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Article

Evaluation of municipal solid waste (MSW) generation rates: A case study in the district of Cumba, Northern Peru

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Abstract: The objective of this research was to evaluate the unit rates of MSW generation in Cumba in the years 2016 and 2022. The calculations were based on the weights of the MSW disposed in the dump located 5 km from the city of Cumba since 2012. The GPC, physical composition, density, humidity were determined in the years 2016 and 2022, studied according to the methodology and group classification of Peruvian regulations. The results show that 5.45 Tn/day^{-1} are generated in 2016, 4.37 Tn/day^{-1} in 2022; according to its physical composition, 82% RO, 14% MICVC and 4% MISVC in 2016; 77% RO, 16% MICVC, 7% MISVC in 2022; density 137.90 kg/m^{-3} in 2016 and 172.69 kg/m^{-3} in 2022; humidity 67.67% in 2016 and 63.43% in 2022. It was also found that in 100.00% there is no solid waste treatment; Everything generated in homes, businesses and streets is evacuated to the final disposal site, which is a dump. In 2022, Cumba acquired 10 hectares to have adequate sanitary infrastructure and begin the closure and recovery of its current dump. This study will contribute to providing accurate data on MSW generation that allows the local government to promote the optimization of collection routes and schedules, resulting in cost savings and reduction of carbon emissions in the Amazon Region. Therefore, it is necessary to raise awareness at all levels of society through various means of communication and education, so that the risks of spreading health risks can be minimized by improving MSW management.

Keywords: waste management; characterization; circular economy; organic waste

1. Introduction

In Peru, literature exists regarding the characteristics of municipal solid waste (MSW), but any efforts are hampered by inadequate waste management policies. These issues are linked to improper waste disposal, ineffective collection methods, and insufficient coverage of current waste collection systems (Echegaray and Morales, 2020; Ministerio del Ambiente, 2009). In addition, the waste generation rate in Peru had an increasing trend in the period of analysis, registering an increase from 6.90 million in 2014 to 8.46 million tons in 2022 (23% increase), with an average rate annual growth of 2.6%. Furthermore, Peru generates 21,000 tons of garbage daily. Comparing the years 2014 and 2022 shows a slight growth in municipal waste per capita, that is, it went from 0.8 kg to 0.85 kg respectively (MINAM, 2023a). In Amazonas, the waste generation rate had an increasing trend in the period of analysis, registering an increase from 45.79 thousand in 2015 to 51.78 thousand tons in 2022 (12% increase), with an average rate of 1.7% annual growth. (MINAM, 2023a; Suarez and Suarez., 2024). Municipal solid waste management (MWSM) is a major challenge around the world, especially in developing countries, where infrastructure and resources for waste management are often limited (Hoornweg, 2012). It is anticipated that the global yearly production of municipal solid waste (MSW) will grow steadily, rising from approximately 2 billion metric tons in 2016 to 3.4 billion metric tons by 2050 (Bassey et al., 2024). In Peru, MSW management is a growing problem due to rapid population growth and urbanization (Perković et al., 2017). These factors increase the generation of waste and complicate its efficient management, which is essential to minimize environmental impacts and promote sustainability (Bos et al., 2020). Different approaches to waste management are currently being implemented globally. Solid waste refers to any waste material that exists in a solid or semi-solid state; this category can encompass anything from solid substances to liquids and gases (MINAM, 2017a, 2017b). Municipal solid waste (MSW) is made up of household waste and waste from the sweeping and cleaning of public spaces, including beaches, commercial activities and other non-domestic urban activities whose waste can be assimilated to public cleaning services, throughout the scope of its jurisdiction (MINAM, 2017a, 2017b).

MSWs pose a major challenge when it comes to management and have been identified as one of the main challenges in achieving sustainability objectives (Cucchiella et al., 2017). The literature discusses different categories of municipal solid waste, which vary based on the origins of the waste generation (Gaviria-Cuevas et al., 2019; Valiente Saldaña et al., 2023). The composition of municipal solid waste (MSW) varies significantly between regions and municipalities, and it can generally be classified into hazardous and non-hazardous components. However, the Peruvian Technical Standard for colors NTP 900.058-2019, approved by the National Quality Institute–INACAL with Directorial Resolution No. 003-2019-INACAL/DN of March 28, 2019 of MSW consist of waste green color usable, gray non-usable waste, brown organic waste and red hazardous waste (Asociación de Ex Becarios de JICA Perú, 2024; Instituto Nacional de Calidad, 2022; Suarez et al., 2024).

