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Generation and characteristics of household solid waste, and effectiveness of delegated management systems in San Pedro, Côte d'Ivoire

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Graphical abstract

Abstract

Delegating public solid waste management services to private structures is increasingly favored by some countries in sub-Saharan Africa. However, waste is still landfilled without recycling and/or recovery of any fraction. This study investigated the generation, characteristics and current management of solid household waste in the city of San Pedro, Côte d'Ivoire. Two surveys were carried out, one with one of the structures responsible for the pre-collection of solid waste and the other with household residents. In addition, samples of solid waste were taken in rubbish bins placed in households for this purpose, in order to assess their density and per capita production, and then separated into twelve categories in order to determine the net weight of each category of waste. The company's area of operation was divided into four collection routes, each with four pre-collection areas, managed by an operations manager, a works manager, three drivers and six waste collectors, with insufficient and unevenly distributed equipment. In high and medium standard housings (high standing habitat and medium standing habitat) waste is collected door-to-door in most households, while in low standard housings voluntary collection in bins is more common. In addition to formal operators, informal pre-collectors operated in most high standing habitat, given the irregularity of the services provided. Waste production was highest in the high standing habitat (0.73 kilogram/capita/day), followed by medium standing habitat (0.68 kilogram/capita/day) and low standing habitat (0.62 kilogram/capita/day). Waste density was highest in low standing habitat (246 kilogram/cubic meters), followed by medium standing habitat (170 kilogram/cubic meters) and high standing habitat (131 kilogram/capita/day).The waste consisted mainly of putrescible materials (49-55 percent), plastics (8-14 percent), cardboard (4-11 percent) and paper (3-6 percent). However, 55.17 percent of the waste was organic, 28.00 percent was recyclable or reusable and 16.83 percent was non-recyclable. The private structure in charge of solid household waste is struggling to provide or ensure adequate management. The characteristics of solid household waste offer good prospects for recovery and recycling. This manuscript could be useful for good management of solid household waste.

Key words: Delegated structures; Household Solid Waste; Méthode DE Caractérisation des Ordures Ménagères (MODECOM); Waste management.

1. Introduction

Uncontrolled urbanization and demographic growth, combined with changing consumption patterns, especially in developing countries, are leading to ever-increasing amounts of waste, making waste management an environmental and health issue in urban areas of most of these countries (Yukalang *et al.* 2017; Zhang *et al.* 2024; Omotayo, 2024). This situation appears to be more worrying in African countries due to weak organizational structures, lack of adequate skills, inadequate budgets, weak legislation, lack of enforcement, low public awareness, corruption, conflict, political instability and lack of political will, among others (Godfrey *et al.* 2020; Debrah *et al.* 2021; Ndam *et al.* 2023). In the urban environments of most African countries, the contamination of the environment due to poor solid waste management through uncontrolled dumping and open burning, which are the main waste treatment and final disposal systems in these low-income countries, is particularly noticeable (Ferronato and Torretta, 2019; Debrah *et al.* 2022; Ichipi and Senekane, 2023). Ultimately, this situation irreversibly exposes human health to environmental diseases such as diarrhea, malaria, cholera and typhoid, etc. (Omang *et al.* 2021; Omato *et al.* 2024).

To mitigate the consequences of poor household waste management in African countries, there is a growing political will at both national (governments) and international (donors) levels, particularly in sub-Saharan Africa (Godfrey *et al.* 2020; Debrah *et al.* 2022; Adedara *et al.* 2023). In fact, only 44 per cent (%) of waste is collected in sub-Saharan Africa, in contrast to North African countries where collection rates are higher. In the face of this situation, there are promising signs of a growing awareness of the need for more rational management of household waste, reflected in the development of new laws and regulations and the increasing involvement of the private sector in waste management at the national level. One example is the withdrawal of public authorities from the provision of waste management services (Godfrey *et al.* 2020; Folarin, 2022; Kumar *et al.* 2022; Nijman-Ross *et al.* 2023).

In Côte d'Ivoire, the creation in 2017 of the public industrial and commercial agency known as the Agence Nationale de Gestion des Déchets (ANAGED), seems to be a new breath of fresh air to improve the country's sanitation conditions (DECRET, 2017). ANAGED covers all municipalities in the Abidjan district and has ten (10) regional delegations, including Man, Bondoukou, Bouaké, Dabou, Daloa, Korhogo, Gagnoa, Grand Bassam, San-Pédro and Yamoussoukro (ANAGED, 2019). As household waste management involves a chain of actors at all stages of the process, from pre-collection to collection, transport and landfill (Vitenko *et al.* 2021), the Agence Nationale de Gestion des Déchets (ANAGED) has been modernizing the sector since its creation, with major initiatives at several levels of the value chain. For Abidjan (the country's economic capital), this includes the recruitment of companies (ECOTI SA and Eco Eburnie) to delegate the public waste management service, the construction of a technical landfill and recovery centre, consolidation stations, etc. (ANAGED, 2019). In the interior of the country, the opening up of regional delegations has led to the construction of landfills to bury waste, the creation of "inter-municipal" infrastructures to pool infrastructure and resources, and the delegation of the public waste management service through a national call for tenders. In this context, cities such as Bouaké, Daloa, Korhogo, San-Pédro and Yamoussoukro have been equipped with pre-collection, collection and transport and landfill operators (ANAGED, 2019).

The significant progress made by the government has attracted the interest of a number of academic researchers to understand the effectiveness of ANAGED's work and its impact on the population. Among other things, these studies look at how to take account of informal actors in pre-collection (given their growing importance in the sector), the causes of collection failures, and local people's perceptions of waste in the light of its new management in urban areas. However, most studies have been carried out in Abidjan (Quonan and Gohourou, 2018), Bouaké (Diabagaté and Konan, 2018; Zouhon, 2021), Daloa (N'Guessan, 2021), Korhogo (Djane, 2019) and Yamoussoukro (Bechi *et al.* 2019). To date, very few studies have been devoted to the city of San-Pédro. However, it is the second largest port city in the country, after Abidjan, with proven potential (e.g. demographic, economic, tourism, etc.). The city of San Pedro, located in the southwest of Côte d'Ivoire on the Atlantic Ocean, on the Gulf of Guinea, is home to the country's second port and is one of the main trade destinations (Tchetche *et al.* 2019; Kadio, 2023). This factor appears to be a major asset (tourism, economic, socio-cultural, etc.) that attracts people from neighboring countries and beyond. This has led to the development of the city's private sector and hence its rapid urbanization, with the population increasing from 31,606 in 1975 to 164,944 in 2014 and 390,654 in 2021 (RGPH, 2014 ; 2021).

Furthermore, in an economic, political or environmental context where there are significant pressures, landfilling may become an unsatisfactory solution (lack of space, risk of pollution, scarcity of raw materials, etc.). This is in line with the global perspective promoting the circular economy, which aims to minimize waste and promote the sustainable use of natural resources through smarter product design, longer use, recycling and other measures, as well as the regeneration of nature (Reis *et al.* 2023 ; Zhang *et al.* 2024). However, for each waste recovery project, its potential must be assessed according to the different types of recovery possible, i.e. material recovery (recycling, reuse, etc.) or energy recovery (biogas, electricity) of the waste deposit (Adenuga *et al.* 2020; Jacobs *et al.* 2022). Waste characterization is therefore necessary to understand the detailed composition of the waste stream. The purpose of waste characterization is to provide a decision-making tool regarding the future of waste streams, the construction and/or adaptation of treatment, recovery and storage infrastructures, and the political and financial levers that need to be mobilized to manage these wastes (Gallardo *et al.* 2016). In this context, while the choice of the number of categories into which waste is sorted depends on the objectives pursued and the resources available to achieve them, the main components of a household waste bin are generally those listed by the Agence De l'Environnement et de la Maîtrise de l'Energie (ADEME) in the MéthOde DE Caractérisation des Ordures Ménagères (MODECOM) in 1993 and included in the

French standard XP X 30-408 (MODECOM, 1993; ADEME, 1993; 2006).

MODECOM (MODE de Caractérisation des Ordures Ménagères) is a method developed by the ADEME to determine the composition of waste collected by public services in a defined geographical area. In practice, waste samples are taken according to standardized protocols (and an appropriate sampling plan) and then sorted into different categories (i.e. putrescible waste, paper, cardboard, composites, textiles, sanitary textiles, plastics, unclassified combustibles, glass, metals, unclassified incombustibles, hazardous waste, fines). This knowledge is important both for prevention initiatives and for optimizing recovery processes. It is a real decision-making tool for technical and organizational choices and for monitoring policies (MODECOM, 1993; ADEME, 1993; 2006). This method, which provides a benchmark for the characterization of household waste, has been used as a guide in several recent studies in the subregion, in particular in Benin (Yemaddje *et al.* 2022), Burkina Faso (Haro *et al.* 2018; Spinato *et al.* 2021), Mali (Spinato *et al.* 2021) and Togo (Spinato *et al.* 2021; Bodjona *et al.* 2022).

