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Characterization of Household Solid Waste in the Town of Abomey—Calavi in Benin

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ABSTRACT

Identification of waste characteristics is an important step towards improving waste recovery. The aim of this research was to determine the physical and physico-chemical characteristics of waste of Abomey–Calavi city and to study the relationship between standard of living and average ratio of daily waste generated by each person. In this study the methodology used French standards to characterize particle size and typology of solid waste generated by the population of Calavi City in Benin, West Africa. According to home criteria, the study area was stratified into three distinct levels of standard of living called: high standing, medium standing and low standing; Waste from 60 households was weighed daily. The total waste produced by each household was collected seven (7) days a week, for a period of three weeks. Waste characterization was performed using ratio, size granulometry and typological composition. Physico-Chemical analysis including organic mater, pH, Total Organic Carbon, total Kjeldahl nitrogen and metal trace element were also performed. To better assess waste compostability, water extractable organic matter was quantified and qualitative identification was made with XAD8 and XAD4 resins. Results show that the amount of waste increases with the standard of living; the average ratio of daily waste generated is 0.89 kg·day^{-1}·person^{-1}. Independently of the standard of living, fermentable compounds represent the largest proportion of waste materials (45%). Qualitative difference of waste content in organic matter is shown as a function of the population's living standards. These results could be explained by a higher consumption of meat in the households with a higher standard of living, reflecting a greater proportion of transphilic (TPI), and hydrophilic (HPI) fractions. The C/N ratio is lower in the high standing households than in low ones. Metal trace element analysis showed a low but still significant pollution, whereas high iron and aluminum concentrations were found in all standings. In conclusion we propose a strategy for waste management in Abomey-Calavi based on sorting at the source to eliminate plastic waste and valorization of wastes via composting.

***Keywords**: Wastes, Standard of Living, Water Extractable Organic Matter, Metal Trace Element, XAD8/XAD4 Resins*

1. Introduction

Choice of waste management systems depends on decisions by city leaders as well as strategic structures related to the nature, quality and quantity of waste produced [1], [2]. Waste management is a challenge that local authorities and researchers address using multidisciplinary approaches ranging from the humanities to exact sciences such as biology and engineering [1].

The level of development of a country has an impact on its waste management choices [1,3]. According to C. Riber *et al.*, developed countries utilize various methods for waste management which give way to renewable energy forms and the emergence of new products such as compost [4]. In these countries, considerable investment is made to recycle waste for the benefit of agriculture [5, 6]. V. François *et al.* (2006), however, notice that waste management in developing countries remains an additional weakness which continues to hinder their emergence [1]. According to K. Kapepula *et al.* (2007), the noticeable delay in waste management, observed in developing countries, is probably due to insufficient investment and difficulties in addressing the issue with approaches suitable to their socio-economical context [2]. According to L. Parrot *et al.* [7] and A. Afon [8], there are insufficient studies focused on waste characterization in waste management planning in African cities which hinders their decision-making in regards to adapting waste management as a tool of environmental protection. Waste characterization is the prerequisite for developing management strategies and/or for maintaining up to date data. The lack of data is due to the exorbitant costs of the methodologies coming from developed countries, and on their inappropriate transfer to less developed countries. These two aspects prevent effective and sustainable waste management in developing countries [5,8].

In Benin, (West Africa), few scientific studies have undertaken the management of household waste. The present study was initiated to overcome this deficit. Its objective is to contribute to better waste management. For this reason, this study will characterize the typology and size of waste particles, their physico-chemical characteristics, organic matter content and contamination by metal trace element to better determine the amount of solid waste produced and collected at the source in the district of Abomey-Calavi, Benin.

2. Materials and Methods

2.1. Area of Study

Wastes have been collected at source in Calavi town in Abomey-Calavi district (**Figure 1**).

Geographically, the district is located at 6°26'46.8" north latitude and 2°20'53" east longitude; population is estimated to 307,745 inhabitants [9].

The district of Abomey Calavi covers an area of 539 km^2 with an average population density of 571 inhabitants per km^2, unevenly distributed within nine (9) administrative subdivisions. Seventy four percent (74.12%) of the population lives in administrative subdivisions of Godo- mey and Calavi [9]. The choice of the Calavi district offers the advantage for the present study, that three distinct standard of living levels are present in a single area.