The current MSW management system in Cumba is rudimentary and faces multiple deficiencies. Waste collection is irregular, with limited coverage, reaching only 60% of the district's population. Collected waste is deposited in an open dump located on the outskirts of the main town, without any type of treatment or prior separation (Suarez and Suarez, 2022b). This practice not only poses a risk to public health and the environment, but also squanders the potential for waste recovery. In addition, the lack of a source segregation system and formal recycling programs results in the loss of potentially recyclable materials and overloading of the final disposal site. To address these challenges and improve MSW management in Cumba, a comprehensive approach combining technical, educational and public policy solutions is proposed. First, it is essential to implement a more efficient collection system with greater coverage. This could be achieved by acquiring collection vehicles suitable for the district's rural conditions and optimizing collection routes. In parallel, a source segregation program should be established, providing households with containers for different types of waste and educating the population on the importance and correct methods of separation.

Given the high proportion of organic waste, the implementation of a community composting program would be highly beneficial. This would not only reduce the amount of waste arriving at the disposal site, but would also produce high quality compost that could be used by local farmers, improving soil fertility and reducing dependence on chemical fertilizers. In addition, the possibility of installing a biodigester to process the organic waste and generate biogas could be explored, providing a source of clean energy for the community. To address the problem of plastics and other recyclable materials, it is proposed to establish a community recycling center. This center would serve as a collection point for recyclable materials, creating local employment opportunities and generating income through the sale of materials to recyclers. In addition, training programs could be implemented to promote upcycling and the creation of handcrafted products from recycled materials, fostering local entrepreneurship and the circular economy (Suarez and Suarez, 2022b).

Environmental education plays a crucial role in the success of any waste management initiative. It is recommended that a comprehensive educational program be developed that encompasses schools, community organizations, and households. This program should focus on the importance of waste reduction, reuse and recycling, as well as the environmental and health impacts associated with inadequate MSW management. The active participation of community leaders and local authorities in these educational campaigns is essential to ensure their effectiveness and acceptance by the community. From a public policy standpoint, it is necessary for the Cumba local government to develop and enforce municipal ordinances regulating MSW management in the district. In terms of waste disposal, it is imperative to close the existing open dump and replace it with a sanitary landfill that meets environmental and public health standards. For which the District Municipality of Cumba, in 2022, has carried out a site selection study to identify the area that meets the technical and regulatory requirements, managing to acquire 10 hectares. Given the scale of the district, the implementation of a manual landfill, which requires less investment and is more appropriate for small communities, could be considered. This landfill should be designed with leachate and gas collection systems, thus minimizing negative environmental impacts. These ordinances should establish clear targets for waste reduction and recycling, as well as penalties for inappropriate practices such as illegal dumping. In addition, collaboration with the regional and national government should be sought to access funds and technical assistance to implement the proposed improvements (Suarez and Suarez, 2022b).

The implementation of these measures would not only improve MSW management in Cumba, but would also bring multiple additional benefits. From an environmental point of view, soil, water and air pollution would be reduced, preserving local ecosystems and improving the quality of life of the inhabitants. In economic terms, the creation of green jobs in the recycling and composting sector, as well as savings in final disposal costs and the generation of income through the sale of recyclable materials and compost, would contribute to local economic development. Socially, these initiatives would foster community cohesion and empower citizens in the management of their waste (Suarez and Suarez, 2022b).

It is important to recognize that the transformation of the MSW management system in Cumba will require time, resources and sustained commitment from all stakeholders. However, the potential for improvement is significant, and success in this district could serve as a model for other rural communities in Peru facing similar challenges. By addressing MSW management in a comprehensive manner tailored to the local context, Cumba has the opportunity to become an example of sustainability and responsible waste management in the Peruvian Amazon region (Suarez and Suarez, 2022b).

Since then, there has been some reluctance to characterize the waste generated in Peru. Nevertheless, as Peru's population continues to grow and its economy becomes more industrialized and commercialized, there has been a noticeable rise in waste generation (MINAM, 2023b). Consequently, this study aims to evaluate the generation rates of municipal solid waste in the town of Cumba in the years 2016 and 2022.

2. Materials and methods

2.1. Study area

Cumba is located in the southwestern central part of the Utcubamba Province in the Amazonas region of Peru. It is located approximately at latitudes 5°55′52″ S and longitude 78°39′47″ E and 8°01′ W. The city shares a northern boundary with the Miracle district. To the Northeast, it shares boundaries with the district of Bagua Grande. To the south, it is delimited by the Province of Utcubamba (see **Figure 1**). To the Southeast, it shares boundaries with the Yamón district. To the west, it shares limits with the Department of Cajamarca. The last population census of Cumba was carried out in 2017. Cumba's current population is estimated to be around 3,266,000 residents, with an average annual growth rate of 1.01% (Instituto Nacional de Estadística e Informática, 2017). Cumba experiences a tropical dry montane forest and tropical premontane dry forest climate, with an estimated annual rainfall of 700 mm. The region also has minimal seasonal and temperature variation (Suarez et al., 2024).