This study examines the production, characteristics and current management of solid household waste in the city of San Pedro, Côte d'Ivoire. The objectives of this study are to describe the organisation and the material and human resources used in the city to manage solid urban waste, and to assess the density and specific production of household waste and the proportions of the different categories of waste defined by MODECOM. This study, carried out in 2023, could serve as a database to help policy makers and development organizations working in the household waste management sector to better address the waste management system in the city of San Pedro, Côte d'Ivoire, and to make the best choice of sector for the recovery of waste produced in the city. The study provides information on the activities of the structures responsible for the pre-collection and collection of solid household waste. It also looks at the characteristics of this waste, which is landfilled without being recycled.

2. Materials and methods

2.1. Geographic and demographic situation

The city of San Pedro is located in West Africa, in the southwest of Côte d'Ivoire, on the Atlantic coast of the Gulf of Guinea, between latitudes 4°15' North (N) and 5°30'N and longitudes 6°15 West (W) and 7°20 W (**Figure 1**). It is the capital of the region (Bas Sassandra) and of the department of San-Pédro. San-Pédro has the second largest port in the country, specializing in the export of timber and cocoa. It is 348 kilometers (km) from Abidjan (the economic capital) and 357 km from Yamoussoukro (the political capital). This privileged geographical position is an asset in terms of the potential for trade with neighboring countries, particularly through maritime exports (Diarrassouba *et al.* 2022). The city covers an area of 662.21 square kilometres (km²) in 2022, with an estimated population of 390,654, corresponding to a population density of 590 inhabitants/km², divided into 75,903 households in seventeen neighborhoods (RGPH, 2021), as it is shown in **Table 1**.

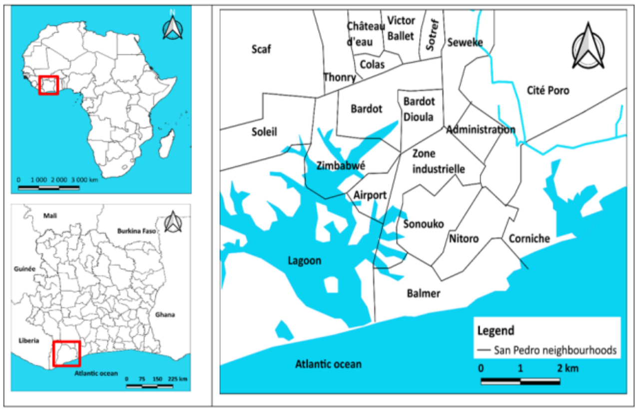

Figure 1. Map of the study area (San Pedro, Côte d'Ivoire)

2.2. Climatic conditions

Like the coastal region of Côte d'Ivoire, the town of San-Pédro has an equatorial or attain climate. Overall, the city has two rainy seasons and two dry seasons. There is a long rainy season from March to July, followed by a short dry season from August to September, a short wet season in October and November and a long dry season from December to February. Rainfall ranges from 1800 to 2200 millimetres (mm), with a cumulative water deficit of 200 to 250 mm. Seasonal temperature variations are negligible. The lowest average temperatures are generally observed during the rainy season, at 24 degrees Celsius (°C), and the highest during the dry season, at 30 °C. The average thermal amplitude is low, around 5 °C, due to the oceanic influence. The average monthly relative humidity varies between 80% and 90% (Traoré, 2016).

2.3. Economic activities

The town of San Pedro, with its beautiful beaches and exceptional cultural wealth, is a popular tourist destination. San Pedro is a town with a rich and varied economic potential. All three sectors of the economy (*i.e.,* primary, secondary and tertiary) are strongly represented and dependent on port activity (Gbitry *et al.* 2021). The opening of a port at San Pedro has had a significant impact on the development of cash crop agriculture in western Côte d'Ivoire, with the creation of thousands of hectares of industrial and village plantations of rubber, oil palm, coconut, lemon, coffee and cocoa. In addition to agriculture, San Pedro has several industrial units, mainly focused on agro-industry and timber, which produce about 65% of the local domestic product (Adou *et al.* 2018).

2.4. Extent of the study area

The study was carried out in the area covered by one of the operators responsible for waste collection in the town of San Pedro. Following the example of the companies Société Ecologique Tuniso-Ivoirienne (ECOTI SA) and Eco Eburnie, which were recruited by ANAGED in the city of Abidjan for the delegation of the public waste management service, there are three operators are in charge of waste management in the city of San Pedro, namely Societe IVOIRienne de COnstruction (SIVOIRCO), MOYA and GANA OUSMANE. While the first two operators collect waste in the city, the last one is in charge of waste disposal, i.e. the burial of waste in the landfill (ANAGED, 2019).

SIVOIRCO operates in six districts, namely Balmer, Nitoro, Poro (Cité), Séwéké, Sonouko (Lac) and Corniche, while MOYA operates in the rest of the city (**Table 1**). However, SIVOIRCO's area of intervention includes most of the buildings and facilities that represent the showcase of the city (*i.e.,* the autonomous port, residential areas, beaches, the general hospital, processing plants, luxury hotels, the airport, etc.). The choice of this area to study waste management in the city would therefore allow us to see the greatest deployment and/or commitment of operators in the field of cleanliness, all the more so as the company SIVOIRCO seems to be the most present in the city of San-Pédro.

Table 1. San Pedro population and household distribution by neighborhoods (RGPH, 2021)

Neighborhood	Population	Households
Bardot	117,507	22,831
Cathédrale	4559	886
Château	19,924	3871
Colas	19,142	3719
Balmer	5743	1116
Digboué	2031	396
Nitoro	11,720	2277
Poro (Cité)	18,752	3643
SCAF	6769	1315
Séwéké	38,089	7400
Soleil	16,212	3150
Sonouko (Lac)	32,425	6300
Sotref	34,377	6679
Thanry (CMA)	16,797	3264
Corniche	2461	479
Victor Ballet	25,003	4858
Zimbabwé	19,143	3719
Total	390,654	75,903

Table 2. The different waste components considered during characterization

No.	Waste components	Contents
1	Putrescible materials	Food waste, other putrescible
2	Papers	Newspapers, magazines, reviews
3	Cardboard	Cardboard boxes, Cardboard packaging
4	Composites	Composite packaging
5	Textiles	Sanitary textiles, clothes, lingerie etc.
6	Plastics	Plastic films, rubber, plastic bag, plastic boxes for various products, etc.
7	Unclassified fuels	Wood, coal, other fuels, garden waste
8	Glass	Glass packaging, jars, colorful and colorless glasses
9	Metals	Iron metals, cans and aluminum materials, Other metal packaging, Other metal waste
10	Unclassified incombustibles	Pebbles
11	Hazardous waste	Sanitary waste, baby diapers, batteries and accumulators
12	Fine elements < 20 mm	Sand, soil, dust, ash

The data collection consisted of an extensive operation carried out over 6 months, from January to June 2023. It consisted of interviews with SIVOIRCO managers on the one hand, and with the heads or managers of households in the study area on the other, in order to examine the solid waste management practices of the households served by the operator. In addition, the solid waste generated by the households in the SIVOIRCO intervention area was collected in order to quantify and characterize it.

2.5. Assessment of solid waste management

In order to gain a better understanding of the management of solid household waste in the town of San Pedro, supervised by ANAGED, interviews were carried out with the company’s management, in particular the operations manager and supervisors, as well as with the precollectors. The aim of these interviews was to describe the organization set up to ensure the pre-collection of waste from the households served and the human and material resources available to the company for its activities. These interviews were supplemented by site visits to illustrate the observations made.

Interviews with the head of the household or any other adult in the household were also designed to gather information on their education and employment status, household size, packaging and waste collection in the household, regularity of pre-collection services and satisfaction levels. For this purpose, the sample size was determined, using Eq. 1 (Taherdoost, 2016), while, the number of households in the different neighborhoods of the city of San Pedro is clearly defined by the General Census of Population and Housing (RGPH, 2022), as also shown in **Table 1**.

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

Where; n = sample size, N = households size and e = error of margin

The number of households surveyed in the different neighborhoods of the company's area of operation was 294 in Balmer, 340 in Nitoro, 360 in Poro (Cité), 379 in Séwéké, 376 in Sonouko (Lac) and 218 in Corniche, making a total of 1967 households.

