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Potential for the Recovery of Solid Household Waste in the City of Ngaoundere (Cameroon)

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Abstract

The city of Ngaoundere collected and delivered to the landfill an average of nearly 39,000 tons of household waste per year, most of which is collected without prior sorting and directly disposed of in landfills, thus exposing the city and its inhabitants to environmental and health contamination risks. This study aims to provide some technical data useful for developing appropriate waste recovery strategies for the solid waste generated in the city of Ngaoundere. To this end, the study was conducted in the city's three districts. The solid waste delivered to the landfill was quantified and then categorized during the dry and rainy seasons of the Vina Department. The fermentable fraction then underwent physicochemical characterization. The results show a predominance of fermentable waste (57.5%), followed by textiles (9.2%), plastics (7.7%), and cardboard (6.9%). These four categories represent 81.3% of the waste collected. Composites, paper, unclassified combustibles, and fine particles (sand and dust) constitute between 2% and 4%. Non-combustible materials, glass, and metals are less abundant (1% to 2%). The waste has a slightly neutral pH (7.6), an average moisture content of 52%, a high volatile matter content (74.5%), and a favorable C/N ratio (26.8), indicating strong potential for composting and biological recovery. These results provide essential information for public authorities and private stakeholders to plan appropriate waste management strategies, including source separation, composting, methanization, and recycling. The study thus highlights the need to transform household waste into valuable resources, contributing to sustainable management and the promotion of the circular economy in the city of Ngaoundere.

Keywords

Household Waste, Characterization, Recovery, Composting, Ngaoundere

1. Introduction

Rapid urban population growth and evolving consumption and production patterns are leading to a significant increase in the production of household solid waste (Hoornweg & Bhada-Tata, 2012; Ngambi, 2015). This accumulation of waste represents a major challenge for environmental protection and public health, particularly in cities in developing countries where management systems are often inadequate (Ngnikam & Tanawa, 2006; Tchuikoua & Elong, 2015; Forje, 2021). Landfilling remains the most widely used method for solid waste disposal due to its relatively low cost. However, this practice generates significant environmental impacts, such as the production of heavy metals, leachate and biogas, which contaminate soils, groundwater, and ambient air (Noubissié et al., 2016; Djimarabeye et al., 2024; Kassie et al., 2021).

In Cameroon, several studies have documented these challenges. For example, Tchuikoua (2010) Tchuikoua & Elong (2015), Dengko Totso (2015) and Doumtsop & Chianebeng (2025) showed that waste management in cities like Douala and Yaoundé remains linear and focused on collection and landfilling, with limited development of recycling and recovery channels. This model of solid waste management, which has existed for several years in Cameroon, had already been criticized in the South-West Region of Cameroon, specifically in the city of Limbe by Manga et al., (2007). These authors highlighted the poor waste management system in Limbe, characterized by a flawed sorting system, irregular collection schedules, and landfilling using an uncontrolled method as the only treatment option. This description is characteristic of the household solid waste (HSW) management system also found in the city of Ngaoundere. Indeed, in Ngaoundere, the capital of the Adamawa region, the HSW is handled by a private contractor (HYSACAM), covering the city's three districts with a fleet of only seven trucks. No sorting at the source is carried out, and recycling channels are virtually nonexistent. Collected waste is directly buried in landfills. The causes of negative impacts on the physical environment and public health are primarily observed during the collection and inadequate treatment of household solid waste (HSW). Indeed, the irregular execution of the collection operation by HYSACAM leads to the accumulation of garbage in the open air and over large areas. This garbage is unfortunately visible both in neighborhoods and along urban streets. Furthermore, once the HSW is sent to a landfill, the waste, whether buried underground or left in the open air within the city, is exposed to the elements (rain and sun). Over time, leachate containing dissolved pollutants (nitrates, phosphates, metals), odors, and greenhouse gases contaminates the soil, water sources, and air (Nduwimana, 2025; Mwanza & Mbohwa, 2017; Lemieux et al., 2004; Njeru, 2006; Asfaw et al., 2023). The heterogeneity and decomposition of the fermentable fraction of this waste promote the proliferation of insects, including mosquitoes, which are responsible for certain tropical diseases such as malaria (Kassie et al., 2021). To help avoid, or at least limit, these environmental and health risks in the city of Ngaoundere, it is imperative to develop a sustainable strategy for managing its municipal solid waste.

Planning sustainable waste management strategies relies on reliable data regarding the composition and quantity of waste produced (Reinhart & McCauley-Bell, 1996; Sidi Ould, 2006). However, this information remains largely unavailable or outdated for the city of Ngaoundere. In this context, this study aims to characterize the city's household waste both qualitatively and quantitatively, in order to provide a solid scientific basis for developing appropriate recycling and recovery streams, thereby contributing to more sustainable management and the promotion of the circular economy (Ngambi, 2015; Dengko Totso, 2015).