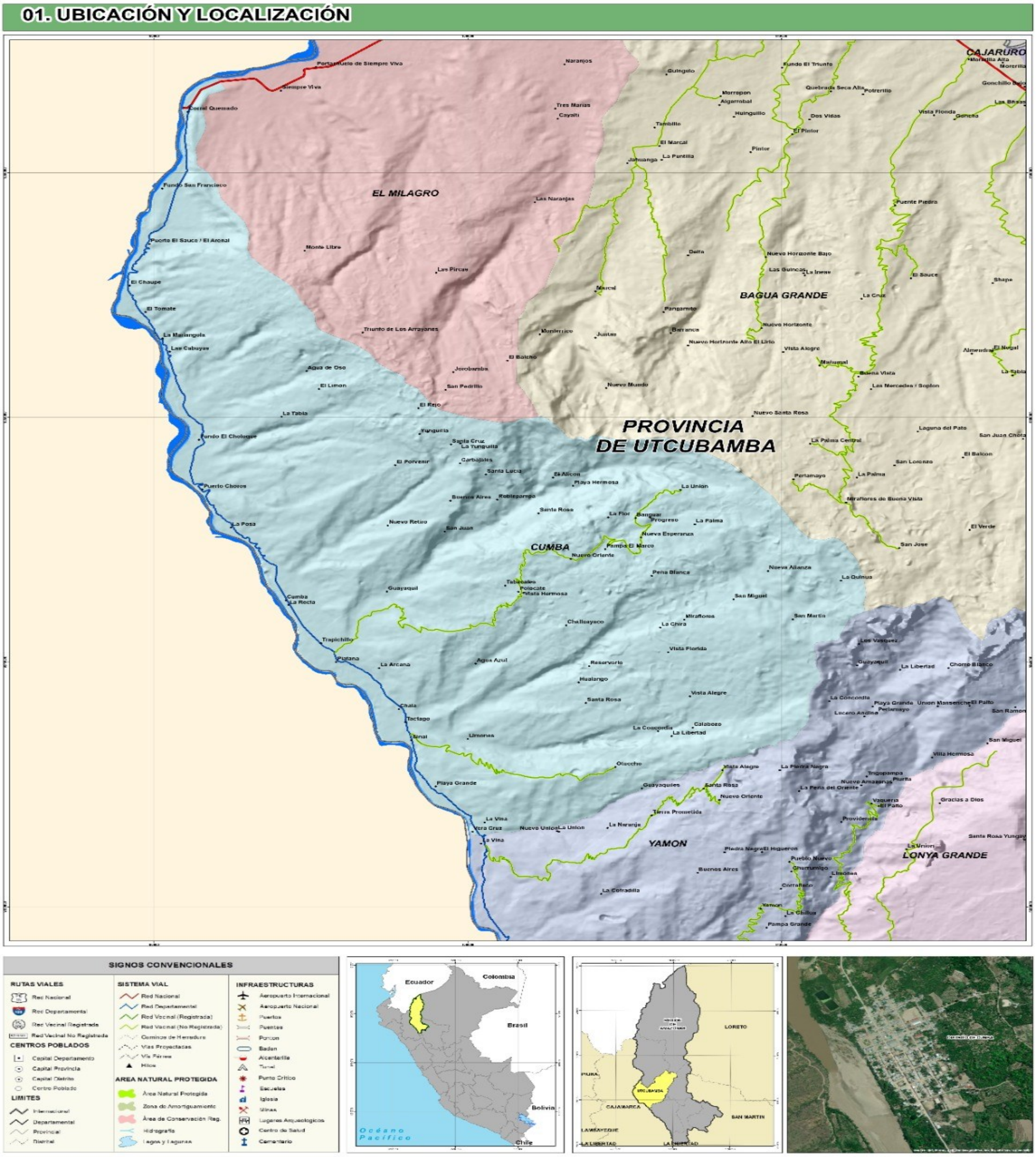

Figure 1. Location map of the town of Cumba.

2.2. Waste characterization study design

2.2.1. Research technology roadmap

The proposed Roadmap offers an overview of the different elements and practical measures that should be considered for the characterization study of municipal solid waste in the district of Cumba, including: the Methodological design (Sampling method, collection technology, temporality); primary data collection (field technology and data quality control) Data analysis (Data Processing); Validation of results (technological validation); Proposal of technological solutions (composting plant and landfill) and the process of stakeholder participation (see **Figure 2**).