2.6. Determining waste production and characteristics

Given the importance of data on waste production and characterization for any recovery policy, and even for the construction and/or adaptation of treatment and storage infrastructures, the mass composition of solid waste produced by households was determined. For this purpose, 50 and 100 liter garbage bags were placed in the households for a period of two days (at weekends) at the same time as the surveys to collect the waste produced in the households. Once the bin bags were collected from the households, they were taken to the nearest waste consolidation facility in the area and weighed on a scale, while the volume of waste in each bin bag was assessed before sorting, to determine the density and specific waste production of the waste produced by the household that generated it. The specific waste production, i.e. the amount of waste produced per person per day (kg/capita/day), and the density of waste in each bin bag were determined, using equations 2 and 3 (Letshwenyo and Kgetseyamore, 2020):

$$\text{Specific waste production} = \frac{\text{Mass of wastes generated}(\text{kg})}{\text{Number of people x number of days}} \quad (2)$$

$$\text{Density of the waste sample} = \frac{\text{Mass of the sample}(\text{kg})}{\text{Volume occupied by sample}(\text{m})^3} \quad (3)$$

For the sorting operation, the waste bags transported to the collection site were segregated by housing typology (i.e., high, medium and low standing), as done by Haro *et al.* (2018) and Miezah *et al.* (2015) in Burkina Faso and Ghana, respectively. High standing habitat is made up of very well-off neighborhoods, including residential areas, with a good road network and sanitation infrastructure. Medium standing consists of well-off neighborhoods characterized by a road network including unpaved roads, some improvement in social services and little sanitation infrastructure. On the other hand, low standing habitat is made up of outlying neighborhoods that are not well served, with no passable road network and no real sanitation infrastructure. In the case of this study, the neighborhoods of the city of San-Pédro, such as Balmer, Nitoro and Corniche, can be classified as high standing habitat (HSH). On the other hand, the neighborhoods of Poro (Cité) and Sonouko are of medium standing habitat (MSH). In the study area, only the neighborhood of Séwéké corresponds to the low standing habitat (LSH) typology.

After weighing the bags containing the waste and grouping them by habitat type, the waste contained in the bags for each habitat was grouped and homogenized before taking the 500 kg mass recommended by the MODECOM method. The waste categories defined by MODECOM (1993) and ADEME (2006) and listed in **Table 2** were used for sorting. However, in the present study, textiles and sanitary textiles were combined into a single textile fraction. The actual characterization was performed on 120 kg of waste, obtained after the quartering of the previously constituted 500 kg of waste, as described by Guermoud and Addou (2014). This characterization process was repeated three times during the data collection period of this study. After sorting, each of the separated fractions was weighed and the weight percentage of each waste category was then calculated, using Eq. 4 (Miezah *et al.* 2015):

$$\text{Percentage of each category}(\%) = \frac{\text{Weight of the sorted waste fraction}(\text{kg})}{\text{Total weight of the waste sample}(\text{kg})} \times 100 \quad (4)$$

2.7. Data analysis

The data in this study were analyzed according to whether they were qualitative or quantitative. The qualitative data from the household surveys (*i.e.,* household size, method and location of waste packaging, type of pre-collection, pre-collection provider, frequency of pre-collection, level of satisfaction with the operator's services, etc.) and the interviews with the waste management operator (*i.e.,* organization of waste collection and pre-collection, material and human resources, etc.) were organized and summarized on the basis of the responses obtained during the discussions and observations in the field. The relative frequency of each variable was calculated in relation to the number of households surveyed and the variables taken into account in the organization of the pre-collection, using equation 5 (Agresti, 2018):

$$\text{Frequency}(\%) = \frac{\text{Number of the modality}}{\text{Total number of the modality}} \times 100 \quad (5)$$

As for the quantitative data, in particular the density and specific production of waste and the weight percentages of the different categories of waste sorted, they were statistically compared between the habitat typologies (high, medium and low standing) in order to assess their difference. As they follow a normal distribution, the analysis of variance (ANOVA) test was used to compare them. The difference was considered statistically significant if $p < 0.05$. However, for the analysis of the waste characterization data, the households were divided according to the type of habitat, with 852 households in the high standing habitat (i.e. 294 in Balmer, 340 in Nitoro and 218 in Corniche), 736 households in the medium standing habitat (i.e. 360 in Poro (Cité) and 376 in Sonouko) and 379 households in the low standing habitat, i.e. the number of households in Séwéké.

As for the household survey data, households were divided according to their membership of the different waste collection routes established by the company. This gave a total of 634 households on the route serving Balmer and Nitoro, 736 on the route serving Poro (Cité) and Sonouko, 379 on the route serving households in all sectors of Séwéké and 218 households on the route serving all areas of the Corniche.

3. Results and discussion

3.1. Household solid waste pre-collection and collection by the company

Interviews with SIVOIRCO managers revealed that their area of operation is divided into 16 waste pre-collection zones, which are subdivided into four (04) collection routes A, B, C and D (**Figure 2**), with four (04) pre-collection zones per collection route. The routes represent the paths of the loaded waste collection trucks, while the pre-collection zones are defined for the use of cargo three-wheel motorcycle. In addition to the pre-collection carried out by the cargo three-wheeled motorcycle, ten (10) waste pre-collection points (**Figure 3**) have been set up in the company's area of operation, with bins where trucks collect waste for transport to the city's municipal landfill. According to those responsible, the different routes are designed to cover all sectors of the area allocated to the company for pre-collection and waste collection operations in the town of San-Pédro. Route A covers the Balmer and Nitoro neighborhoods and their extensions (*i.e.* Francophonie and Quarter Blanc). Route B covers the sub-neighborhoods of Poro (Cité) and Sonouko (*i.e.,* Manzan, Jules Ferry, Lac cité paisible and Lac Pavé). Route C covers all sectors of the Séwéké neighborhoods (*i.e.,* Seweke 1, 2, 3, 4 and 5). Finally, route D covers all areas of the Corniche neighborhoods (*i.e.,* Regional council, BNETD, triangle, Camp Douane, Quartier Caisse, Super marché Mory and Diamant Rose). Based on the work of Haro *et al*. (2018) and Miezah *et al*. (2015), the neighborhoods on routes A and D are classified as High Standing Habitat (HSH), while the neighborhoods on routes B and C are classified as Medium Standing Habitat (MSH) and Low Standing Habitat (LSH), respectively, in terms of the social level of the inhabitants and the coverage of road and sanitation infrastructure.

The organizational plan drawn up by the company, which is based on collection routes and pre-collection zones, is a good strategy for effectively reaching all households in the area of operation. In addition, the plan highlights two pre-collection methods, i.e. door-to-door pre-collection using cargo three-wheeled motorcycle, and voluntary pre-collection promoted through spaces equipped with waste bins throughout the intervention zone (Kaghembega *et al.* 2020). In this way, organised pre-collection and collection could effectively remove all waste generated in the area. In most urban areas in developing countries, particularly in sub-Saharan Africa, the lack of roads that can be driven on or used by cars is still an obstacle to the removal of household waste in neighborhoods (Zhang *et al.* 2024). Consequently, the three-wheeled cargo motorcycles used or planned in the current waste management system in San-Pédro are an asset in that they can reach households even in areas least served by road networks in good condition. This is in line with the arrangements made in most cities in sub-Saharan Africa to reach the majority of households for household solid waste collection (Kumar *et al.* 2022). However, in the case of bins that are placed throughout the intervention zone and involve the voluntary collection of waste by the community, the company should initiate awareness-raising sessions for the residents of the areas served, to ensure the healthy use of the collection points. The company's awareness-raising activities should be carried out in conjunction with those of the State and its financial backers in the field of cleanliness, using in particular the means of communication at their disposal, with community leaders, young people, women, etc. in the various neighbourhoods. This is all the more important as residents may dump waste in places such as the city's waterfronts, abandoned houses and rotting buildings, or burn it in the open air, as Adeniyi *et al.* (2023) found in certain localities.

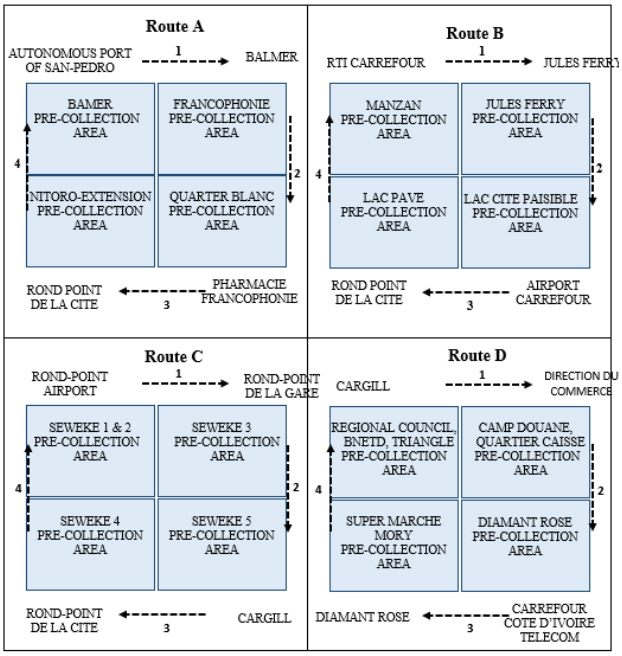

Figure 2. Household solid waste collection routes and associated pre-collection areas