2. Material and Methods

2.1. Presentation of the Study Area

The city of Ngaoundere, capital of the Adamawa Region (Cameroon), is a transitional and transit city between the South and the North of the country. It is located on high plateaus with an altitude ranging from 1000 to 1500 m and covers an area of approximately 17,196 km^2. The city is administratively divided into three districts and its population is estimated at nearly 300,000 inhabitants (INS, 2010) (**Figure 1**).

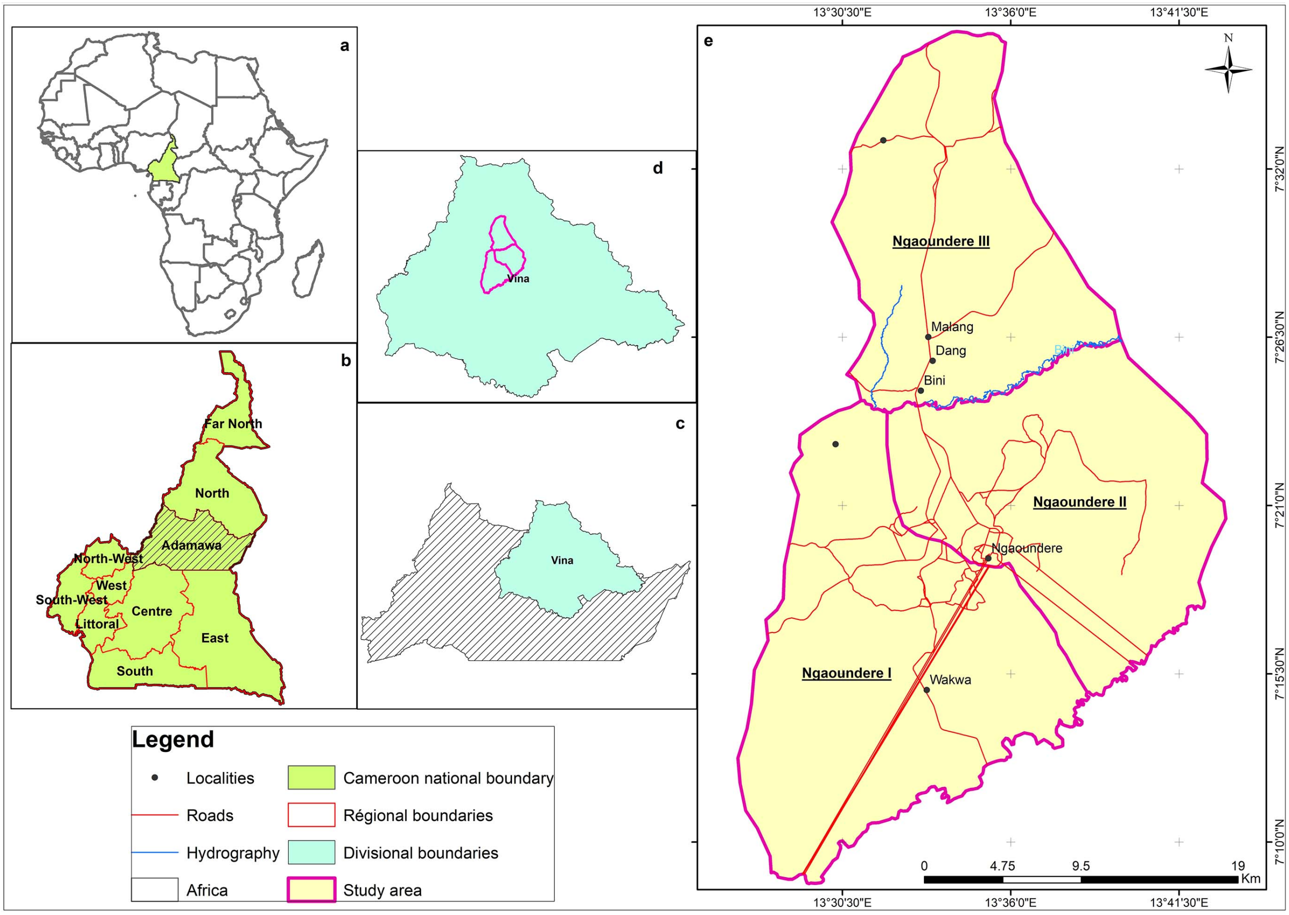

Figure 1. Map showing the location of the study area.

Ngaoundere has a tropical Sudano-Guinean climate, tempered by altitude, with annual rainfall between 1500 and 1600 mm. The vegetation is characterized by wooded savanna. The local hydrography is dense, with several watercourses forming a dendritic-type hydrographic network, facilitating both natural irrigation and urban drainage. Socioeconomically, the Fulani (Foulbé) are the majority ethnic group, but the city is cosmopolitan, hosting several other communities. The main economic activities are livestock farming, agriculture, and trade, with the city playing an important role as a regional transit and exchange hub. These characteristics directly influence the generation and composition of household solid waste produced in the city (Dengko Totso, 2015; Hotou, 2016).