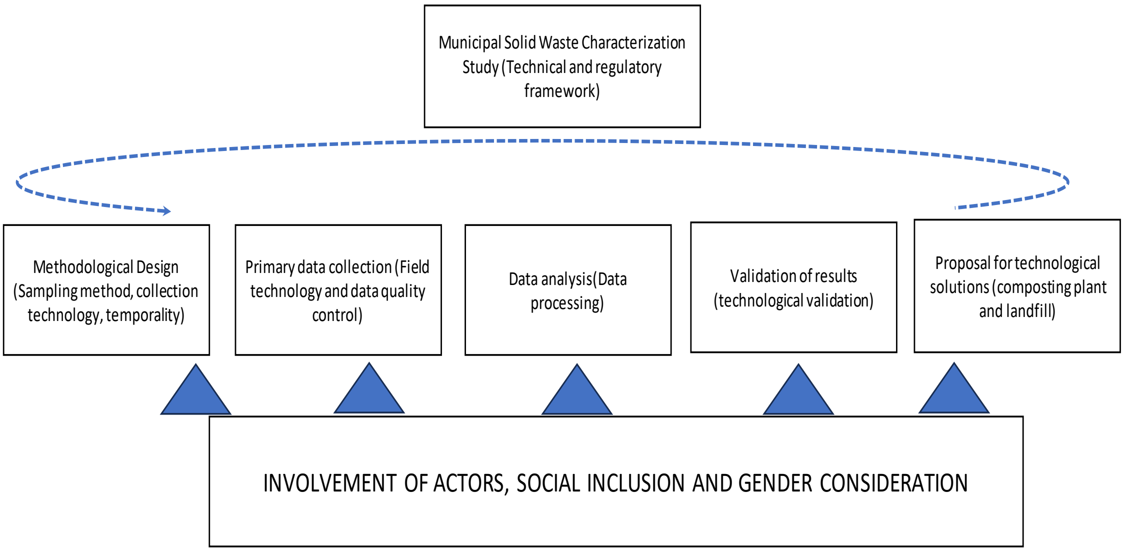

Figure 2. Research technology roadmap.

2.2.2. Waste characterization

The characterization studies of municipal solid waste were carried out in the town of Cumba in the years 2016 and 2022, the waste from this study was sampled using the quartering technique (Cantanhede et al., 2005; MINAM, 2018). This sampling technique is commonly employed for heterogeneous materials like municipal solid waste, particularly when the sample is too large to analyze in full. The method involves dividing the entire sample into four equal parts, discarding two opposite quarters, and then combining and mixing the remaining two quarters. This process is repeated until the sample is reduced to a smaller, more manageable size.

In this study, waste samples were collected from "homes, juice stores, restaurants, market stalls, schools, public institutions", immediately after unloading in the place prepared by the District Municipality of Cumba, this was carried out using five people in both studies to carry out the characterization. The sample size was essential for ensuring the accuracy and reliability of the research results. To achieve this, the sampling formula for continuous variable measurements was utilized Equation (1), as applied by Dr. Kunitoshi Sakurai in 1982 (Cantanhede et al., 2005, 2006).

$$n = \frac{Z^2_{1-\infty/2} N \sigma^2}{(N-1)E^2 + Z^2_{1-\infty/2}\sigma^2} \quad (1)$$

where n = the sample size, Z = value for a selected alpha level from each tail = 1.96; N = Population size, σ = estimated population standard deviation based on a previous study and E = allowable error 10% of the National Per capita Generation in the corresponding year. (Cantanhede et al., 2005, 2006). For both studies, there was community involvement, with 56 and 80 households correspondingly in 2016 and 2022 (Alimoradiyan et al., 2024). According to the calculation, the total waste analyzed was 965.32 kg and 1057.17 kg, respectively. The waste sample was manually divided using the quartering method (Cantanhede et al., 2005, 2006; MINAM, 2018). The entire sample was mixed by five individuals and spread out on a paved surface covered with a large plastic sheet to avoid contamination from soil. Then, the bags were torn open and the residue was poured into a pile. We divided the pile into four parts (quartering method) and the two opposite parts were chosen to form a smaller pile. It was mixed again and divided into four parts again, then we chose two opposite parts and formed another smaller sample. This process was carried out four times until a manageable sample size of 50 kg was obtained. The characterization work for this study was conducted over a span of seven consecutive days.