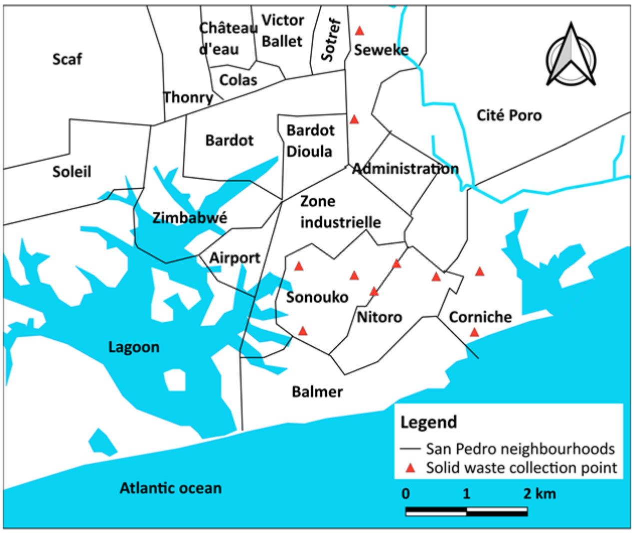

Figure 3. View of the distribution of household solid waste collection points on the company area in San-Pédro

The staff mobilized by Societe IVOIRienne de COnstruction (SIVOIRCO) for the pre-collection of solid household waste consisted of 11 people, including one (01) operations manager, one (01) works manager, three (03) drivers and six (06) waste collectors. This nomenclature for the company's staff (operations manager, works manager, drivers and waste collectors) means that the same person cannot perform several different tasks at the same time, making the team very efficient in coordinating and carrying out the waste collection work. Field staff, particularly drivers and waste collectors, were all male, mostly educated (66.7%), including 11.1% at primary level and 55.6% at secondary level, and most of them (88.8%) were aged between 20 and 40 years (**Table 3**). The fact that the vast majority of pre-collectors are men can be explained by the physical effort required and the unhealthy nature of the work, but above all by the many difficulties encountered, such as the stigma associated with the profession (Belarmino *et al.* 2022).

Furthermore, the high proportion of educated people among the field staff is linked to the growing interest of young people in the sector due to the lack of jobs, but above all to the fact that it does not require any professional skills or previous experience to carry out this activity (Debrah *et al.* 2021). However, most of them (55.6%) had less than five (05) years of work experience in pre-collection activities. The working hours were from 7.30 ante meridiem (am) to 4 post-meridiem (pm), every day of the week except Sunday, with a one-hour break between 12 pm and 1 pm. In addition, they had received no pre-collection training up to the time of the study (**Table 3**). As a result of the above, as suggested by Lissah *et al.* (2021) in Ghana, the state should encourage or require companies to provide capacity building and/or training for waste management staff. This would ensure that workers in the field care more about the quality of the service they provide and the good management of their working materials.

The equipment used on a daily basis in the company's pre-collection activities consisted of three cargo tricycles, three shovels, three rakes and 13 waste containers (20 m^3), unevenly distributed per zone and pre-collection route (**Table 4**). One cargo tricycle, one shovel and one rake are allocated per zone, i.e. three zones and pre-collection routes (A, B and D), per rotation. As for the waste containers, eight were placed on pre-collection route A, three on route B and two on pre-collection route C. No waste containers were planned for pre-collection route D. This shows that the company uses modest resources to carry out its activities, probably due to the low budget allocated by the government for pre-collection of waste in inland cities and the difficulty of accessing certain neighborhoods. The state should therefore both repair the roads in the various districts of the city and make it easier for waste management companies to purchase field equipment, for example by reducing or exempting the purchase of such equipment from customs duties. This could solve the problems that undermine the management of solid household waste (Lissah *et al.* 2021). For example, Kouassi (2016) has shown that the Séwéké district of Circuit C, which is not covered by the company, is less developed and that the state of the roads makes it difficult to access certain areas. However, the pre-collection equipment could be diversified, as is done in countries such as Burkina Faso, Mali, Mauritania, Senegal and Pakistan, where two-wheeled or animal-drawn carts are used (Shah *et al.* 2019 ; Ndiaye *et al.* 2021; Adedara *et al.* 2023).

Table 3. Socio-professional characteristics of field staff of the company

Socio-professional characteristics		Percent
Gender	Male	100
	Female	0
Age	20 - 30 years	44.4
	30 - 40 years	44.4
	> 40 years	11.1
Education level	Secondary school education	55.6
	Primary school education	11.1
	No formal education	33.3
Professional experience	0 - 5 years	55.6
	5 - 10 years	22.2
	> 10 years	22.2

Table 4. Distribution of household solid waste pre-collection equipment by work route

Equipment	Company's intervention routes				Total
	Route A	Route B	Route C	Route D	
Cargo three-wheeled motorcycle	1	1	0	1	3
Shovels	1	1	0	1	3
Rakes	1	1	0	1	3
Waste containers (20 m^3)	8	3	2	0	13

3.2. Solid waste management in the households surveyed

Looking at **Table 5**, households on routes B and C, with between 5 and 10 persons, appear to be more populous than those on routes A and D, with between 1 and 5 persons. This reflects the social level of the inhabitants of the different neighborhoods. In fact, routes A and D, which group residential neighborhoods (*e.g.* Balmer, Nitoro, Pink Diamond, etc.), are mostly the least populated areas in African cities, in contrast to less socially developed areas such as routes B and C (*e.g.* Poro, Sonouko, Seweke, etc.), which group medium and low status housing (Ongo-Nkoa and Song, 2019).

In African cities, the least socially developed neighborhoods generally have the highest number of people living in communal courtyards (Steyn, 2005), which is consistent with the findings of this study (**Table 1**). In fact, the areas of routes B and C in the city of San-Pédro, which have medium and low status housing respectively, are mainly made up of communal courtyards, while the areas of routes B and C are generally made up of high status housing. Given the population density of households on routes B and C, one would expect large amounts of waste to be generated in these locations, based on the work of Suthar and Singh (2015), Mongtoeun *et al.* (2019) and Kibonde (2024), among others.

Table 5. Socio-economic demographics and waste management in households

Household variables		**Demographic parameter**	**Solid waste pre-collection and collection routes**			
			Route A	**Route B**	**Route C**	**Route D**
			n = 634	***n = 736***	***n = 379***	***n = 218***
Socio-economic demographics	Gender	Male	52	57.3	62.4	50.7
		Female	48	42.7	37.6	49.3
	Household size	[1- 5 persons]	55	35	10	54
		[5- 10 persons]	45	50	67.5	36
		[10 persons and above]	0	15	22.5	10
	Type of housing	Single courtyard	90	45	15	80
		Common courtyard	10	55	85	20
	Employment status	Pensioners	4.7	6.4	12	8.1
		Civil servants	59.1	43.5	36	61.1
		Port workers	26.9	38.3	30	18.2
		Business	9.3	12	22	12.6
Management methods	Packaging of waste	Garbage bins	45	50.2	41.3	39.4
		Plastic bags	55.4	18.8	3.6	53.7
		Buckets	4.6	32	55.1	6.9
	Waste disposal point	Inside the yards	77.5	30.2	16.4	92.7
		Backyards	22.5	69.8	83.6	7.3
	Pre-collection service providers	Door to door	85,3	54.6	21,1	79.4
		Voluntary drop-off	14.7	45.4	78.9	21.6
	Pre-collection type	Formal pre-collectors	75.6	76.9	30	77.8
		Informal pre-collectors	64.7	38.5	80	66.7
	Pre-collection frequency	Two days a week	24.6	60.2	90.7	30.1
		Six days a week	75.4	39.8	09.3	69.9
	Satisfaction with pre-collection services	Satisfied	53.8	52.5	20	57.1
		Dissatisfied	46.2	47.5	80	42.9

Table 6. Composition of solid household waste gendered in the study areas of the San Pédro neighborhoods

Waste components (%)	**High standing habitat**	**Medium standing habitat**	**Low standing habitat**	**Average (%)**
Putrescible materials	49.09^{a} ±2.01	55.61^{bc}±1.68	60.81^{c}±0.65^{c}	55.17±1.32
Papers	6.20^{a} ±0.77	4.75^{ab} ±0.56	3.52^{b} ±0.05	4.83±0.36
Cardboard	10.92^{a} ±0.84	8.64^{a} ±0.40	4.42^{b} ±0.79	7.99±0.60
Composites	2.21^{a} ±0.70	2.03^{a} ±0.75	1.03^{a} ±0.24	1.76±0.56
Textiles	3.98±0.68^{a}	3.42^{a} ±0.46	2.94^{a} ±0.35	3.45±0.50
Plastics	14.09^{a} ±1.56	11.63^{a} ±2.36	8.82^{b} ±0.89	11.51±1.60
Unclassified fuels	0.80^{a} ±0.19	1.45^{b} ±0.08	2.44^{c} ±0.06	1.56±0.08
Glass	1.43^{a} ±0.14	1.06^{a} ±0.04	0.80^{b} ±0.07	1.10±0.04
Metals	3.65^{a} ±0.13	2.28^{ab} ±0.50	1.81^{b} ± 0.19	2.58±0.19
Unclassified incombustibles	1.20^{a} ±0.17	1.49^{a} ±0.11	1.82^{a} ±0.09	1.50±0.11
Hazardous waste	1.39^{a} ±0.12	1.72^{a} ±0.15	2.80^{c} ±0.20	1.97±0.15
Fine elements < 20 mm	5.04^{a} ±0.60	5.92^{a} ±0.57	8.79^{b} ±0.49	6.58±0.55

**Values within the same line followed by the same superscript letter (i.e., a, b) are not statistically significantly different at* $p < 0.05$

The dominance of civil servants (between 36 and 61.1%) and port workers (between 18.2 and 38.3%) in households in the study area reflects the importance and assets of the city of San Pedro, which benefits from the deployment of public administration by the government and the impact of the presence of the autonomous share. This clearly contributes to a change in consumption patterns that can increase waste production in the city (Liu *et al.* 2019;

Nguyen *et al.* 2020), hence the importance of implementing a good household solid waste management policy. Indeed, this explains the work of Hazra *et al.* (2015) on taking into account socio-economic characteristics when formulating policies to improve solid waste management services in an urban area.