2.2. Sampling

Sampling was conducted according to methods used by Bernache-Perez and al [10,11]. The target population represents all households in the Abomey Calavi district. Stratified random sampling was performed. According to home criteria, the study area was stratified into three distinct levels of standard of living called: high standing, medium standing and low standing [10,11]. Criteria to assess standard of living were based on building materials, finish work, and access to electricity and running water.

For each category, twenty (20) households were selected at random. Bins were distributed each day to the 60 selected households to collect the waste generated daily. Household wastes were sampled and routed to the sorting site daily. Waste from each household was weighed daily. The total waste produced by each household was collected seven (7) days a week, for a period of three weeks.

2.3. Sorting

For each sorting operation, 500 kg of household waste were divided into four equal parts. A part was taken for physico-chemical characterization; two other parts were selected and submitted to particle size and typological sorting [11]. The fourth part was eliminated.

Waste composition was divided into eight (8) main categories: fermentable, metals, glass, plastics, paper, sand, gauze and other materials [6]. Gravel, paving stones and debris from materials used in house building were gathered in the category “other materials”.

Particle size characterization was performed on a sorting table with pores of various diameters (100 mm, 80 mm and 20 mm) [11,12].

2.4. Physico-Chemical Analysis

Wastes were dried at 105˚C for 24 hours and then were crushed, (2 mm and 0.25 mm) [1]. Organic matter, pH, Total Organic Carbon (TOC), Total Kjeldahl nitrogen and concentrations of metal element traces [1,2,4,8] were analyzed using fine powder samples.

Organic matter was determined after calcination of 3g of dry waste at 550˚C for 4 hours. Organic matter rates were obtained in accordance with the difference between mass of dry matter before and after burning compared with initial mass introduced in the furnace [2,4].

Values for pH were measured on a suspension of thin powder in boiled water with a 2.5 liquid/solid weight ratio. Water mixed with waste was homogenized and then cooled to room temperature [6].

TOC was measured using a Total Organic Carbon analyzer, Solid Module: Shimadzu_SSM 5000.

Determination of nitrogen portion was made with the Kjeldahl method [13,14].

Reflux wet mineralization (aqua regia), was chosen with 1g of sample and 20 ml of *aqua regia* (1/3 HNO_3 –2/3 HCl) [15]; Metals Al, Fe, Mn, Pb, Zn, Cd, Cr, Cu and Ni were determined by ICP AES JY 2000 Ultrace sequential.

2.5. Extraction and Characterization of Water Extractable Organic Matter (WEOM)

2.5.1. Extraction

Water Extractable Organic Matter (WEOM) was extracted by shaking 200 g of waste thin powder in 400 mL of ultrapure water using 500 mL plastic bottles for 15 min. The mixture (emulsion) set for 15 min. The supernatant liquid was subsequently filtered through 0.45 µm membrane filters (Durapore®, Millipore, France). WEOM was conserved in the dark at −24˚C in acid-washed and oven-dried glass flasks [16,17].

