Reception: **May 15, 2023** | Acceptance: **November 10, 2024**| Publication: **February 1, 2025**

Study of Generation of Municipal Solid Waste in the Municipality of Chiapilla, Chiapas, and Waste Management Improvement Strategies

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To quote this article:

Araiza Aguilar, J. A., & Nájera Aguilar, H. A. Estudio de Generación de Residuos Sólidos Urbanos en la Cabecera Municipal de Chiapilla, Chiapas, y Estrategias de Mejoramiento de Manejo de Residuos. *Espacio I+D, Innovación más Desarrollo, 14*(39). https://doi.org/10.31644/IMASD.39.2025.a01

— Abstract—

Municipal solid waste management is one of the main challenges faced by society today. Knowing the quantities of waste produced allows us to quantify the equipment needed to acquire it, such as garbage trucks and containers. In addition, they serve as a basis for designing engineering works, such as landfills and waste separation plants.

In this work, a study of the generation of municipal solid waste in the municipal seat of Chiapilla, Chiapas, was developed to generate information that allows making decisions regarding the management of such wastes. The work carried out allowed us to determine the per capita generation rates for the municipal generation source (0.733 kg/inhabitant-day), households (0.615 kg/inhabitant-day), and non-domestic generation (0.118 kg/inhabitant-day). On the other hand, through the study of the composition of solid waste, it was determined that the organic component continues to maintain high percentages in the study area (65.71 %), followed by other subproducts such as plastics (7.38 %), as well as paper and cardboard (4.31 %). Based on the results obtained, some waste management strategies were proposed for the City Council, which include the modification of its local regulations, the formulation of environmental education campaigns, and others. All these actions can serve to improve current conditions in the municipality in terms of waste management.

Keywords:

Solid waste; subproducts; waste generation.

Globally, there has been a drastic change in the generation rates and characteristics of Municipal Solid Waste (MSW), influenced by factors such as population growth, changes in consumption habits, purchasing power, migration, or new customs (Buenrostro & Bocco, 2003; GTZ, 2003; Ojeda & Beraud, 2003). In Mexico, this phenomenon is also present, causing the entities responsible for providing urban cleaning services to face new challenges in the search to provide greater efficiency in those activities.

According to Bernache (2015), among the main challenges faced by the municipalities of Mexico are: i) the lack of economic resources to meet the payment of personnel involved in urban cleaning; ii) the poor vehicle fleet to carry out waste collection; iii) the inadequate location of final disposal sites and their poor operation; iv) the lack of strategies for sustainable waste management; v) the low social participation in management processes, particularly about minimizing the production and separation of waste. Other challenges that include political aspects are established in (Environmental Protection Agency [EPA], 2020), such as the political rotation between trienniums of municipal government and government coordination between different state and municipal agencies.

Before solving problems and challenges associated with MSW through good decision-making, it is essential to know the amounts of waste generated, so studies are used to generate and quantify sub-products of MSW. Bernache et al. (2001) and Ojeda et al. (2008), point out the importance of systematizing methodologies for generation studies, which provide information that serves for the planning of urban toilet services. They are also indispensable because they technically make it possible to quantify the equipment necessary to purchase collection trucks and containers. In addition, they serve as a basis for the design of engineering works, such as landfills and separation plants (Ministry of Environment and Natural Resources [SEMARNAT], 2020). Unfortunately, few municipalities have the infrastructure or knowledge to be able to carry them out

The lack of data on waste production in municipalities can be detrimental to proper waste management. Currently, there are few works carried out in small municipalities or rural communities. The work of Alvarado et al. stands out (2009) and Araiza et al. (2015), since not only waste management figures are generated, but also proposals according to the size of the settlement. This work shows the results of a study of generation and quantification of sub-products of MSW, carried out in the municipality of Chiapilla, Chiapas. This municipality, like many others in the country, has undergone different socio-cultural changes in recent years, which have had an impact on MSW generation rates. For example, according to data from the National Institute of Statistics, Geography, and Informatics (INEGI, 2010, 2020), between 2010 and 2020, the population had an increase of 13.65% that is, the population went from 3,809 to 4,329 inhabitants. In this same sense, the number of homes went from 1,139 to 1,447, that is, there was an increase of 27.04%. In terms of services and commercial establishments, in the same period, there was a small increase in these establishments, from 198 to 205. It is important to mention that the most notable change can be seen in the central area of the municipality or the first picture.