2.2.3. Waste sorting

For easier identification, the waste in the municipal solid waste characterization study was categorized by grouping similar types of waste into the following categories (MINAM, 2018):

i. Organic material.
ii. Inorganic Matter with Exchange Value (Paper, Cardboard, Plastic, Metal, Tetrapak).
iii. Inorganic Matter without Exchange Value (Wood, toilet paper, diapers).

2.2.4. Waste density

In this study, once the entire segregation and weighing process was carried out; The waste collected during the day is homogenized and separated into four equal parts (quartering method), from which the most homogeneous part is taken, weighed and then deposited in a container of defined volume, height and known diameter, to proceed to determine the density (Cantanhede et al., 2005, 2006; MINAM, 2018).

For municipal waste, a plastic cylinder of defined volume (approximately 100.00 L) of known height and diameter was used. The following steps were performed:

- The tank is filled or, failing that, leaving a free height, it is raised about 10 cm above the ground and dropped three times, to make the sample uniform.
- If the tank is full, the calculation height will be equal to its height. If there is a free height, the distance from the maximum height of the waste to the edge of the tank is measured.
- The density calculation was found in the office, using the following formula: Equation (2) (MINAM, 2018).

$$\text{Density} = \frac{W}{V} += \frac{W}{\pi \times \left(\frac{D}{2}\right)^2 \times (H - h)} \tag{2}$$

where:

W: Solid waste weight;
V: Solid waste volume;
D: Cylinder diameter;
H: Total cylinder height;
h: Solid waste free height;
π: Constant “pi” (3.1416).

2.2.5. Waste moisture

At the end of taking the density data, all the day’s waste was collected and only 3 kg of organic material was taken from it, which was chopped (shredded) into particles as small as possible and from there three samples of 3 kg each, which are placed in properly labeled shaded environments, to be weighed after three days. Samples have been taken in five (05) days, the same days that have been averaged to obtain the humidity percentage. Equation (3) (Cantanhede et al., 2005, 2006; MINAM, 2018).

$$\text{Humidity} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \tag{3}$$

where:

W_2 = Weight shows humidity;

W_3 = Dry sample weight;

W_1 = Box Weight.

3. Results and discussion

3.1. Quantification of municipal solid waste

The assessment of municipal solid waste (MSW) generation rates in the district of Cumba, located in the Amazonas region of northern Peru, reveals a complex situation that reflects both local challenges and national trends in waste management. Cumba, with a predominantly rural population and an economy based on agriculture and livestock, faces unique challenges in managing its MSW. A detailed study conducted in the district during 2016 and 2022 respectively revealed that the average per capita MSW generation rate is 0.61 and 0.67 kg/day, significantly lower than the national average of 0.85 kg/day (MINAM, 2023b). This difference is mainly attributed to the rural nature of the district and more conservative consumption patterns compared to urban areas of the country.

The global generation of MSW in 2016 and 2022 responds to the differences in local and regional economic development and urban population growth. In the year 2022, approximately 15.52% has increased urban population growth compared to 2016, responding to an increase of 28.09% in MSW generated in the town of Cumba, that is, it is pertinent to take into account that about 77% is dedicated to extractive activity, characterizing them as underemployed and consequently, they only have a single source of subsistence work and job opportunities, there is migration to other regions (**Table 1**). The study of Huseyin (Ozcan et al., 2016), They found that the generation reached at the Low Level 46.4 Tn/day, Medium Level 30.7 Tn/day, High Level 30.42 Tn/day, Center Level 15.38 Tn/day, values higher than those of our study. The study of Bassey (Bassey et al., 2024), They found that the generation reached 1.89 Tn/day in the year 2023 and 2.24 Tn/day in the year 2029, values higher than those in our study, this may be associated depending on income levels and seasonal conditions, some homes have only a few residents during the week, resulting in relatively small amounts of waste being generated. The study by Obiora B. Ezeudu (Ezeudu et al., 2021) found that generation reached 66,828 tons/day in 15 cities in Nigeria in 2020, values higher than those in our study, this may be associated depending on population and income levels, generating a more in-depth analysis of the prospects and implications of adopting the circular economy in solid waste valorization in Nigeria.

Table 1. Population and MSW for the years 2016 and 2022 of the town of Cumba.

Year	Population Inhabitants	MSW Tn/day	% Increase MSW	% Increase Population
2016	2771	1.68	28.09	15.52
2022	3201	2.15		

Fountain: Own elaboration, with data from (INEI, 2017; Suarez and Suarez, 2016, 2022a).