2.2. Quantification of Solid Waste

Since 2008, the management of street sweeping, collection, transport, and landfilling of solid waste in the city of Ngaoundere has been handled by a private contractor with a fleet of seven (7) trucks. To optimize collection, the city's three districts have been divided into five collection routes, combining door-to-door collection (individual and collective) and collection at fixed points. The collected waste is transported to the landfill where it is weighed on a weighbridge before being buried and compacted. The total quantity of waste collected was determined over a ten-year period (2010 to 2020), using daily tonnage data provided by the service provider. This approach allows for a reliable estimate of the annual production of urban solid waste (Dengko Totso, 2015; Hotou, 2016). It should be noted that the tonnage data used in this study represent the quantities of waste collected and transported to the landfill, and do not account for the total waste generated within the city.

2.3. Physical Classification of Waste

The qualitative and quantitative characterization of waste was carried out according to the method recommended by ADEME (2014), which describes the steps involved in implementing a characterization campaign and proposes various methodological options adapted to local authorities. This method is based on five main steps: collection, sampling, sorting, analysis, and use of results (Manga et al., 2007). The characterization campaign was conducted continuously during the dry season (February to March 2021) and the rainy season (July to August 2022). It covered the three municipalities of the city of Ngaoundere, with collection areas defined according to the service provider's collection routes.

The waste collection service in the city of Ngaoundere is operated using a fleet of seven (7) trucks, including three compactor trucks (BOM), two non-compactor trucks (VDP type), and two roll-on/roll-off (ampliroll) trucks with removable containers. For the purpose of this study, it's mainly compactor trucks (BOM) were considered for sampling, as they are specifically dedicated to door-to-door household waste collection across the different neighborhoods of the municipality. This choice ensures that the sampled waste is representative of household waste generated at the source, excluding waste collected from communal points or mixed deposits. Sampling was conducted along the predefined collection routes in each municipality. For each district, three collection rotations were carried out during each sampling campaign. During each rotation, truckloads were selected at regular intervals along the route, allowing coverage of different neighborhoods and socio-economic contexts. This approach ensured a representative sampling of household waste generated across the study area while maintaining operational feasibility.

Upon arrival at the landfill, the waste was weighed and dumped into piles in the sorting area, then homogenized by turning it over with a bulldozer. A quartering process was carried out to obtain representative subsamples, and a final subsample representing a representative subsample obtained through successive quartering was retained for characterization. The final subsample mass ranged between 150 and 300 kg. Each trial was repeated three times for each route and season, allowing for the calculation of standard deviations and the assessment of the variability in waste composition.

The collected waste was classified into 11 categories. The chosen categories are fermentable waste (DF), papers (P), cardboards (CA), composites (CO), textiles (Tex), plastics (Plast), unclassified combustibles (CNC), glass (Ver), metals (Me), unclassified non-combustibles (ICNC), and fine particles (ELF). Each waste category was weighed. To avoid issues related to certain liquid waste, plastic and glass packaging containing liquids was initially emptied before being weighed.

2.4. Physicochemical Characterization of Waste

2.4.1. Sampling

The collected waste samples underwent physicochemical analyses to determine their composition and energy recovery potential. Only the fermentable fraction was included in this characterization. Samples were taken during the pre-collection stage. Ten households were selected per district, where the pre-collected waste was first sorted. Households were selected using a purposive sampling approach based on accessibility and their location within the main collection areas. The sorting specifically consisted of removing all plastics, ferralitic materials, and silicates from the pre-collected waste. The pre-collected waste from the 10 households was mixed. The mixture was divided into quarters, and each sample used for characterization was taken from that quarter.

2.4.2. Characterization

1) Determination of moisture content, volatile matter and ash content

The moisture content of the sample, its volatile matter, and its ash content were determined according to the method defined by AFNOR (1982 and 1981). The moisture content of the samples was determined by subjecting them to the successive stages of drying at 105˚C in an oven until a constant mass was reached (24 hours), cooling in a desiccator, and then weighing on an electronic balance. The moisture content (M_c), representing the difference in mass before and after drying, was calculated using Equation (1).

$$M_c = \frac{M_1 - M_2}{M_1 - M_0} \times 100 \quad (1)$$

M_0 = mass of the empty basket (tare)

M_1 = mass of the basket containing the wet sample

M_2 = mass of the basket containing the dried sample

The volatile matter (VM) of a fuel is the portion of organic matter that escapes as a gas during combustion. To obtain this value, a sample was first dried at 105˚C, then burned at 550˚C for a few minutes (7 min). The volatile matter (VM) content of the sample, which represents the mass loss during heating, was calculated using Equation (2).

$$VM = \frac{M_{105^\circ C} - M_{550^\circ C}}{Mi} \times 100 \quad (2)$$

VM = volatile matter content (%)

$M_{150^\circ C}$ = mass of the sample after drying at 105˚C

$M_{550^\circ C}$ = mass of the sample after combustion at 550˚C

Mi = mass of the sample before drying

The ash content (Ac) was also determined after drying the sample at 105˚C, then calcining it at 550˚C until carbon-free white ash was obtained. The ash content per 100 g of dry matter was calculated using Equation (3).

$$Ac = \frac{MA \times 100}{Mi \times Md} \times 100 \quad (3)$$

Ac = ash content (%)

MA = mass of ash (g)

Mi = mass of the sample (undried)

Md = dry matter of the sample.