This work is expected to generate useful information for municipal authorities that can use the data to design works, plans, and programs in waste management, for example, redesign the current final disposal site, as well as acquire more collection units. Additionally, some strategies focused on regulatory aspects and environmental education are proposed.

MATERIALS AND METHODS

Waste Management Study Area and Context

This work was carried out in the municipality of Chiapilla, Chiapas, located in southeastern Mexico. Its location coordinates are 16°34' 12.67'' north latitude and 92° 43' 12.76” west longitude (**Figure 1**). The municipality has a total territorial area of 53.04 km^2, has seven localities, of which only the capital is urban, and has a population of 4,329 inhabitants (CEIEG 2023). Currently, the municipality has some deficiencies in waste management, particularly in the stages of collection and final disposal, which are operated with poor infrastructure, so their attention is urgent. Regarding the final disposal site, new cells are required, while, in the case of collection, a greater number of collection vehicles. These deficiencies can be solved through the information provided by the study of sub-product generation and quantification.

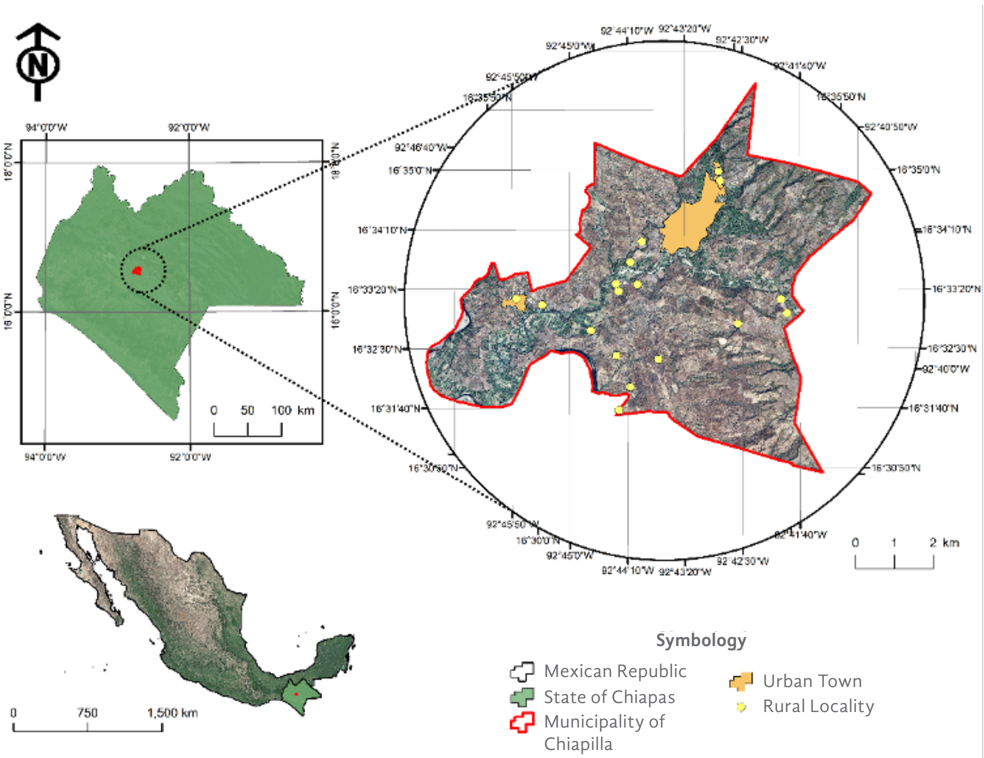

Figure 1. Research area

Collection of baseline data and housing selection

Initially, the INEGI databases were used, in addition to the City Hall of Chiapilla, Chiapas, to confirm the only visible socioeconomic stratum in which waste sampling would be carried out. Subsequently, as indicated by NMX-AA-061-1985 (Ministry of Commerce and Industrial Development [SECOFI], 1985d), to work with a confidence level of 90%, at least 80 houses were determined as pre-samples within the capital, which were numbered on a plan of the study area, and chosen through random numbers produced by statistical software.