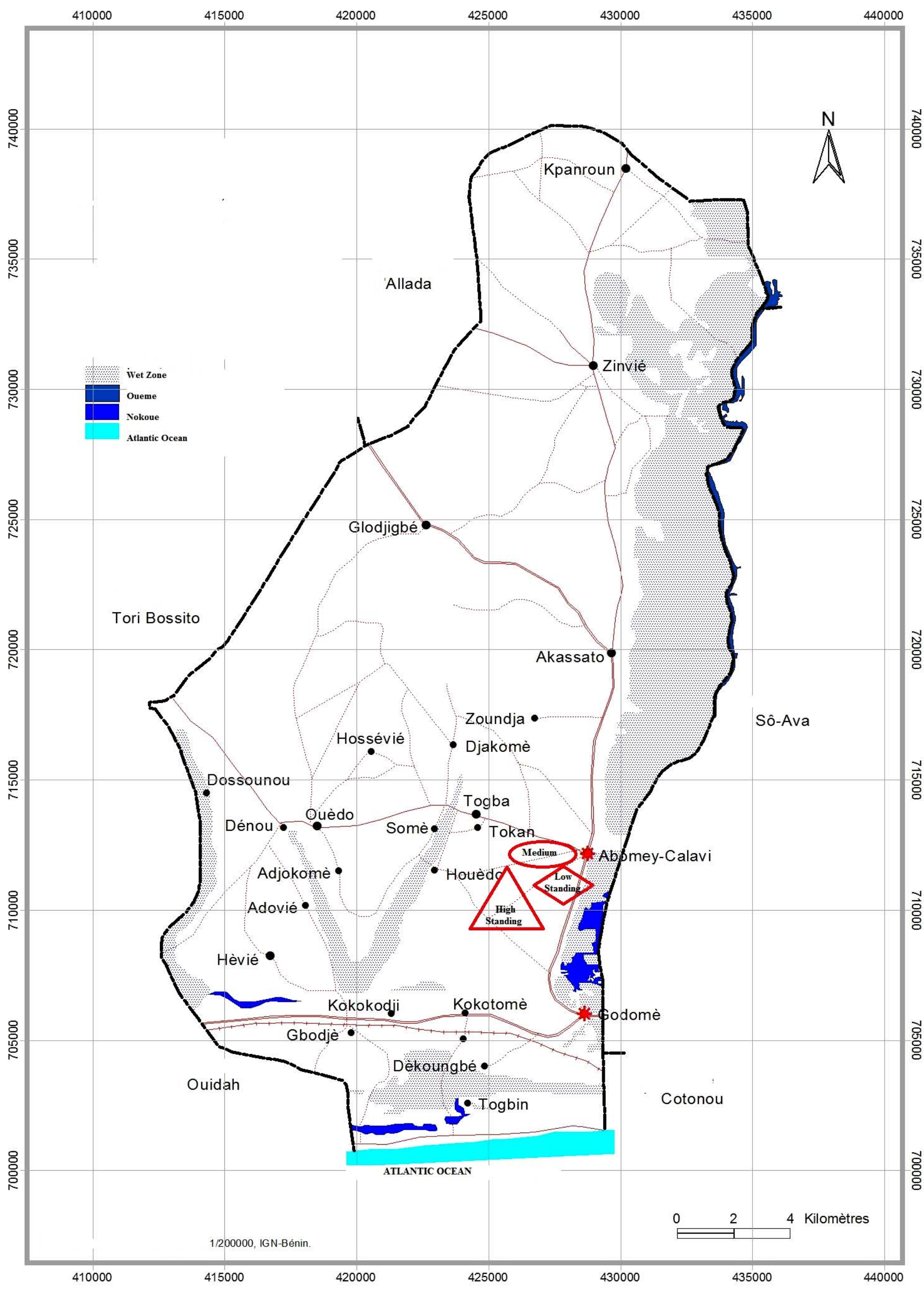

Figure 1. Physical location of Abomey – Calavi District.

2.5.2. Fractionation on XAD-8/4 Resins

Fractionation on XAD resins was performed according to a method modified by Mohammad H, Martin and Mousset using Amberlite XAD-8 and XAD-4 resins connected in tandem (**Figure 2**) [17,18]. Resins were extensively cleaned by Soxhlet extraction using different organic solvents and continued using acidified Milli-Q water (HCl, pH = 2) until resin effluent contained less than 0.20 mg·C·l^{-1} (Hassouna *et al*.). Prior to fractionation, samples were acidified to pH 2 by adding 5.0 M HCl. No precipitation following acidification was observed in any of the samples analyzed in this study. The hydrophilic acids fractions (HPIA), contained in the resin effluent, were progressively collected during fractionation. The hydrophobic (HPOA) and transphilic (TPIA) acid fractions were respectively recovered by back eluting XAD-8 and XAD-4 resins using 0.10 M NaOH. Fractions were named following the nomenclature proposed by Croué *et al*. [16]. Due to this relatively high yield, no further manipulations were attempted to recover residual OM non-desorbed with 0.1 M NaOH. Immediately after desorption, all fractions were re-acidified to pH 2 and kept in the dark at 4˚C for further analysis.

Carbon contained in the three fractions (Total, Transphilic, Hydrophobic and hydrophilic fraction) was analyzed by Total Organic Carbon analyzer, Solid Module: Shimadzu_SSM 5000.