In the households surveyed, waste storage consisted of garbage bins, plastic bags and used old buckets (**Table 5**). It can be seen that conventional means of storage (*i.e.* garbage bins, plastic bags) are more commonly used in high (routes A and D) and medium (route C) status housing compared to low status housing (route B) where old buckets are more commonly used. This can be explained by the economic level of the inhabitants of these households, who would not have the financial means to buy traditional bins, even though they are environmentally friendly (Guerrero *et al.* 2013). In the study area the waste storage facilities are mainly located inside the yards in the routes A and D and outside the yards (in the backyard) in the routes B and C (**Table 5**). While outdoor waste disposal is effective in controlling the spread of pathogens associated with household waste, vandalism of waste bags and bins (foraging by animals (dogs, mustangs, etc.) or theft of bins) leads some households to place them in the yard (Haywood *et al.* 2021), as is the case in routes A and D. However, the frequency of pre-collection recorded in routes A and D (6 days per week) may limit the negative impact of waste in households (Madsen *et al.* 2021).

Regarding the type of pre-collection of waste in the area, it is generally door-to-door on routes A, B and D. On the other hand, pre-collection by voluntary drop-off is more common on route C. This situation can be explained by the fact that the access roads to the households in this area (route C) are in poor condition, making it difficult for vehicles of all types to reach all households for door-to-door collection. This means that residents have to travel long distances to dispose of their waste in bins (20 m^3), which are usually placed at specific locations in the neighborhoods. Similar situations have been observed by Volsuuri *et al.* (2023) in Tamale, Ghana, and Nzalalemba (2024) in Alexandra Township, Johannesburg, South Africa. Because of this situation, some households use the services of informal pre-collectors in addition to formal pre-collectors (*i.e.,* those from the company). This situation is also linked to non-compliance with the pre-collection schedule in some areas, but above all to the quality of the service and the absence of the company's service in some areas, as observed by Katusiimeh *et al.* (2013) in Kampala (Uganda), Andrianisa *et al.* (2016) in Abidjan (Cote d'Ivoire) and Oduro-Appiah *et al.* (2020) in Accra (Ghana). This undoubtedly justifies the fact that 80% of households on route C and between 42.9% and 47.5% of households on routes A, B and D in the study area are not satisfied with the company's pre-collection services.

3.3. Solid waste generation and characteristics of households

Household waste generation per capita differed significantly (ANOVA test, $p < 0.05$) according to household economic status (**Figure 4A**). It varied between 0.62 and 0.95 kg/day in the High Standing Habitat (HSH), between 0.52 and 0.84 kg/day in the Medium Standing Habitat (MSH) and between 0.50 and 0.76 kg/day in the Low Standing Habitat (LSH), with an average of 0.73, 0.68 and 0.62 kg/day respectively, giving an average per capita waste production of 0.68 kg/day in the study area in the town of San-Pédro. The more economically advanced the household, the more waste was generated per capita. The higher per capita waste generation of economically advanced households is undoubtedly related to their lifestyle. With sufficient financial resources, advanced households can fully satisfy their domestic needs. Several studies, including those by Albira *et al.* (2019), Nguyen *et al.* (2020), Zhao *et al.* (2021) and Blagoeva *et al.* (2023), have observed a close relationship between the availability of financial resources and changes in consumption patterns, which naturally have a significant impact on specific household waste generation. A similar trend in per capita waste generation according to household economic level has been observed in several studies, including Dikole and Letshwenyo (2020) and Noufal *et al.* (2020) in Palapye (Botswana) and Homs (Syria).

However, the specific production of household waste obtained in this study is also consistent with long-term studies (Hoornweg and Bhada-Tata, 2012), which estimate per capita waste production in sub-Saharan Africa to be between 0.09 and 3.0 kg per person per day, with an average of 0.65 kg/capita/day. The same sequence of per capita waste production is also observed according to the economic status of the countries, even on the basis of projections from 2020 to 2030 and then to 2040 and 2050 (Kaza *et al.* 2021). However, the average waste production per inhabitant, estimated at 0.68 kg/day in the area studied in the city of San-Pédro, is high and similar to that found by Noufal *et al.* (2020) in the city of Homs, Syria. This state of affairs is probably linked to the assets of the town of San-Pédro, which offers various opportunities for professional integration in the port sector, tourism, administration, etc., especially since more than 90% of the households surveyed are home to workers of all kinds (**Table 5**).

The density of waste generated by households in the study area differed significantly between the different housing types (ANOVA test, $p < 0.05$), with higher values ranging from 158 to 422 kg/m^3 in LSH, followed by 104 to 328 kg/m^3 in MSH and 100 to 169 kg/m^3 in HSH (**Figure 4B**). The corresponding average waste densities were 246 kg/m^3 (LSH), 170 kg/m^3 (MSH) and 131 kg/m3 (HSH). This difference could be related to the eating habits of the inhabitants of the different households. The composition of the waste in large quantities of plastic, tin, glass, garden waste, etc. among the residents of high status dwellings, as mentioned by Letshwenyo and Kgetseyamore (2020), could justify a larger volume in these households and thus lower densities. On the other hand, in lower status households, where according to the same authors the waste consists of putrescible elements and sand, it would be denser and therefore constitute less voluminous waste. It is precisely on the basis of these findings that these authors mention that waste density is important in determining the size of storage facilities, the type of collection vehicle and the design of the disposal facility. However, the average waste density of all households surveyed in San-Pédro (182 kg/m^3) is roughly in the same order of magnitude as the density of around 221 kg/m^3 found by Qu *et al.* (2009) in Beijing (China). However, the apparently higher density found in this Chinese city compared to San-Pédro would be justified by the economic status of this country (developed country) compared to Côte d'Ivoire, which is classified as a developing country.

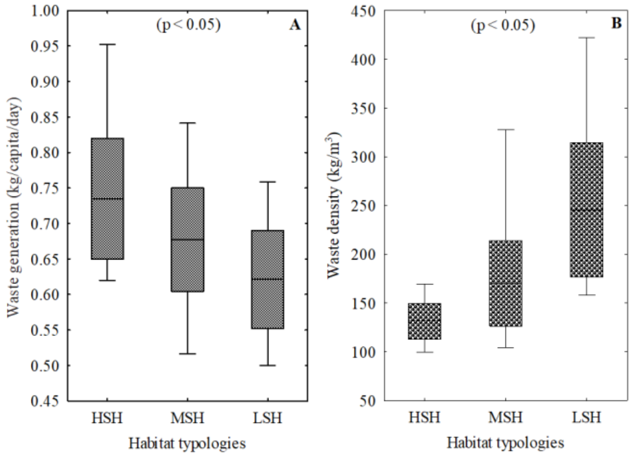

Figure 4. Variation in per capita household waste production (A) and waste density (B) as a function of housing type in the survey area; HSH = High Standing Habitat, MSH = Medium standing habitat and LSH = Low standing habitat

Knowledge of the composition of the waste generated is an important factor that can help determine the best methods of recovery, treatment, storage, transportation and final disposal, and it seems important to proceed by habitat typology as Miezah *et al.* (2015), Dikole and Letshwenyo (2020), Letshwenyo and Kgetseyamore (2020) and Noufal *et al.* (2020) to arrive at a good strategy. This study shows that waste is landfilled without sorting or recovery of any fraction. In fact, as Vega and Bautista-Rodriguez (2024) point out, the lack of or low levels of reuse and recycling of municipal solid waste in cities in developing countries can be attributed to underinvested decision-making processes that do not take into account waste flows, recovery capacities and recycling potential. This also justifies the under-equipping of waste management companies and the improvement of working conditions for these companies (lack of good roads, lack of civic awareness of the population, etc.). Irrespective of the type of housing, however, the waste generated includes all the categories defined by MODECOM (1993) and ADEME (2006) and listed in **Table 6** (i.e. putrescible waste, paper, cardboard, composites, textiles, sanitary textiles, plastics, unclassified combustibles, glass, metals, unclassified incombustibles, hazardous waste, fines). Burial of such wastes without prior sorting is likely to cause multiple environmental nuisances, including heavy metal contamination of surface water, groundwater and agricultural products in the vicinity of landfill sites (Pande *et al.* 2015, Parvin and Tareq, 2021).