Before taking samples in each home, we proceeded to tour the study area, visiting the inhabitants of the selected houses to explain the reason for the sampling, in addition to collecting general information on urban cleaning services. The fieldwork began on Wednesday, June 15, 2022, delivering a polyethylene bag daily, which had to be filled with the waste generated in the house, and collected the next day for further analysis. This operation was repeated until June 21, 2022, when the fieldwork was completed.

It is important to note that the collection of samples was carried out at 7:00 am every day, except for some households where there was no one at home. In addition, the cleaning operation was considered, which consisted of collecting the waste stored the day before the start of the studies, to avoid biases in subsequent sampling.

The analysis of outlier data of *per capita* waste production rates was performed considering the Dixon r22 criterion for samples larger than 14 elements within the MINITAB software. The equations and critical values of the aforementioned exclusion criterion can be found in Davis and McCueen (2005).

Concerning non-household generation (commercial and service), databases shown in Heredia et al. (2007) and Alvarado et al. (2009), which contain waste generation rates by type of commercial establishment, were used. Additionally, information from the National Statistical Directory of Economic Units (DENUE) of INEGI (2023), was used to identify the number of establishments within the capital of Chiapilla, Chiapas. **Table 1** presents a classification of economic units suggested by Araiza et al. (2017a).

Table 1

Establishments and economic units that may be analyzed

Economic units	Description
Commercial	This classification includes both small and large establishments, where necessities and other goods are sold. Among the main establishments are self-service stores, commercial establishments of various types, as well as grocery stores, and meat and vegetable stores.
Services	In this classification are the establishments that assist society, regarding transportation, paperwork, and others. The establishments correspond to public and private offices, cultural and religious centers, as well as gas stations and hotels.
Specials	It is made up of educational centers, medical units, and land terminals.
Others	In the latter classification, the green areas of parks and gardens were grouped.

Determination of the composition of residues and volumetric weights

After collecting the bags of waste from each house/room sampled, they were taken to the workspace assigned by the City Hall, where each bag was weighed and recorded in a database, and the per capita generation rate was obtained based on **Equation 1**.

$$GPD_R = \frac{mBolsa_R}{Hab_{viv}} \quad (1)$$

Where GPD_R is the per capita household generation rate in kg/hab-day; $mBolsa_R$ is the weight of waste within each bag in kg; Hab_{viv} is the number of inhabitants in each dwelling of the day sampled.

Subsequently, the waste from each bag was placed on the floor and mixed as indicated in NMX-AA-015-1985 (SECOFI, 1985a), applying the quartering method, which consists of dividing the waste (into four parts) until obtaining an adequate portion for the subsequent steps. With the support of a 200 L container and following what is described in NMX-AA-019-1985 (SECOFI, 19852b) and **Equation 2**, the operation was carried out to determine the volumetric weight of the waste.

$$\rho_R = \frac{m_{cm}(lleno) - m_{cm}(vacío)}{V_{cm}\ x\ N_{llenado}} \tag{2}$$

Where ρ_R is the density of waste in kg/m^3; m_{cm} (*lleno*) is the weight of the full sampling container (kg); m_{cm} (vacio) is the weight of the empty sampling container (kg); V_{cm} is the volume of the sampling container (0.2 m^3); $N_{llenado}$ is the fill level of the sampling container (%).

Finally, to characterize or quantify the sub-products, a portion of approximately 50 kg from quarrying was used. In this activity, the residues were placed on a table, categorizing them based on the fractions and components listed in **Table 2**, in addition to what is indicated in NMX-AA-022-1985 (SECOFI, 1985c). It is important to note that the weight percentage of each of the sub-products was determined through **Equation 3**.

$$P_{sub} = \frac{m_{sub}}{m_T} \tag{3}$$

Where P_{sub} is the percentage of the sub-product considered; m_{sub} is the weight of the sub-product considered in kg, discounting the weight of the bag or container used in the weighing; m_T is the total weight of the sample in kg (50 kg or close to that value).

Table 2
Component of the MSW fractions.