3. Results and Discussions

3.1. General Characteristics

Average ratios (**Table 1**) registered in Abomey Calavi show that daily production of waste is lower in Benin than in France or USA, two of the top five countries in terms of gross domestic product (GDP). Moreover, results of this study do not differ much from those observed by Tezanou *et al*. [20] in Ouagadougou, a city with a socioeconomic level similar to Abomey Calavi. However, the results of Aouleimine in Mauritania revealed a lower ratio [19]. But comparison would be difficult because the ratio for Mauritania does not take into account organic matter. Compared with some other countries with limited resources, the ratio of daily waste generated per capita in the city of Calavi is high. However, comparison must be initiated because dates of study are different and waste production grows over time. Ma. C. Hernandez-Berriel, *et al.* indicated that ratio changes over time [20]. For example in Mexico the daily ratio was 0.865 in 2000 and 0.963 in 2005 [21]. Similarly, A. Le Bozec showed that, in 40 years, the production of household waste was multiplied by two in France [22]. This research helped to establish the link between the living standards and quantity of waste produced. Rotich K. *et al.* confirmed that changes in lifestyles, food habits, consumption and population growth had a strong impact on daily waste production. Increase of waste production in developed countries and in developing countries is due to impact of wealth, of food habits and reflects a relationship between the standard of living and quantity of waste produced.

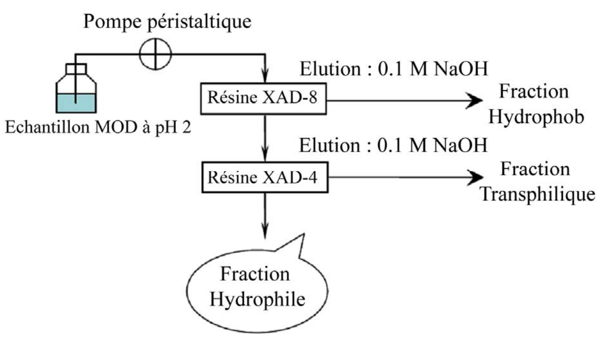

Figure 2. Global division of the (WEOM) on XAD 8/4 XAD resins.

Moreover, similar variation in the standard of living was observed between the countries compared in **Table 1**. High and medium standings have close values, though systematically slightly larger for high standing. Low standing produced the lowest amount of waste according to Tezanou J. and Sara Ojeda-Ben [11,23].

Fermentable matter was the largest proportion regardless of the standing status (**Table 2**). Green wastes (vegetable, scraps) were the most representative components of fermentable materials. These results confirm those of P. Féniel *et al.* and O. Oyelola *et al.* [6,24]. High proportion of fermentable materials in waste could suggest organic matter valorization by composting.

Table 2 also showed that sand was present in more than 20% in each standing class, especially in the lower class where the proportion is around 40%. The type of house explained the presence of sand. In the lower class, the soil was generally not covered. The sand was much more present in these homes in contrast with higher standing homes in closed building protected from erosion by a generally well arranged courtyard. Debris and other construction materials represented less than 5% in the lower class household waste whereas they were in large quantity, up to 22%, of high class waste where building improvements are more common. All standing considered paper and cardboard, plastics, glass, metals, were less than 5%. Paper and cardboard waste were easily recyclable.

Material size was under 20 mm for nearly 30% of waste in high and medium standing households and more than 50% in the low standing ones (**Table 3**). These results showed that sand presence could be an obstacle to waste valorization through composting.

Table 1. Comparison of ratios of Abomey—Calavi with other cities.

	Daily ratio per standing (kg/day/inh.)			Average ratio of the population (kg/day/inh.)	Sources	Ranks GDP (2)
	High	Medium	Low			
Ab-Calavi/ Benin	0.94	0.92	0.82	0.89	Present study (2009)	133rd
Ouagadougou/ Burkina faso	0.68	0.61	0.56	0.62	Tezanou J. (2001) [23]	128th
Nouakchott/ Mauritanie (1)	0.40	0.34	0.30	0.35	Aouleimine (2005) [19]	150th
Paris /France	na	na	na	1.4	A. Le Bozec (2008) [22]	5th
Washington/USA	2.51	2.0	1.85	2.10	EPA (2002) [21]	1st

na: not available. (1) Nouakchott ratios do not take into account organic material. (2) Source: World Bank and IMF.

Table 2. Typological Characterization of waste.

	High standing	Medium standing	Low standing
Fermentable (%)	48.26 ± 4.53	55.34 ± 3.28	49.61 ± 4.12
Sand (%)	21.45 ± 5.26	20.99 ± 7.01	38.76 ± 5.51
Cardboard paper (%)	0.50 ± 0.05	2.29 ± 0.23	1.55 ± 0.21
Plastics (%)	2.68 ± 0.25	3.81 ± 0.15	1.67 ± 0.02
Glass (%)	2.68 ± 0.08	0.19 ± 0.14	1.55 ± 0.08
Metal (%)	0.27 ± 0.10	1.90 ± 0.81	1.54 ± 0.07
Textiles (%)	0.34 ± 0.02	5.72 ± 0.09	1.55 ± 0.18
Other (%)	22.79 ± 5.98	8.59 ± 2.21	3.10 ± 1.95

Table 3. Granulometry characterization of waste.