An analysis of **Table 6** shows that most of the waste generated in households consists of putrescible materials (49-55%), followed by plastics (8-14%), cardboard (4-11%) and paper (3-6%), which is in line with people's eating habits (Abdel-Shafy *et al.* 2018; Haro *et al.* 2018). Eating habits, which are still linked to the economic status of households, could justify the decrease in the proportion of waste categories, *i.e.* paper, cardboard, composites, textiles, plastics, glass and metals, from high to low standard housing, as observed by Dikole and Letshwenyo (2020) and Noufal *et al.* (2020). The same is true for wastes such as putrescible materials, unclassified fuels, unclassified incombustibles, hazardous wastes and fine elements, where the proportions decrease from low to high standing habitats. However, the proportion of fine elements between 5 and 9% can be justified by the fact that the soil is not covered and, in particular, by the characteristics of the soil at San Pédro, which is located in the coastal area of Côte d'Ivoire. In fact, in low standard dwellings, the floors are generally unpaved, unlike in other dwellings where the yards are generally well paved. Thus, when sweeping the dwellings, sand particles remain mixed with waste, as observed by Topanou *et al.* (2011) in Abomey - Calavi in Benin and Monney *et al.* (2013) in Wa in Ghana.

An analysis of waste categories from a recovery perspective reveals three main components: organic wastes (*i.e.*, putrescible), recyclable or reusable wastes (*i.e.,* paper, cardboard, plastics, glass, and metals), and non-recyclable wastes (*i.e.,* composites, textiles, unclassified fuels, unclassified incombustibles, hazardous wastes, and fine elements) [Abdel-Shafy and Mansour, 2018]. These different fractions represent respectively between 49.09-60.81% with an average of 55.17% of putrescible wastes, between 19.37-36.29% with an average of 28.00% of recyclable or reusable wastes and between 14.62-19.82% with an average of 16.83% of non-recyclable wastes of the wastes generated in the study area. These wastes provide an opportunity to produce compost and biogas from the organic fraction consisting of putrescible elements (Abdel-Shafy and Mansour, 2018; Zhou *et al.* 2020; Calbry-Muzyka *et al.* 2022). Moreover, sales and recycling (food waste, waste paper, materials, plastics, metals, etc.) would only allow the last fraction of waste to be buried, especially the non-recyclable waste (Kibria *et al.* 2023). In fact, this fraction represents the smallest part of the waste generated in this study (16.83%) in the town of San-Pédro. These conditions could therefore guarantee a long life for the landfill and preserve the quality of the environment around the landfill (Bello *et al.* 2022), while generating income, for example through job creation (Reis *et al.* 2023). From an environmental perspective, burying only the final fraction of waste, i.e. composites, textiles, unclassified fuels, unclassified incombustibles and fine elements, eliminates or limits the production of leachate and thus protects the quality of soil, water, air and groundwater around landfills (Abdel-Shafy *et al.* 2024).

In fact, separating waste according to its different components and recovering them according to their potential is a good solution to reduce the amount of solid waste sent to landfills. In most cases, organic matter constitutes the majority of the solid waste generated, which is why several studies, including those by Bashir *et* *al.* (2018), Lekkas *et al.* (2022) and Sharma *et al.* (2024), recommend the production of compost. However, public awareness seems to be an important key to improve the problem of solid waste management (Bashir *et al.* 2018). In addition, the work of Niyomukiza *et al.* (2023), which investigated the effectiveness of using crushed glass waste to modify the engineering properties of soil, showed that adding glass powder to a foundation soil strengthens it and reduces its susceptibility to volume changes. This paves the way for promising recycling of waste glass. The same is true for plastic waste from the construction industry. Recent work by Ponmalar et al (2024) has shown that a concrete mix based on plastic aggregates meets the basic durability characteristics of normal strength concrete.

4. Conclusion

This study investigated the generation, characteristics and current management of solid household waste in an area of the city of San Pedro that is assigned to a delegated waste management structure. The following points emerge:

- The company's area of operation is divided into collection routes, each with pre-collection areas, where door-to-door pre-collection is carried out by three-wheeled tricycles, and voluntary pre-collection, encouraged by areas equipped with 20m^3 containers.

- The structure is staffed by an operations manager, a works manager, three drivers and six waste collectors, with field equipment consisting of cargo tricycles, shovels, rakes and waste containers, unevenly distributed by zone and pre-collection route.

- Most households have between 5 and 10 people, mostly workers, whose waste is stored in garbage bins, plastic bags and buckets outside most courtyards in medium and low standing habitat, and inside those in high standing habitat.

- Most households in high and medium-standard housing have door-to-door waste collection. On the other hand, voluntary waste collection in bins was more common among households in low standard housing.

- In addition to the formal operators, households also use the services of informal pre-collection operators, especially in the low standard areas, due to the irregularity of the service provided by the delegated structure, which varies from zone to zone (twice a week in the medium and low standard zones and 6 times a week in the high standard zones).

- Per capita waste generation remains closely linked to the socio-economic status of households, with a higher value in high standard housing (0.73 kg/capita/day), followed by medium standard housing (0.68 kg/capita/day) and low standard housing (0.62 kg/capita/day), giving an average of 0.68 kg/capita/day.

- The order of importance of waste density appears to be inverse to that of production, with a higher average for low standard housing (246 kg/m^3), followed by medium standard housing (170 kg/m^3) and high standard housing (131 kg/m^3), giving an average of 182 kg/m^3.

- Household solid waste consists mainly of putrescible materials (49-55%), plastics (8-14%), cardboard (4-11%) and paper (3-6%), with a total composition of 55.17% organic waste and 28% recyclable or reusable waste, which suggests good prospects for the production of compost and biogas, to be confirmed by work including the study of the methanogenic potential of the waste.

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References

Abdel-Shafy H.I., Ibrahim A.M., Al-Sulaiman A.M. and Okasha R.A. (2024). Landfill leachate: Sources, nature, organic composition, and treatment: An environmental overview, *Ain Shams Engineering Journal*, **15**, 102293.

Abdel-Shafy H.I. and Mansour S.M.M. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization, *Egyptian Journal of Petroleum*, **27**, 1275–1290.

Adedara M.L., Taiwo R. and Bork H.R. (2023). Municipal solid waste collection and coverage rates in Sub-Saharan African countries: A comprehensive systematic review and meta-analysis, *Waste*, **1**, 389–413.

Ademe (1993). Method for characterizing household waste, Modecom TM – Basic manual – published by the ADEME Center of Angers, September 1993 – Ref 1601 - Coll., Knowing to act.

Ademe (2006). Campagne nationale de caractérisation des ordures ménagères ; Choix des catégories et des sous catégories pour l'analyse de la composition des déchets, ADEME, France.

Adeniyi L.A. (2023). Assessment of the effects of location of disposal-sites on waste disposal practices of urban residents in Nigeria, *GeoJournal*, **88**, 3889–3903.

Adenuga O.T., Mpofu K. and Modise K.R. (2020). An approach for enhancing optimal resource recovery from different classes of waste in South Africa: Selection of appropriate waste to energy technology, *Sustainable Futures*, **2**, 100033.

Adou S.G., Silue K. and Kablan N.H.J. (2018). Impact des infrastructures portuaires sur la dynamique des activités: Cas de San Pedro, *Revue Espace Géographique et Société marocaine*, **24–25**, 329–334.

Agresti A. (2018). Statistical methods for the social sciences. 4th. Ed., Boston: Pearson.

Albira I.A., Hamzah T.A., Yusoff S.Y., Noor N.M. and Emenike C.U. (2019). Household solid waste generation: a case study of Misrata City in Post-War Libya, *The Arab World Geographer Journal*, **22**, 32–46.

ANAGED (2019). Semaine nationale de la propreté 2019: Périr ou réussir pour le gouvernement de Côte d'Ivoire, AnagedMag, le trimestriel de Agence Nationale de Gestion des Déchets n° 003, Abidjan, Côte d'Ivoire.

Andrianisa H.A., Brou Y.O.K. and Séhi B.A. (2016). Role and importance of informal collectors in the municipal waste pre-collection system in Abidjan, Côte d'Ivoire, *Habitat International*, **53**, 265–273.

Bashir M.J.K., Tao G.H., Abu Amr S.S. and Tan K.W. (2018). Public concerns and behaviors towards solid waste minimization using composting in Kampar district, Malaysia, *Global NEST Journal*, **20**(2), 316–323.

Bechi G.F., N'dri K.S. and Koffi K. (2019). L'amélioration de la gestion durable des déchets ménagers dans la ville de Yamoussoukro, *International Journal of Innovation and Applied Studies*, **26**(2), 357–368.

Belarmino D.V.B., Pagani M.E.B., Tanouye A.T.A., Garcia L.F. and Massuda E.M. (2023). Perception of work and health among waste collectors, *Revista Brasileira de Medicina do Trabalho*, **20**, 574–581.