Fraction	Components
Organic	Fraction of rapid biodegradability which includes food and gardening waste, as well as pieces of wood.
Paper and cardboard	This includes printing paper, magazine or waxed paper, newspaper, cardboard, and waxed cardboard.
Plastics[a]	In this fraction, pet, HDPE, LDPE, PP, PS, PVC, and mixtures thereof were incorporated into the plastics.
Glass	Two categories were considered: transparent and color
Metals	This includes aluminum in cans and profiles, as well as metals in both can and piece form.
Hazardous[b]	It includes all materials that have CRETIB characteristics, such as syringes, batteries, and medicines.
Technology	Any equipment or part from a household appliance is included.
Not usable	This fraction includes paper and sanitary napkins, as well as other sub-products such as rubber, earthenware and ceramics, construction materials, and fine items.

Note: [a] PET (terephthalate polyethylene), HDPE (high-density polyethylene), LDPE (low-density polyethylene), PP (polypropylene), PS (polystyrene), PVC (polyvinyl chloride).
[b] CRETIB (corrosive, reactive, explosive, toxic, flammable, and infectious biological).

$$GT_R = GD_R + GND_R \tag{4}$$

$$GPU_R = \frac{GT_R}{PT} \tag{5}$$

$$GS_R = GPU_R \ x \ P_s \tag{6}$$

Where GT_R is the total waste generation of the study area in tons/day; GD_R is the rate of waste production from the household source in tons/day; GND_R is the rate of waste production from the non-household source (for example, schools and small businesses) in ton/day; GPU_R is the urban per capita generation in kg/hab-day; PT is the total population of the study area; GS_R is the rate of waste production by sector, colony, or another type of area in ton/day; P_s is the population of each sector, colony, or any other area. **Equation 4** is useful for clearly identifying domiciliary and non-domiciliary sources, while Equation 5 allows the per capita rate to be obtained. **Equation 6** allows us to calculate waste production rates but at the generating source level.

RESULTS AND DISCUSSION

Statistical analysis of per capita household generation

In this study of waste generation, it was possible to work with 86 homes, which participated by delivering the samples with waste during the 8 days that the field activities lasted (including the cleaning operation). After the weighings, obtaining volumetric weights, and characterization of residues, the database was examined by applying an atypical data exclusion analysis, specifically the Dixon r22 criterion (for samples greater than 14 elements), within the MINITAB statistical package (**Figure 2**).

Through the aforementioned exclusion criterion, no data was removed because the value of the test statistic and the p-value are higher than the r22 value of Dixon and *α* respectively. Therefore, the statistics of the sample were obtained, obtaining an average per capita generation of 0.615 kg/house-day, a median of 0.580 kg/house-day, and a standard deviation of 0.289 kg/house-day. In addition, the calculation of the actual sample size yielded a value of 56, so the 86 pre-samples with which we worked during the study were accepted. This was done considering a sampling error of 0.05 kg/house-day and a percentile of the student t distribution corresponding to the 90% confidence level.

Finally, the reliability analysis indicated that the statistics of the sample can be used as the population parameters since the null hypothesis that the sample mean does not differ from the population mean is accepted (H_0:X =µ vs. H1:*X* ≠µ). The above, through the p-value obtained, which is higher than the chosen significance value (0.99 > 0.05), considers a 95% confidence level and a two-sided test.

