waste. Cheniti et *al*. (2013) also found that 53.27% of household waste could be recovered by composting. The work of Bah et *a*l. (2021) found 33% of compostable waste in Faladié's household waste consisting solely of remaining food, vegetables and fruits, leaves, wood, unsoiled paper, biodegradable textiles and skin residues. Furthermore, composting is a valuable alternative as it reduces methane emissions from aerobic decomposition of organic waste and is an alternative to petrochemical fertilizers that emit particularly nitrous oxide (N_2O) (Zaafour et *al*., 2019). The proportion of semi-inert and inert waste, respectively 33.84% and 14.24%, is also significant (Zaafour et *al*., 2019). On the other hand, the level of inert waste is low compared with 57% of Bah et *al*. (2021) and 55% of Ngahane (2015).

4.1.6. Distribution by Hazard

Predominantly composed of medical and biomedical waste, the ultimate hazardous waste has an average rate of 2.26% relatively above the 0.3% obtained by Bah et al. (2021) in Faladié. In contrast to the 1% of hazardous waste generated by solid waste in Bembéréké (Ngahane, 2015), at all landfills, potentially hazardous waste is found with a minimum rate of 11.83%. According to ADEME (2021a), the supply of hazardous waste to waste disposal sites in France is 5%. Burning of waste on the site is frequently observed in an anarchic and random manner. This contributes enormously to a reduction in waste volume but poses a long-term threat as some studies have shown that open burning of household waste produces huge amounts of CO_2, NO_x and SO_2 (Wang et *al*., 2023). Unlike the organic part of household waste, heavy metals in household waste are not destroyed during incineration, and will therefore contribute to increasing the heavy metal content of certain ecosystems (Menard, 2003).

4.2. Characterization of the physico-chemical parameters and heavy metals of waste from landfills in the industrial zone

4.2.1. Assessment of heavy metal contents

All of the waste samples analyzed contain heavy metals at varying concentrations. These results corroborate those of Bodjona et al. (2012), which had found heavy metals (Pb, Cd, Ni, Cu and Zn) in the fine fraction of the waste with contents that varied depending on the metal under consideration. Thus, the large variation in heavy metal contents can be associated with the high heterogeneity of the waste (Merzouki et *al*., 2015). Depending on the importance of their contributions in the different categories, the same metals were found in household waste in Nouakchott (Aloueimine, 2006). Furthermore, the work of Ibrahim et al. (2020) confirmed the presence of heavy metals in landfills with a decrease in the following levels: Pb > Zn > Fe > Cu > Cr > Ni > Cd > As. In general, all the metals analyzed have maximum levels more or less above the limit values according to AFNOR U44-05. Furthermore, the average concentration of Cd (5.28 mg/Kg), Hg (5.81 mg/Kg) and Zn (7973.31 mg/Kg) is higher than the accepted standard. These results show that heavy metals are abnormally present in waste from landfills, as has been demonstrated by numerous studies (Merzouki et *al*., 2015; Ibrahim et *al*., 2020). However, Aïna et *al*. (2007) did not find Cd in the Saaba landfill in Burkina Faso, but average Zn, Ni, and Cu contents ranged from 200 to 300 mg/kg and Pb levels ranged from 500 to 700 mg/Kg. Solid urban waste from the city of Tunis contains 3.6 mg/kg Cd (Ayari et *al*., 2008) similar to that found in our study. The work of Compaoré et al. (2010) on a landfill site in the town of Bobo-Dioulasso had found Zn (137.5 mg/Kg); Ni (12.5 mg/Kg), Pb (37.5 mg/Kg), Cu (14.5 mg/Kg) levels below the limit values indicated by the standard and the results which we have also reached. Similar results were found by Bodjona et al. (2012) in the city of Agoè in Togo.

4.2.2. Assessment of physico-chemical parameters

Analyzes of the samples give us an average low acid pH (6.50) at all landfills, which could lead to the release of metals into soils and groundwater (Ibrahim et *al*., 2020). Contrary to the work of Bodjona et *al*. (2012) and Compaoré et *al*. (2010), the waste from the Bobo-Dioulasso industrial zone is acidic (5.83 to 7.06). Compaoré et *al*. (2010) in his work on garbage from a public dump in the town of Bobo-Dioulasso had found the same pH (7.30). Bodjona et *al*. (2012) had also obtained basic pH values in samples from landfills at the Agoè landfill in Togo. The values of certain parameters such as pH, C/N ratio and organic matter content indicate that the waste can be used as fertilizer (Compaoré et *al*., 2010). Organic matter levels range from 5.63 to 68.84%, which is consistent with other work by Bodjona et al. (2012) and Naïma et *al*. (2012). Our results also support those of Compaoré et *al*. (2010) for the values obtained with the physico-chemical parameters such as C, MO, N and P.

V. CONCLUSION

The aim of this work was to characterize the waste from the rubbish dumps in the Bobo-Dioulasso industrial zone. The results show that all landfills in the landfill cover highly heterogeneous waste. Waste categories such as fine waste are most represented in almost half of landfills followed by plastic waste. When looking at the origin, it is found that household and industrial waste are the most prevalent. Organic waste also ends up in landfills. Given its high content of putrescible organic matter, the landfill has a high recovery potential for composting. The values of certain physicochemical parameters such as pH, C/N ratio and organic matter content indicate that the waste is of good agronomic quality. However, all the samples of waste analyzed contain heavy metals at concentrations more or less higher than the value allowed by the AFNOR U44-051 standard. The results of the present study have made it possible to demonstrate the presence of heavy metals and to carry out the typology of waste at landfills in the industrial zone of Bobo-Dioulasso. These results should serve as a basis for local authorities to take decisions to raise awareness and prevent health and environmental risks arising from the landfill.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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