Bello A.S., Al-Ghouti M.A. and Abu-Dieyeh M.H. (2022). Sustainable and long-term management of municipal solid waste: A review, *Bioresource Technology Reports*, **18**, 1–12.

Blagoeva N., Georgieva V. and Dimova D. (2023). Relationship between GDP and municipal waste: Regional disparities and implication for waste management policies, *Sustainability,* **15**, 15193.

Bodjona M.B., Kondoh E., Tchegueni S. and Koledzi E.K. (2022). Physico-chemical Characterization of Household Waste from the City of Tsévié (Togo), *Asian Journal of Applied Sciences*, **10**, 339–406.

Calbry-Muzyka A., Hossein M., Rüsch-Pfund F., Gandiglio M. and Biollaz S. (2022). Biogas composition from agricultural sources and organic fraction of municipal solid waste, *Renewable Energy,* **181**, 1000–1007.

Debrah J.K., Teye G.K. and Dinis M.A.P. (2022). Barriers and Challenges to Waste Management Hindering the Circular Economy in Sub-Saharan Africa, *Urban Science*, **6**, 57–73.

Debrah J.K., Vidal D.G. and Dinis M.A.P. (2021). Raising Awareness on Solid Waste Management through Formal Education for Sustainability: A Developing Countries Evidence Review, *Recycling*, **6**(6), 1–21.

DECRET, (2017). N° 2017–692 du 25 Octobre 2017 portant création, attributions, organisation et fonctionnement de l'établissement public à caractère industriel et commercial, dénommé Agence Nationale de Gestion des Déchets (ANAGED), Abidjan, Côte d'Ivoire.

Diabagaté S. and Konan K.P. (2018). Gestion des ordures ménagères dans la ville de Bouaké, sources d'inégalités socio spatialeset environnementales, *Revue Espace Territoires, Sociétés et Santé*, **1**(2), 126–142.

Diarrassouba B., Yapi A.C. and Kouadio W.A. (2022). Occupation des Zones à Risques à San Pedro (Côte D'ivoire): Entre Laxisme des Autorités et Insouciance des Populations, *European Scientific Journal*, **18**, 46–69.

Dikole R. and Letshwenyo M.W. (2020). Household Solid Waste Generation and Composition: A Case Study in Palapye, Botswana, *Journal of Environmental Protection*, **11**(2), 110–123.

Djane K. A. (2019). Crise de la gestion de l'environnement en Côte d'Ivoire : Vers une sociologie du réseau de gouvernance des ordures ménagères à Korhogo, *Revue Africaine de Sciences Politique et Sociales*, **24**, 451–471.

Ferronato N. and Torretta V. (2019). Waste Mismanagement in Developing Countries: A Review of Global Issues, *International Journal of Environmental Research and Public Health*, **16**, 1060–1088.

Folarin O.S. (2022). Achieving sustainable solid waste management in Sub-Saharan Africa: The option of valorisation and circular economy model. In *Waste Management*, Processing and Valorisation; Yaser A.Z., Tajarudin H.A. Embrandiri, A., Eds.; Springer: Singapore.

Gallardo A., Edo-Alcón N., Carlos M. and Renau M. (2016). The determination of waste generation and composition as an essential tool to improve the waste management plan of a university, *Waste Management,* **53**: 3–11.

Gbitry A.B., Kouadio A.K., Ogui C.O.P. and Nassa D.A.D. (2021). Urban Biodiversity In The Light Of The Dynamics Of Industrial Activities In San-Pedro (South-West Of The Ivory Coast), *International Journal of Social Sciences and Humanities Invention*, **8**, 6475–6487.

Godfrey L., Tawfic A.M., Giday G.K., Jamidu K.H.Y., Oelofse S., Osibanjo O., Richter U.H. and Yonli A.H. (2020). Solid Waste Management in Africa: Governance Failure or Development Opportunity? Regional Development in Africa. In Edomah N, editor. *Regional Development in Africa*, London: IntechOpen.

Guermoud N. and Addou A. (2014). Etude et caractérisation des déchets ménagers de la ville de Mostaganem (Ouest-Algérie) », *Déchets sciences et techniques*, **66**, 45–50.

Guerrero L.A., Maas G. and Hogland W. (2013). Solid waste management for cities in developing countries, *Waste Management*, **33**, 220–232.

Haro K., Ouarma I., Nana B., Bere A. and Koulidiati J. (2018). Characterization and potential recovery of household solid waste in the city of Ouagadougou (Burkina Faso), *Journal of Environmental Protection*, **9**, 309–324.

Haywood L.K., Kapwata T., Oelofse S., Breetzke G. and Wright C.Y. (2021). Waste disposal practices in low-income settlements of South Africa, *International Journal of Environmental Research and Public Health*, **18**, 8176–8188.

Hazra T., Goel S. and Maitra B. (2015). Willingness-to-Pay and Preference Heterogeneity for Service Attributes of Solid Waste Management: An Experience in Kolkata, India, *Global NEST Journal*, **17**(1), 82–92.

Hoornweg D. and Bhada-Tata P. (2012). What a Waste: A global review of solid waste management. urban development series, knowledge papers No. 15, World Bank: Washington, DC, USA.

Ichipi E.B. and Senekane M.F. (2023). An Evaluation of the Impact of Illegal Dumping of Solid Waste on Public Health in Nigeria: A Case Study of Lagos State, *International Journal of Environmental Research and Public Health*, **20**, 7069–7081.

Jacobs C., Soulliere K., Sawyer-Beaulieu S., Sabzwari A. and Tam E. (2022). Challenges to the Circular Economy: Recovering Wastes from Simple versus Complex Products, *Sustainability,* **14**, 2576–2590.

Kadio A.K.C. (2023). The role of the Port of San Pedro in promoting port sustainability: An institutional perspective, *Journal of Human Resource and Sustainability Studies*, **11**, 846–857.

Kaghembega S.H.W., Xia Q., Chen S. and Chaofei S. (2020). Greenhouse gas reduction and cost-benefit through improving municipal solid waste management in Ouagadougou, *African Journal of Environmental Science and Technology*, **14**(8), 222–230.

Katusiimeh M.W., Burger K. and Mol A.P.J. (2013). Informal waste collection and its co-existence with the formal waste sector: The case of Kampala, Uganda, *Habitat International*, **38**, 1–9.

Kaza S., Shrikanth S. and Chaudhary S. (2021). More growth, less garbage. Urban development series. 35998. Washington, DC: World Bank.

Kibonde S.F. (2024). Household solid waste generation patterns and collection systems in urban Tanzania: A case study of Morogoro Municipality, *Journal of the Geographical Association of Tanzania*, **44**, 47–67.

Kibria M.G., Masuk N.I., Safayet R., Nguyen H.Q. and Mourshed M. (2023). Plastic waste: Challenges and opportunities to mitigate pollution and effective management, *International Journal of Environmental Research*, **17**, 20–57.

Kouassi K.H. (2016). Impact costs of materials of building over the housing and the occupation of the space in the city of San Pedro, these for the following wards: Bardot, Seweke, Lac and Cite Thesis for: Master. Universite of Felix Houphouet Boigny, Abidjan-cocody, Cote d'Ivoire.

Kumar C., Bailey-Morley A., Kargbo E. and Sanyang L. (2022). Waste management in Africa: a review of cities' experiences, ODI Working Paper. London.

Lekkas D.F., Kazamias G. and Klontza E.E. (2022). Composting of the organic fraction of municipal solid waste as an alternative to the uncontrolled disposal: The case of Kalamata Municipality (Greece), *Global NEST Journal*, **24**(1), 119–128.

Letshwenyo M.W. and Kgetseyamore D. (2020). Generation and composition of municipal solid waste: case study, extension 7, Palapye, Botswana. *SN Applied Sciences*, **2**, 1665–1673.

Lissah S.Y., Ayanore M.A., Krugu J.K., Aberese-Ako M. and Ruiter R.A.C. (2021). Managing urban solid waste in Gerspechana: Ptives and experiences of municipal waste company managers and supervisors in an urban municipality, *PLoS One*, **16**, e0248392.

Liu J., Li Q., Gu W. and Wang C. (2019). The impact of consumption patterns on the generation of municipal solid waste in China: Evidences from provincial data, *International Journal of Environmental Research and Public Health*, **16**, 1717–1736.

Madsen A.M., Raulf M., Duquenne P., Graff P., Cyprowski M., Beswick A., Laitinen S., Rasmussen P.U., Hinker M., Kolk A., Górny R.L., Oppliger A. and Brian C. B. (2021). Review of biological risks associated with the collection of municipal wastes, *Science of The Total Environment*, **791**, 148287.

Miezah K., Obiri-Danso K., Kádár Z., Fei-Baffoe B. and Mensah M.Y. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana, *Waste Management*, **46**, 15–27.

MODECOM (1993). Méthode de caractérisation des ordures ménagères/ 2 ème édition, ADEME Paris, France.