2) Determination of Organic Carbon and Nitrogen content

The determination of Organic Carbon was performed by the modified direct method according to SIST EN 13137 (2002) and DIN EN 19539 (2016). For this purpose, the sample was first dried, ground and sieved (Ø < 2 mm). Then 300 mg of the dried sample was introduced into ceramic sample boat and acidified using 500 µl of HCl (10%). Completeness of Inorganic Carbon (IC) elimination was verified by addition of a few drops of HCl (25%) until no more gas (CO_2) was produced. The sample boat was then placed onto a heating plate (40˚C) and dried overnight for approximaly 14 hours, and then automatically introduced into the furnace of the Total Organic Carbon analyzer (Multi N/C 2300 duo) at 900˚C for 2 minutes.

The total nitrogen content was determined using the Kjeldahl method proposed by the Quebec Centre for Environmental Analysis (CAEQ) reference MA. 300-NTPT 2.0 (2014). The sample first underwent acid deposition to convert its nitrogenous organic compounds into ammonia. The resulting ammonium ions were then reacted with salicylate, nitroferricyanide, and sodium hypochlorite to form an ammoniacal salicylate complex in an alkaline medium, which was analyzed by UV-Visible spectrophotometry at 660 nm.

All physicochemical analyses were performed in triplicate for each sample in order to ensure analytical reproducibility. The data analysis was primarily descriptive. Results are presented as mean values and standard deviations, without inferential statistical testing.

3. Results

3.1. Quantity of Waste Collected in the City of Ngaoundere

Table 1 shows the results of waste collected and delivered to the landfill in the city of Ngaoundere from 2010 to 2020. The average annual quantity of waste sent to landfill is 38,907 tons.

Table 1. Quantities of solid waste collected and delivered to the landfill in the city of Ngaoundere from 2010 to 2020.

Month/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	TOTAL Months
January	2761	2741	2392	2631	3174	3387	3561	2318	3714	3344	2503	**32,526**
February	2548	1824	2465	2178	2851	3138	3680	3812	2971	1843	3203	**30,513**
March	2761	2421	2223	2919	3122	3458	4165	3857	3641	2517	3438	**34,522**
April	2665	2457	1981	2568	3166	3420	3862	4514	3927	2785	3549	**34,893**
May	2548	2281	2544	2899	3036	3296	4283	3871	3413	3543	3356	**35,070**
June	2761	2390	2410	3482	2981	3532	3856	3524	4569	4930	3349	**37,784**
July	2867	2252	2479	4079	3175	3563	3814	3701	4527	4011	3354	**37,821**
August	2761	2405	2433	2656	3171	3482	3879	3524	3756	3702	3698	**35,467**
September	2798	2387	2271	2474	3250	3496	3776	3383	2021	3944	3685	**33,485**
October	3034	2568	2602	2942	3345	3518	3251	4259	5320	2495	4493	**37,827**
November	2869	2394	2378	2898	3005	3294	3864	4202	4466	3059	9888	**42,317**
December	2982	2253	2196	2643	3099	3764	3768	3578	4279	3631	3559	**35,752**
Annual total	**33,355**	**28,373**	**28,375**	**34,369**	**37,374**	**41,347**	**45,759**	**44,543**	**46,604**	**39,804**	**48,075**	

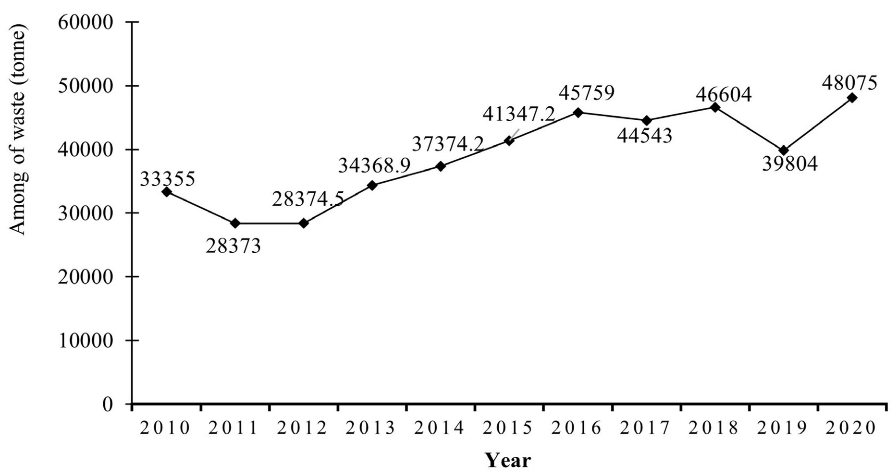

Figure 2. Evolution of the annual tonnage of solid waste collected in Ngaoundere from 2010 to 2020.