3.2. Composition of municipal solid waste

The composition of MSW in Cumba reflects its rural nature: approximately 82% in 2016 corresponds to organic waste, mainly food scraps and agricultural waste; 14% inorganic waste with exchange value and 4% inorganic waste with no exchange value; and in 2022 77% corresponds to organic waste; 16% inorganic waste with exchange value and 7% inorganic waste with no exchange value. This composition presents both challenges and opportunities for sustainable waste management in the district. On the one hand, the high proportion of organic waste offers significant potential for composting and biogas production, which could generate agricultural and energy benefits for the community. On the other hand, the presence of plastics and other non-biodegradable materials poses challenges in terms of recycling and proper disposal (Suarez and Suarez, 2016, 2022a).

The composition of municipal solid waste from ECRSM 2016 and ECRSM 2022 (Suarez and Suarez, 2016, 2022a), using the quaternary method described in the methodology, is summarized in **Table 2**. It shows that the largest component of waste generated in the town of Cumba in both 2016 and 2022 (by weight and volume) was mixed organic waste. This can be partly attributed to the region's agricultural and cultural practices, where farming is the primary activity even among working-class households. Conversely, the combined fractions of cardboard, metal, plastics, and paper saw an increase of approximately 2% and a decrease of 15%. This can be partly explained by: (1) increased consumption of packaging materials, influenced by the growing commercial and sales activities in the area, and (2) population growth driven by significant migration from rural to urban areas in recent times. Furthermore, **Table 2** indicates that the total fraction of organic solid waste (plastics + metal + paper) exceeds 70% of the total waste. This presents an opportunity to incorporate thermochemical waste conversion methods, as existing technologies could enhance the region's power generation capacity, noting the ongoing challenge of insufficient power supply. Huseyin's study (Ozcan et al., 2016) found that the composition of municipal solid waste included 57.69% organic waste, 4.81% paper, 8.41% plastics, and 1.01% metals, which are lower values compared to our study. Conversely, Bassey's study (Bassey et al., 2024) reported that the composition consisted of 34.2% organic waste, 6.9% paper, 30.9% plastics, and 7.5% metals, with lower values in organic waste and paper, but higher in plastics and metals compared to our findings. Based on the results of this study, it has been shown that solid waste, particularly organic waste, can be economically beneficial through effective waste management planning. Considering the methods applied in the selected study area, enhancing separate collection activities will not only increase the volume of organic waste and the number of containers collected but also improve the profit margins for authorized companies. Additionally, it will reduce the overall amount of waste sent to disposal. Consequently, this approach will offer better opportunities to use waste as a secondary raw material while lowering total disposal costs. Characterizing waste is crucial for integrated waste management. Such studies should be conducted more regularly to track improvements in municipal solid waste management systems and reduce the overall volume of waste. The study by Obiora B. Ezeudu (Ezeudu et al., 2021), found that the composition of 15 cities in Nigeria ranged from 22% to 79.1% of organic waste, lower values compared to our study. In contrast, inorganic waste ranged from 0.1% to 20.3%, high values compared to our study. We therefore recommend that urban policy makers in Cumba explore this new urban policy mechanism, which, by implementing actions to create an adequate and safe waste recycling operation, could legalize the current urban informal economy that relies more on waste collection. They should be included in social and economic policy planning.

Table 2. Composition of solid waste from the years 2016 and 2022 in the town of Cumba.

Years	PESO			VOLUMEN		
№	**Organic Waste %**	**Inorganic Waste with exchange value %**	**Inorganic Waste without exchange value %**	**Organic Waste %**	**Inorganic Waste with exchange value %**	**Inorganic Waste without exchange value %**
2016	82	14	4	39	54	7
2022	77	16	7	53	39	8

Fountain: Own elaboration, with data from (Suarez and Suarez, 2016, 2022a).

3.3. Municipal solid waste density

Cumba waste had low densities of 137.90 kg/m^3 and 172.69 kg/m^3 in 2016 and 2022 respectively (**Tables 3–5**) and (**Figures 3** and **4**). The results indicate that rural areas produce denser waste compared to urban centers. This difference may be due to the prevalence of bulky items in rural areas, whereas urban waste is often dominated by lightweight packaging materials such as cardboard and cans (SO Ojoawo, 2009). The finding is in line with a previous report by (Cantanhede and Sandoval, 1997) which establishes the density of loose waste at 200–300 kg/m^3, values higher than those of our study. The study of Ojoawo (Ojoawo et al., 2011), They found that the density reached 438.1 kg/m^3, values higher than those of our study.

Table 3. Average solid waste density for the years 2016 and 2022 in the town of Cumba.

Years	Density (kg/m^3)
2016	137.90
2022	172.69

Fountain: Own elaboration, with data from (Suarez and Suarez, 2016, 2022a).