Mongtoeun Y., Fujiwara T. and Vin S. (2019). Household solid waste generation and socioeconomic factors in the capital city of Cambodia, *International Journal of Environmental Sciences & Natural Resources*, **20**, 556029.

Monney I., Tiimub B.M. and Bagah H.C. (2013). Characteristics and management of household solid waste in urban areas in Ghana: the case of Wa, *Journal of Civil and Environmental Research*, **3**, 10–21.

N'Guessan K., Yéo K. A. J., Kouassi K. and Barima Y.S.S. (2021). Gestion des déchets solides du centre hospitalier régional de DALOA (centre-ouest de la Côte d'ivoire) et des risques associés, *Environnement, ingénierie & développement*, **1**, 26–32.

Ndam S., Touikoue A.F., Chenal J., Baraka M. J.-C., Kemajou A. and Kouomoun A., (2023). Urban Governance of Household Waste and Sustainable Development in Sub-Saharan Africa: A Study from Yaoundé (Cameroon), *Waste,* **1**, 612–630.

Ndiaye R., Ndiaye M., Traore B. and Diaw V.B. (2021). Household solid waste, a challenge of urban sanitation: case of N'gor municipality (Dakar, Senegal), *American Journal of Remote Sensing*, **9**, 47–54.

Nguyen K. L., Chuang Y. H., Chen H. W. and Chang C. C. (2020). Impacts of socioeconomic changes on municipal solid waste characteristics in Taiwan, *Resources, Conservation and Recycling*, **161**, 104931.

Nijman-Ross E., Umutesi J.U., Turay J., Shamavu D., Atanga W.A. and Ross D.L. (2023). Toward a preliminary research agenda for the circular economy adoption in Africa, *Frontiers in Sustainability,* **4**, 1061563.

Niyomukiza J.B., Eisazadeh A., Akamumpa J., Kiwanuka M., Lukwago A. and Tiboti P. (2023). Use of waste glass powder in improving the properties of expansive clay soils, *Global NEST Journal*, **25**(3), 139–145.

Noufal M., Yuanyuan L., Maalla Z. and Adipah S. (2020). Determinants of household solid waste generation and composition in Homs City, Syria, *Journal of Environmental and Public Health*, 1–15.

Nzalalemba S.K. (2024). Analysing, the challenges of solid waste management in low-income communities in South Africa: a case study of Alexandra, Johannesburg, *South African Geographical Journal,* 1–21.

Oduro-Appiah K., Scheinberg A., Afful A. and De Vries N. (2020). The contribution of participatory engagement strategies to reliable data gathering and inclusive policies in developing countries: Municipal solid waste management data in the Greater Accra Metropolitan Area of Ghana, *African Journal of Science, Technology, Innovation and Development*, **13**, 735–746.

Omang D.I., John G.E., Inah S.A. and Bisong J.O. (2021). Public health implication of solid waste generated by households in Bekwarra Local Government area, *African Health Sciences*, **21**(3), 1467–1473.

Omotayo A.O. (2024). Investigating the drivers of solid waste generation and disposal: Evidence from South Africa, *Environment, Development and Sustainability*, 1–33.

Omato C., Jerie S., Mutekwa T.V., Shabani T., Shabani T. and Tafadzwa M. (2024). Impacts of solid waste management strategies in urban high density suburbs: a case of Amaveni suburb, Kwekwe, Zimbabwe, *Discover Environment*, **2**, 1–17.

Ongo-Nkoa B.E. and Song J.S. (2019). Urbanisation et inégalités en Afrique : une étude à partir des indices désagrégés, *Revue d'Économie Régionale & Urbaine*, **3**: 447–484.

Pande G., Sinha A. and Agrawal S. (2015). Impacts of Leachate Percolation on Ground Water Quality: A Case Study of Dhanbad City, *Global NEST Journal*, **17**(1), 162–174.

Parvin F. and Tareq S. M. (2021). Impact of landfill leachate contamination on surface and groundwater of Bangladesh: a systematic review and possible public health risks assessment. *Applied Water Science*, **11**(6),100.

Ponmalar S., Revathi P., Sankar B. and George k George. (2024). Valorization of plastic waste aggregate in concrete: A study on durability and microstructural properties, *Global NEST Journal*, **26**(8), 05828.

Qu X.Y., Zhen-Shan L., Xie X.Y., Sui Y. M., Yang L. and Chen Y. O. (2009). Survey of composition and generation rate of household wastes in Beijing, China, *Waste Management*, **29**, 2618–2624.

Quonan C.Y.K. and Gohourou F. (2018). L'influence de la pré-collecte des ordures ménagères sur la qualité de la salubrité dans le District d'Abidjan (Côte-d'Ivoire), *Environnement, Ingénierie & Développement, EPI sciences*, **76**: 3–10.

Reis W.F., Barreto C.G. and Capelari M.G.M. (2023). Circular economy and solid waste management: Connections from a bibliometric analysis, *Sustainability*, **15**, 15715.

RGPH (2021). Abidjan, Côte d'Ivoire, 2021, Recensement Général de la Population et de l'Habitation.

RGPH (2014). Abidjan, Côte d'Ivoire, 2014, Recensement Général de la Population et de l'Habitation.

Shah S.Z.A., Nawaz Z., Nawaz S., Carder G., Ali M., Soomro N. and Compston P.C. (2019). The role and welfare of cart donkeys used in waste management in Karachi, Pakistan, *Animals,* **9**, 159–176.

Sharma P., Nagabhooshanam N., Kumar R., Sharma K. and Vani S. (2024). Exploration of composting strategies for sustainable organic waste management in urban environments, *Global NEST Journal*, **26**(6), 05970.

Spinato S., Yiougo L.S.A. and Bues M. (2021). Urban solid waste transportation, composting, recycling, and landfill issues in sub-Saharan Africa cities, *Journal of Urban and Environmental Engineering*, **15**, 88–102.

Steyn G. (2005). African courtyard architecture: Typology, art, science and relevance, *Acta Structilia*. **12**, 106–129.

Suthar S. and Singh P. (2015). Household solid waste generation and composition in different family size and socio-economic groups: a case study, *Sustainable Cities and Society*, **14**, 56–63.

Taherdoost H. (2016). Sampling methods in research methodology, how to choose a sampling technique for research, *International Journal of Academic Research in Management*, **5**, 18–27.

Tchetche N., Kouadio K.A. and Gogbe T. (2019). Développement du potentiel touristique dans la ville de San Pedro (Côte d'Ivoire), *Revue Espace Géographie et Societe Marocaine*, **28**, 283–299.

Topanou N., Domeizel M., Fatombi J., Josse R. and Aminou T. (2011). Characterization of household solid waste in the town of Abomey - Calavi in Benin, *Journal of Environmental Protection*, **2**, 692–699.

Traoré K.M. (2016). Analyse des vulnérabilités de la ville côtière de San-Pedro (sud-ouest de la côte d'ivoire), Environnement et Société, Université Felix Houphouet Boigny de Cocody-Abidjan.

Vega D.I. and Bautista-Rodriguez S. (2024). The impact of circular economy strategies on municipal waste management: A system dynamics approach, *Cleaner Engineering and Technology*, **21**, 100761.

Vitenko T., Marynenko N. and Kramar I., (2021). European experience in waste management, *Environmental Science Proceeding*, **9**, 17–21.

Volsuuri E., Owusu-Sekyere E. and Imoro A.Z. (2023). Unequal location, unequal access: the spatial analysis of solid waste disposal services in Northern Ghana, *Discover Environment*, **1**, 14–24.

Yemaddje A.A.S., Vifan E.L., Tchakpa C. and Akakpo S. J. (2022). Quantification and Management of Household Solid Waste in the Urban District of Bantè, *International Journal of Advanced Research*, **5**, 89–103.

Yukalang N., Clarke B. and Ross K. (2017). Barriers to effective municipal solid waste management in a rapidly urbanizing area in Thailand, *International Journal of Advanced Research*, **14**, 1013–1036.

Zhang Z., Chen Z., Zhang J., Liu Y., Chen L., Yang M., Osman A. I., Farghali M., Liu E., Hassan D., Ihara I., Lu K., Rooney D.W. and Yap P-S. (2024). Municipal solid waste management challenges in developing regions: A comprehensive review and future perspectives for Asia and Africa, *Science of the Total Environment*, **930**, 172794.

Zhao Y., Diunugala H.P. and Mombeuil, C., (2021). Factors affecting household solid waste generation and management in Sri Lanka: an empirical study, *Environmental Monitoring and Assessment*, **193**, 838–860.

Zhou X., Yang J., Xu S., Wang J., Zhou Q., Li Y. and Tong, X., (2020). Rapid in-situ composting of household food waste. *Process Safety and Environmental Protection*, **141**, 259–266.

Zouhon L.N.M. (2021). Stratégies de maintien des prés collecteurs privés dans la gouvernance locale des déchets solides ménagers à Bouaké. *Revue Espace, Territoires, Sociétés et Santé,* **5**, 313–326.