It reveals that the quantities of waste collected in Ngaoundere saw a significant overall increase over the period studied. The annual tonnage rose from 33,355 tons in 2010 to 48,075 tons in 2020, representing an increase of approximately 44% in ten years. This trend reflects the city's population growth over time, economic and commercial development, sustained urbanization leading to changes in consumption patterns, and the gradual improvement of waste collection coverage (Figure 2).

3.2. Seasonal Variations in Waste Collected in Ngaoundere

Figure 3 shows the monthly variations in waste delivered to landfill in the city of Ngaoundere between 2010 and 2020. It reveals that the peaks in waste collected are divided into two main periods.

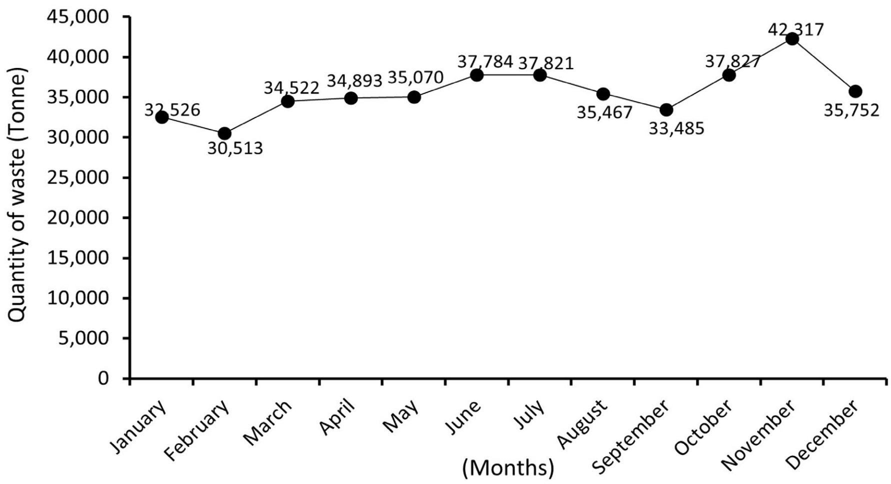

Figure 3. Monthly evolution of waste collected in Ngaoundere between 2010 and 2020.

The first is from June to September, corresponding to the local rainy season. This period sees high production, exceeding the annual average by slightly more than 20%. The second is from November to March. This corresponds to the dry season in the department and notably saw a record monthly amount of 9888 tons in 2020.

These variations are explained by an increase in commercial activity during the rainy season, and a greater abundance of green waste. This is compounded by the more frequent turnover of perishable goods and high urban population density, as well as seasonal cultural events. Statistical data reveal an average annual growth in waste, estimated at over 3.9% each year. The average tonnage between 2010 and 2020 was 38,907 tons per year, with a maximum-minimum range of 19,702 tonnes. This growth is similar to trends observed in other rapidly urbanizing African cities (Ngnikam & Tanawa, 2006).

3.3. Characteristics of Waste

It should be noted that waste composition and physicochemical properties presented in this section are derived exclusively from the characterization campaign conducted in 2021-2022, and not from the 2010-2020 tonnage dataset.

3.3.1. Distribution of Waste Categories by Municipality

Figure 4 shows the composition of solid waste collected in the different municipalities of the city of Ngaoundere based on the characterization campaign conducted during the dry season (2021) and rainy season (2022).

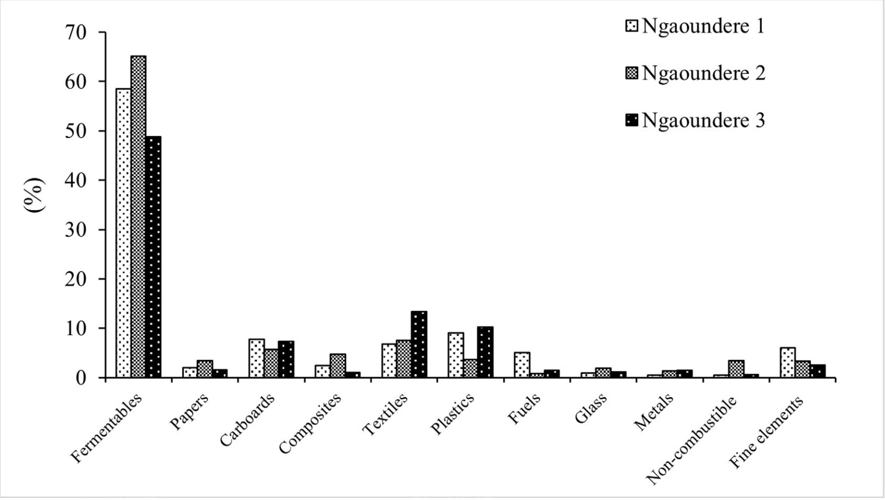

Figure 4. Composition of solid waste collected in the city of Ngaoundere.