Waste density is important for predicting the total waste generation per capita, providing valuable data for waste planning and management. Since organic wastes typically have higher water content, denser waste tends to produce more leachate. As a result, it is anticipated that the study area is less likely to experience significant leachate contamination from the open-air dump. The study by Ingrid Milagros Albán Meléndez (Albán Meléndez, 2022), which establishes the average densities of household solid waste are 114.38 kg/m^3 and the average densities of non-household solid waste is 308.55 kg/m^3, lower values compared to household waste and higher compared to non-household waste.

Table 4. Weight (kg), volume (m^3), density (kg/m^3) in 2016.

Date	Weight (kg)	Volume (m^3)	Density (kg/m^3)
31.03.16	35.23	0.25	140.67
01.04.16	34.76	0.26	133.06
02.04.16	34.17	0.24	143.11
03.04.16	33.21	0.27	122.25
04.04.16	34.74	0.21	165.81
05.04.16	33.19	0.25	132.92
06.04.16	34.075	0.27	127.53
Promedio	34.196	0.25	137.9

Fountain: Own elaboration, with data from (Suarez and Suarez, 2016, 2022a).

Table 5. Weight (kg), volume (m^3), density (kg/m^3) in 2022.

Fechas	Peso kg	Volument m^3	Densidad kg/m^3
06.07.22	16.1	0.11	146.45
07.07.22	8.9	0.04	202.39
08.07.22	8.7	0.06	139.43
09.07.22	9.05	0.04	205.8
10.07.22	11.1	0.06	176.22
11.07.22	12.35	0.07	187.23
12.07.22	8.9	0.06	151.28
Promedio	10.729	0.06	172.69

Fountain: Own elaboration, with data from (Suarez and Suarez, 2016, 2022a).

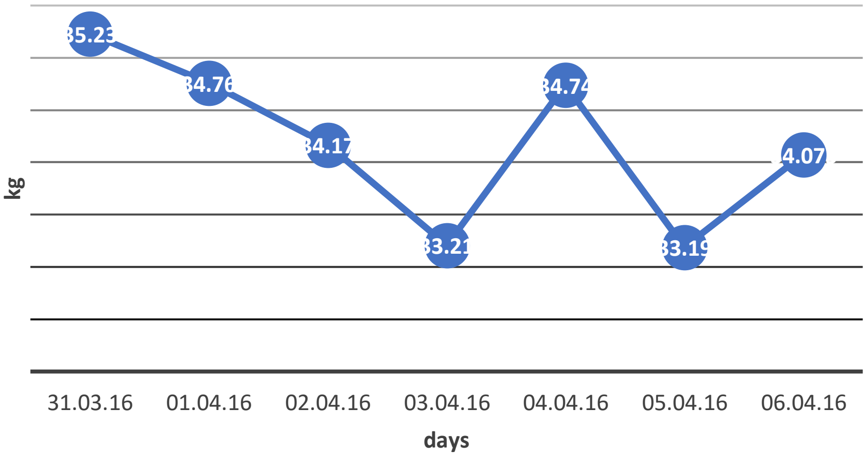

Figure 3. Weight trend (kg), according to its physical composition of waste in the year 2016.

Fountain: Own elaboration, with data from (Suarez and Suarez, 2016, 2022a).

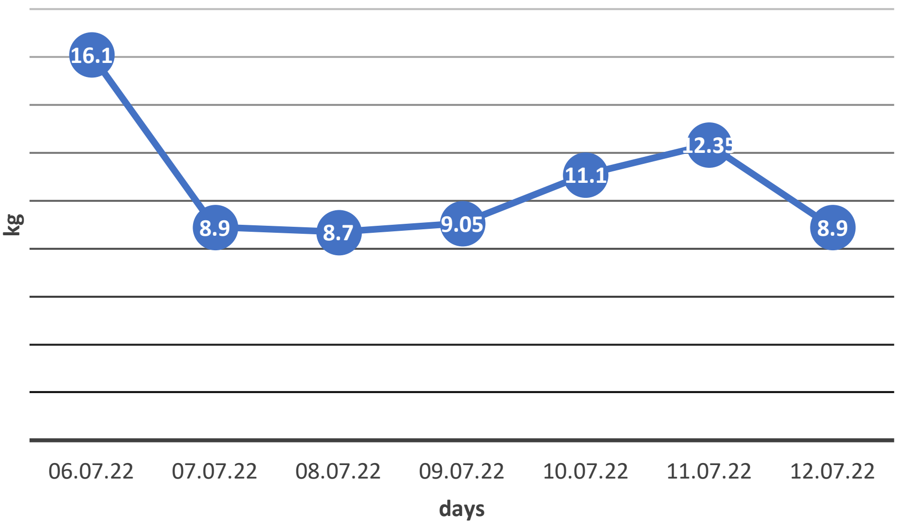

Figure 4. Weight trend (kg), according to its physical composition of waste in the year 2022.