Granulometry size (mm)	High standing	Medium standing	Low standing
> 100	0.33 ± 0.05	4.25 ± 1.23	11.60 ± 0.97
] 100-80]	1.84 ± 0.86	17.28 ± 5.94	14.43 ± 7.75
] 80-20]	70.97 ± 21.51	49.20 ± 15.89	20.80 ± 14.02
< 20	26.84 ± 15.12	29.25 ± 18.88	53.08 ± 8.05

Plastic bags, metals and paper constituted the major part of waste debris of diameter between 20 and 80 mm. For this category of waste, high standing uses an extremely high quantity of plastic bags, the highest proportion (70%) in these samples. A reflection on the use, recovery and recycling plastic waste has to be conducted.

3.2. Chemical Characterization

In agreement with results observed previously, organic matter concentration and pH were similar (**Table 4**) irrespective of the standing. The rate of organic matter is lower in low standing than medium and high standing.

In medium standing, green wastes from food mainly composed of fruit and vegetable left-overs were present. Organic matter rate was an important indicator in the choice of waste treatment process (incineration or composting). Usually a high organic matter rate suggests composting. C/N ratio varies with the standing confirming that waste quality was not identical for all standings. C/N ratio of low standing was high and closer to the ratio of lignin content wastes [25]. Concerning C/N ratio of medium and high standing, they were quite similar. It seems evident that the difference between these ratios is related to the type of food consumed in each standing. High standing populations eat much higher quantity of meat. This ratio is also a good indicator of compostable waste. Compostable waste must have a C/N ratio close to 15 to allow faster organic matter degradation [25]. Wastes collected at the level of high and medium standing could be composted. On the other hand, C/N ratio could be too high in the lower standing to expect a rapid composting and satisfy industrial requirements.

3.3. Characteristics of Water Extractable Organic Carbon (WEOC) and Its Fractions

Although composting could be an appropriate way of waste valorization, identification of water extractable organic carbon (WEOC) had to be made. In this study,

Table 4. Chemical parameters of the solid waste according to the standard of living.

	High standing	Medium standing	Low standing
pH	7.85 ± 1.34	7.96 ± 1.19	7.70 ± 0.93
Moisture	57.41± 2.30	70.16 ± 1.53	73.4± 1.45
Organic matter (%)	63.33 ± 1.85	66.66 ± 1.73	52.73 ± 2.06
Total Organic Carbon (mg of carbon/g dry material)	15.26 ± 6.12	12.37 ± 6.51	17.52 ± 6.86
Nitrogen Kjeldahl (mg/g)	1.42 ± 0.23	0.73 ± 0.08	0.55 ± 0.04
Report C/N	10.72	16.83	31.97

the choice was to identify the total water extractable organic carbon (WEOC) and its 3 sub-fractions (**Figure 2**). This choice allowed us to better assess WEOC, the bioavailable fraction of wastes and the most accessible fraction to microorganisms. Extraction technique was based on the WEOM size, on the one hand, and on more or less hydrophilic functional groups on the other hand. WEOC-HPI represents the fraction of extractable organic carbon in water present in the hydrophilic phase not retained on resin. WEOC-HPO (retained on XAD8 resin) represents the fraction present at the hydrophobic phase and WEOC-TRA represents the transphilic fraction retained on XAD4 resin (**Table 5**).

Concentration of water extractable organic carbon is substantially the same irrespective of the standing. However, differences were observed for other fractions (**Table 5**). Results show that concentrations of hydrophilic fractions increase with standing. The higher the standing-, the more important the hydrophilic fraction is. Conversely, WEOC-HPO and WEOC-TRA ratios decrease when standing increases. M. Hassouna *et al.*, and Peuravuori *et al.*, reveal that WEOC-HPO fractions contain most large size aromatic molecules [17,26]. These hydrophobic substances reveal the presence of humic-like substances in waste produced by low standing people. These results must be compared with those observed in **Table 4**, in which C/N and organic matter proportions were higher in waste produced in high standing households. This confirms that waste quality was different according to the standing and that low standing wastes contain a non-negligible portion of green waste. The WEOC-TRA and WEOC-HPI fractions, however, include organic compounds of smaller molecular size with simple structures and low aromatic content. Their presence confirms the hypothesis of a relationship between the standing level and waste quality. As mentioned above, it is indicative of a higher consumption of meat in the high standing population. Nevertheless, these results confirm that waste, especially from high standing, could be composted.