This result shows a strong dominance of fermentable waste in the three municipalities. This indicates a food consumption primarily composed of fresh produce and a significant amount of organic waste. In Ngaoundere 1st, fermentable waste represents 58.5% of the total tonnage. Plastics (9.1%), cardboard (7.8%), and textiles (6.8%) follow. Fine materials constitute 6%, while paper and unclassified combustibles remain modest (approximately 2%). Glass, metals, and unclassified non-combustibles represent proportions of less than 1%.

In the Ngaoundere 2nd district, the proportion of fermentable waste is the highest of the three municipalities (65.1%). Textiles (7.5%), cardboard (5.7%), and composites (4.7%) are the most significant fractions after organic waste. Other categories, such as plastics, paper, fine materials, and non-combustible materials, represent between 2% and 3%. Glass, metals, and non-flammable materials remain the least represented (<2%). In Ngaoundere 3rd district, fermentable waste constitutes the lowest proportion among the three municipalities (48.8%). Textiles (13.4%), plastics (10.2%), and cardboard (7.3%) are relatively more abundant there. The other categories have proportions below 2%, indicating a composition more oriented towards dry waste.

3.3.2. Overall Composition of Household Waste in the City of Ngaoundere

The results presented in Figure 5 shows that fermentable waste represents the largest fraction, accounting for 57.5% of wet waste. This is followed by textile waste (9.2%), plastics (7.7%), and cardboard (6.9%). These four categories alone constitute 81.3% of the waste collected in the city. Composite waste, paper, unclassified combustibles, and fine materials (sand and other particles) each represent between 2% and 4% of the waste. Unclassified non-combustible waste, glass, and metals are the least abundant, with proportions ranging from 1% to 2%.

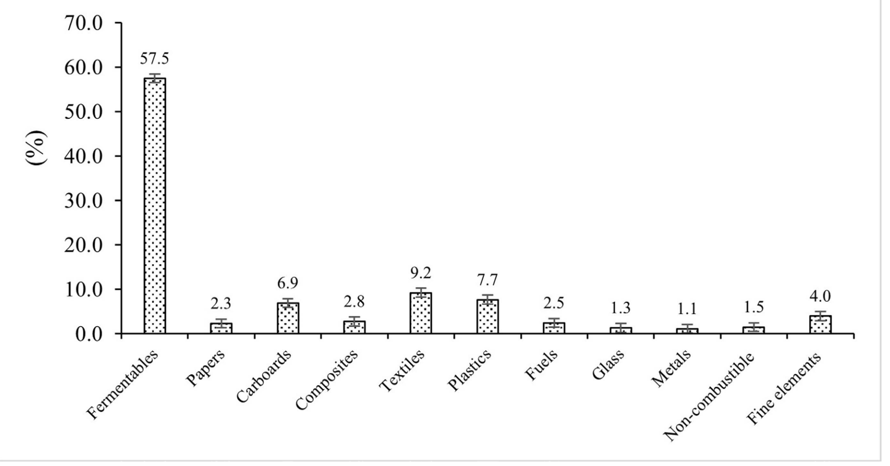

Figure 5. Overall composition of household solid waste in the city of Ngaoundere.

3.4. Physicochemical Characteristics of the Fermentable Fraction of Solid Waste

Table 2 presents some physicochemical characteristics of solid waste, primarily based on the fermentable fractions of waste generated in Ngaoundere obtained from samples collected during the 2021-2022 characterization campaign.

Table 2. Physico-Chemical characteristics of the fermentable fraction of waste collected in Ngaoundere.

Categories	Ngaoundere 1st	Ngaoundere 2nd	Ngaoundere 3rd	Average
pH	7.5 ± 0.3	8 ± 0.2	7.2 ± 0.5	7.6 ± 0.4
Moisture (%)	45.9 ± 5.2	56.5 ± 7.1	53.7 ± 2.4	52.0 ± 5.5
Volatile matter (%)	77.1 ± 2.8	74.6 ± 4.2	72.02 ± 3.6	74.6 ± 2.5
Ash content (%)	22.9 ± 0.8	25.3 ± 0.4	27.9 ± 0.7	25.4 ± 2.5
Organic C (%)	30.7 ± 0.2	29.2 ± 0.5	27.1 ± 0.1	29.0 ± 1.8
N Total %	1.1 ± 0.0	1.3 ± 0.0	0.9 ± 0.0	1.1 ± 0.2
C/N ratio	27.9	22.4	30.11	26.8 ± 4.0

Table 2 shows that the fermentable waste collected and delivered to the landfill in the city of Ngaoundere generally has a more or less neutral pH (7.6), with little variation from one district to another. However, this waste is very moist, with a water content of at least 50% in the city's various districts. The moisture content of the waste significantly influences its evolution over time when stored. Indeed, a moisture content exceeding 50% can slow natural oxidation and promote fermentation, especially if the sorting process did not separate organic waste. This high proportion is strongly linked to the predominance of food waste demonstrated in the previous analysis (**Figure 5**). Volatile matter represents the biodegradable organic fraction. With values ranging from 72.02% to 77.1%, it indicates that the waste is rich in organic matter. This is consistent with the high proportion of fermentable waste (fruits, food scraps, etc.) and is interesting for composting or biogas production.