Fountain: Own elaboration, with data from (Suarez and Suarez, 2016, 2022a).

3.4. Municipal solid waste moisture

Based on the classification process carried out during the characterization studies conducted in 2016 and 2022, representative samples were collected in April 2016 and July 2022 to determine the moisture content values. The results of these analyzes are presented in (**Table 6**). As expected, the moisture content rates of the solid waste samples were higher in the year 2016 compared to the year 2022. The moisture content of the solid waste was measured to be 63.43% in the year 2022. and 67.67% in 2016. The average moisture content of the waste in the town of Cumba in both years was measured at 65.55%. Taking into account the analyzes of moisture content, the average value for the years 2016 and 2022 is 65.55%. The substantial presence of organic matter in solid waste can notably raise its moisture content. Even though this value appears elevated compared to the theoretical moisture content of municipal solid waste (MSW), it aligns with findings from earlier research in the literature (Jaramillo, 2002). The study of Huseyin (Ozcan et al., 2016), They found that the moisture content reached 71.1%, values higher than those of our study. The study by Józef Ciula (Ciuła et al., 2024), found that the moisture content is between 32.9% to 40.9%, values lower than those in our study, which does not disqualify them for energy use in the production of waste-derived fuel.

Table 6. Average humidity of solid waste for the years 2016 and 2022 in the town of Cumba.

Years	Humidity %
2016	67.67
2022	63.43

Fountain: Own elaboration, with data from (Suarez and Suarez, 2016, 2022a).

4. Conclusions

This article focused on Evaluation of Municipal Solid Waste (MSW) generation rates in Cumba, Amazonas Region, Peru. The waste generation indices were evaluated in the town of Cumba in the years 2016 and 2022, a characterization study design was carried out, the amount of daily waste, density and humidity was calculated. Therefore, the following conclusions were drawn:

Plastic, paper, glass, and metal waste accounted for less than 15% of the total waste collected in the District Municipality of Cumba, indicating a significant opportunity for valorizing the recyclable portion of the waste.

Organic waste made up over 70% of the total waste collected in the District Municipality of Cumba, highlighting a substantial opportunity for energy recovery from the organic fraction of the waste, such as composting and biogas production.

The existing waste management system is inadequate for managing the volume of waste produced in the District Municipality of Cumba, with most of it being disposed of in open dumps. This issue is expected to worsen over the next ten years, during which time waste generation is projected to increase by 40%.

Despite the irregular topographic conditions and delimitation of its streets in the district of Cumba there are areas that are difficult to access with the current mobile units, so there is 80% coverage, 100% of the service.

At present, much of the potential value of waste is squandered in open dumps. However, significant opportunities exist for generating energy and income if proper source segregation is implemented.

In the district of Cumba it is of immediate need to carry out a process of segregation at source through the application of the 3Rs: “Reduce–Reuse–Recycle”, house by house to take advantage of the transformation of the Organic solid waste (organic fertilizers), segregation and commercialization of inorganic solid waste with exchange value, considering the criterio corresponding technicians.

Gradually reducing and eventually eliminating waste disposal in open dumps is crucial. This can be accomplished through collaboration between private entities and the municipality. Additionally, it is essential to create incentive strategies to motivate citizens to engage in a comprehensive waste management plan.

The solid waste management system in the Cumba District will achieve continuous improvement with adequate diagnosis and planning; segregation at the Source (environmental awareness and education); Optimization of collection and transportation (route design, time and movement studies); Treatment and final disposal infrastructure (organic and inorganic waste recovery plant and manual landfill); economic incentives (difference rates for solid waste volume and promotion of green businesses); community involvement (citizen participation and the incorporation of informal recyclers); Continuous monitoring and evaluation (performance indicators and monitoring technology); alliances and financing (interinstitutional collaboration and international cooperation projects) and continuous training (training of local managers), which promote more sustainable and efficient practices that in turn will reduce environmental impacts and improve the quality of life in the community.

5. Expressions of gratitude

This article is the result of the analysis of the indicators (quantity (kg/inhabitant/day); physical composition (%); density (kg/m^3); and humidity (%)), of the years 2016 and 2022. We thank the District Municipality de Cumba for facilitating access to the data that has been of valuable importance in the preparation of this article.

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