3.4. Metal trace Element Analysis

Metal trace element concentration (**Table 6**) in wastes is also a fundamental criterion for choice of waste valorization. Presence of such pollutants in high concentration, in household solid waste, may create adverse effects on public health [15,25].

These concentrations are of the same order of magnitude as concentration ranges found in the literature [27, 28]. For wastes collected in Calavi, aluminum and iron represent the most important concentration, irrespective of standing. Lead concentration was under detection limit. These results confirm those of S. Mohan *et al*. (2009), and C. Riber *et al*, indicating that iron and aluminum are metals most commonly found in household solid waste [4,27]. Concerning differences between standing levels, it was observed that Mn, Cu, and Cd were present in the same concentration. In the case of Zn and Cr concentrations, they are always lower in low standing than in high and medium standing. Aluminum and iron contents were different in high compared to medium standing. The highest proportion of iron was observed in high standing, whereas the highest proportion of aluminum can be seen in the medium standing. This tends to confirm that low standing wastes are different, reflecting great differences between high and medium standing on the one hand, and low standing on the other hand.

Specific wastes present in the two higher standing levels probably increased the presence of metal trace element in household waste. Therefore, sorting household waste would lead to a significant decrease of metal presence. Composting of household solid waste after sorting could be the most appropriate method of waste management in Abomey Calavi.

4. Conclusions

Study of waste composition is an important step in selecting strategy for waste management. Results of this study have highlighted size characteristics and typology of waste per social standing level. They provide information on the average daily waste generated per capita in

Table 5. Average concentrations in WEOC of solid wastes and proportions of different fractions obtained by separation on XAD8 and XAD4 resins.

		High standing	Medium standing	Low standing
	WEOC (mg·C·l^{-1})	9.98 ± 0.97	9.88 ± 1.13	10.10 ± 1.05
Fractions(%)	**WEOC – HPI**	49.83 ± 0.80	31.05 ± 0.62	18.85 ± 0.41
	WEOC - HPO	19.24 ± 0.46	34.94 ± 0.65	36.42 ± 0.49
	WEOC - TRA	29.04 ± 0.64	30.57 ± 0.56	40.28 ± 0.59

Table 6. Metal concentration in waste according to standing.

		High standing	Medium standing	Low standing	Urban solid waste min -max
Al	**mg/g**	4.88 ± 0.21	7.17 ± 0.26	5.94 ± 0.16	4 - 9[a]
Fe		7.14 ± 0.36	5.27 ± 0.37	5.58 ± 0.51	5 - 11[a]
Mn		0.16 ± 0.01	0.18 ± 0.01	0.16 ± 0.01	0.15 - 0.25[a]
Zn	**µg/g**	0.17 ± 0.01	0.21 ± 0.01	0.09 ± 0.01	0.3 - 0.6[b]
Cd		2.37 ± 0.31	1.62 ± 0.29	1.81 ± 0.36	0.2 - 0.4[b]
Cr		95.95 ± 8.06	102.19 ± 8.01	70.44 ± 4.24	80 - 100[b]
Cu		14.52 ± 0.94	13.58 ± 0.88	12.53 ± 0.36	0.15 - 0.3[b]
Ni		44.01 ± 2.36	46.78 ± 3.32	32.22 ± 1.37	40 - 50[b]
Pb		BDL	BDL	<BDL	0.25 - 0.50[b]

BDL: Below Detectable Limit = 12.71 µg/g. [a] [27]. [b][28].

Abomey-Calavi.

These results have confirmed relationship between social standard of living and average ratio of daily waste generated by person. Metal trace element concentrations were not very significant in the household waste studied; however, large quantities of plastic bags are identified indicating that a policy of plastic waste recycling is required. A high rate of organic matter proportion is a good reason to suggest household waste valorization via composting.

Characterization of organic matter after extraction followed by fractionation on ion exchange resins enables a better understanding of water extractable organic matter and different sub fractions. A study of these different fractions will be a matter for deeper analysis, in particular for better organic-matter composting and metal separation at source.

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