Waste ash consists of the inorganic components remaining after combustion. The average ash content of the fermentable fraction of waste generated in Ngaoundere is 25.4% ± 2.5%. The relatively high ash content (25.4%) indicates a significant presence of inert and mineral materials in the waste stream. This may be attributed to the inclusion of soil, sand, dust, and other inorganic materials, likely resulting from collection practices, unpaved surfaces, and the mixing of household waste with street sweepings or informal disposal on bare ground. Organic carbon, on the other hand, is the main energy source for waste. It has an average value of 29%. Although the relatively high volatile matter content indicates a potential for energy recovery, the high moisture content (52%) and the dominance of biodegradable waste reduce the calorific value and limit the efficiency of direct combustion without prior drying or pre-treatment. In this context, biological treatment options such as composting or anaerobic digestion are more suitable and sustainable for the management of household waste in Ngaoundere.

4. Discussion

This discussion distinguishes between long-term waste quantity trends (2010-2020) and waste characterization results obtained from the 2021-2022 seasonal campaign.

4.1. Waste Production and Dynamics

It is important to note that the reported tonnages reflect only the fraction of waste collected by the formal waste management system. Incomplete collection coverage, informal disposal practices, and uncontrolled dumping may lead to an underestimation of the total waste generated in the city.

Depending on the quantity collected, we observe that household waste production in Ngaoundere increased significantly between 2010 and 2020, rising from 33,355 to 48,075 tonnes per year, representing a growth of approximately 44%. This trend reflects population growth, economic development, and the gradual improvement of collection coverage by the private service provider (HYSACAM), and is comparable to what has been observed in Douala and Yaounde (Ngnikam & Tanawa, 2006; Tchuikoua, 2010; Tchuikoua & Elong, 2015). Seasonal variations in the amount of waste collected, with peaks in June-August and November, are explained by the increased production of green waste, the intensification of commercial activities, and cultural events, consistent with the observations of Hotou (2016) and Dengko Totso (2015). It is important to note that the period from June to August in Ngaoundere is characterized, on the one hand, by heavy rainfall, which promotes agricultural growth and crop rotation. On the other hand, this period is characterized by continuous harvests associated with large-scale commercial distribution and the consumption of fresh food. Indeed, certain foodstuffs such as maize, vegetables, peanuts, white yams, sweet potatoes, plantains, avocados, and mangoes are harvested, while beans, soybeans, and potatoes are cultivated. During this period, therefore, the special markets selling fresh food and its regular consumption in households constitute the activities that generate significant quantities of solid waste in general, and of the fermentable fraction in particular.

4.2. Waste Composition and Spatial Variability in Ngaoundere

Fermentable waste is by far the most prevalent (57.5%), followed by textiles (9.2%), plastics (7.7%), and cardboard (6.9%). This organic predominance is consistent with studies conducted in other Cameroonian and African cities (Tchuikoua, 2010; Ngambi, 2015; Camara et al., 2026). Recycling opportunities exist for materials such as plastics, paper, and cardboard, which together represent a significant fraction of the waste stream. However, further characterization would be required to determine the specific types of materials and assess their suitability for recycling processes.

Comparing the 11 waste categories reveals spatial variability linked to the socio-economic characteristics of each municipality. The observed differences between districts and seasons should be interpreted as indicative trends rather than statistically significant differences. Waste distribution varies across districts. Densely populated and commercial areas (Ngaoundere 1st and 2nd) produce more organic waste, while the university district (3rd) generates more textiles and plastics. Fine particles (sand and dust) are more abundant in the urban center. These differences reflect the influence of local socio-economic activities and consumption habits, as observed in other African cities (Guermoud & Addou, 2014; Dengko Totso, 2015; Hotou, 2016; Asfaw et al., 2023; Camara et al., 2026). The significant predominance of fermentable waste in Ngaoundere 1st and 2nd is also explained by a higher population density, combined with the presence of daily markets that generate organic waste and a large informal food sector.

The lower quantity of fermentable waste recorded in Ngaoundere 3rd district is explained by the social composition of its population, which is predominantly made up of students. Indeed, the student community generates less organic waste due to a relatively higher consumption of low-residue foods (particularly bread). The presence of only one weekly market al.so explains the lower production of fermentable waste. Conversely, the relative high proportion of textiles and plastics recorded in Ngaoundere 3rd district could be linked to the consumption habits of the student population and the seasonal nature of the collection, potentially amplifying the proportion of textiles. The visibly higher proportion of cardboard waste in Ngaoundere 1st and 3rd districts is attributable to the city's administrative and commercial activities (Ngaoundere 1st district) and the numerous reprographic and office services (Ngaoundere 3rd district), which generate increased production of cardboard and paper.

In summary, the composition of waste in Ngaoundere varies considerably depending on urban uses, commercial dynamics, and consumption patterns specific to each municipality. Organic waste is by far the most prevalent, suggesting the need for management geared towards biological recovery (composting, biomethanization), while the increase in plastic and textile waste in certain areas highlights the challenges of recycling and source reduction.

4.3. Physicochemical Characteristics and Valorization Potential

4.3.1. Fermentable Waste

The high proportion of fermentable waste (57.5%) in Ngaoundere, combined with moist (52%), rich in organic matter (74.5% volatile matter), and relatively neutral (pH 7.6), with a favorable C/N ratio (26.8) indicates strong potential for biological treatment processes such as composting and anaerobic digestion. These characteristics promote microbial activity and biodegradation, making organic recovery a suitable and sustainable waste management option in the study area. These data are in agreement with the recommendations made by Reinhart & McCauley-Bell (1996) on the importance of physico-chemical characteristics to guide waste management. The spatial variation in quantities shows that some districts are slightly richer in carbon, which could necessitate improving the C/N ratio to balance the composting process (Ngakou et al., 2008).

4.3.2. Non-Fermentable Waste

Non-fermentable waste represents approximately 43% of the total. Its recovery is a major lever for reducing landfill and stimulating the local economy.

Plastics waste, representing 7.7%. Its recovery relies primarily on mechanical recycling, yielding granules usable by local processing industries. Eco-construction is an increasingly widespread alternative in Africa, where plastics are incorporated into the manufacture of composite paving stones, slabs, and tiles. On a smaller, more artisanal scale, flexible plastics can be transformed into mats, tarpaulins, or bags, while some experimental units are using pyrolysis to produce liquid fuel. This sector offers significant employment potential for collectors, sorters, and craftspeople, while reducing plastic pollution and the pressure on construction materials. The diversity of these products largely reflects trends observed in several African studies, notably those of Conakry (Gbilimou et al., 2024) or Kinshasa (Lokango et al., 2024).

Papers and cardboards, which represent 9.2% of the waste collected, can be recovered through industrial or artisanal recycling, resulting in the production of recycled paper, packaging cardboard, toilet paper, or egg cartons. They can also be added to compost as a carbon source. This sector helps reduce the volume of waste in landfills, limits pressure on forest resources, and creates economic activity.

Metals constitute 1.1% of the waste collected and are mainly recovered by scrap metal dealers, then resold to be melted down and transformed into iron, metal parts, or utensils. Their reuse in small-scale production to make pots, pans, agricultural tools, or metal accessories is common. This sector is one of the most profitable: it reduces the need for minerals, supports thousands of informal workers, and provides a regular source of income for scrap metal collectors.

Glass can be reused, particularly through the existing deposit system. When it cannot be reused, it can be crushed to produce cullet for glassworks, or crafted into decorative objects. The products resulting from this process are varied. This recycling generates quick income for collectors, reduces the demand for sand, and supports local craft workshops.

Other waste materials, such as used tires, also represent accessible avenues for recycling. They are generally used as decorative elements, flower containers, or even for the handcrafted production of chairs. Textiles can be transformed into bags, rugs, decorations, or accessories. The development of this sector in the local area would help reduce the health risks associated with tire accumulation and provide economic opportunities for artisans.

Overall, the high proportion of organic waste and the significant presence of recyclable fractions suggest the need to:

- Implement source separation to separate organic and recyclable waste.
- Biologically recover value from fermentable waste through composting or methanization.
- Develop the collection and recycling of plastics, textiles, and cardboard to reduce landfilling and extend the lifespan of landfill sites.

These measures are in line with the circular economy strategies recommended for developing African cities (Manga et al., 2007; Hoornweg & Bhada-Tata, 2012; Ngambi, 2015).

5. Conclusion

Sustainable household waste management in Ngaoundere is a major environmental and socio-economic challenge. Waste, far from being mere residue, now represents a potential resource for the production of compost and biogas, and the recovery of recyclable materials, highlighting the importance of understanding its qualitative and quantitative composition. The waste characterization campaign conducted in the three districts, based on the 2021-2022 seasonal sampling, revealed a predominance of fermentable waste with physicochemical characteristics favorable for the production of bioenergy or organic amendments (compost), the chemical equivalent of which is expensive on the local market. Textiles, plastics, and paper/cardboard also offer recycling opportunities for economically viable purposes. The remaining waste, consisting of glass, metals, and non-combustible materials, which are equally economically viable through targeted recycling, represents a small minority (<2%). All this data provides public authorities and private stakeholders with reliable information to plan and develop recovery pathways such as composting, methanization, and recycling, which are adapted to the local context. However, the successful implementation of these various recovery pathways depends on respecting a preliminary step: source separation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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