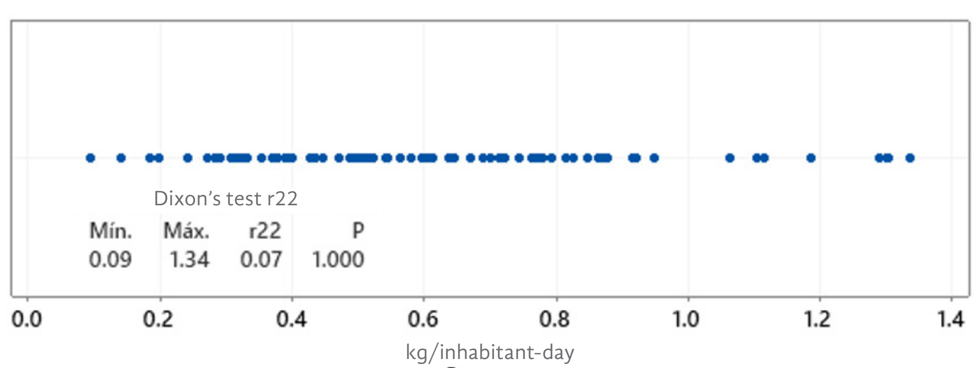

Figure 2. Outliers and application of the exclusion criterion

Household and non-household waste production

Table 3 shows the per capita household generation per day, obtained through the study carried out. A standard deviation of 0.046 kg/house-day is observed concerning the global average rate obtained of 0.615 kg/house-day. It is important to mention that this value is slightly below the national average of 0.653 kg/inhabitant-day, and also below the per capita generation value for small localities of 0.642 kg/inhabitant-day (<10 thousand inhabitants), both data reported by SEMARNAT (2020).

Concerning other studies carried out in Chiapas, the average obtained in this study is higher than the figures reported by Alvarado et al. (2009), Araiza et al. (2015), Araiza et al. (2017a), and Araiza et al. (2017b), for municipalities such as Chiapa de Corzo, Las Margaritas, Berriozábal, and Villaflores respectively, which range between 0.3 and 0.5 kg/inhabitant-day. These differences may be due to the timing of the studies, since according to Jaramillo (2002), normally waste production rates tend to increase annually at a rate of 1 to 2%.

Table 3
Household per capita generation rates obtained in generation study

Day	kg/inhabitant-day average per day	Global average kg/inhabitant-day	Standard deviation kg/inhabitant-day
15/06/2022	0.680		
16/06/2022	0.628		
17/06/2022	0.672		
18/06/2022	0.604	0.615	0.046 kg/inhabitant-day
19/06/2022	0.577		
20/06/2022	0.565		
21/06/2022	0.584		

Regarding the production of non-household waste, according to the information described in the INEGI's Directory of Economic Units (2023), Chiapilla, Chiapas has 205 establishments (**Table 4**), which presented a waste generation rate of around 0.516 tons/day, equivalent to a per capita rate of 0.118 kg/inhabitant-day. It should be noted that commercial economic units, particularly grocery stores and small stores predominate in the study area since they correspond to 36.59% of the total economic units. In contrast, fruit and vegetable stores (1.95%), as well as medical units (1.46%), and educational centers (3.90%) are the economic units with the lowest presence.

Table 4
Waste production from non-domestic sources

Economic units		No. of units	Generation per unit (kg/day)	Total generation (ton/day)
Commercial	Local commercial establishments	47	3.5	0.165
	Small grocery store	75	0.925	0.069
	Butcher shop	13	2.43	0.032
	Fruit and vegetable stores	4	3.92	0.016
	Miscellaneous	18	0.803	0.014
Services	Public/private/cultural offices	18	1.05	0.019
	Restaurants/Food	19	5.96	0.113
Specials	Schools	8	0.059/alumno	0.081
	Medical Units	3	0.92/consultorio	0.003
Others	Parks and gardens (m^2)	402	0.00993/m^2	0.004
	Total	205	--	0.516

Note: The area of parks and gardens is not being considered in the sum of economic units.

Generation per urban capita

With the data on household and non-household generation obtained previously, it can be established that the municipality of Chiapilla, Chiapas, generates around 3.2 tons/day (with statistical figures for 2020), that is, an equivalent to 0.733 kg/inhabitant-day in urban per capita generation and 0.615 kg/inhabitant-day in household per capita generation. It should be noted that this last figure is lower than the national average of SEMARNAT (2020) but higher than the data reported in other studies carried out in Chiapas (see **Table 5**), which, as previously indicated, may be due to climatic and temporal aspects, as well as local economies of the sites where such studies were applied. According to GTZ (2003), other factors could be involved in altering waste production rates, such as household income levels, consumption patterns, population growth, or even urbanization rates. All this information is relevant because it can be used in waste management plans or programs for both household and non-household sources. The population growth factor is usually the most commonly used in all studies related to waste since it provides useful information for future projections (Araiza & Rojas, 2020). Cultural aspects also tend to affect waste production rates, depending on the number of patron saint festivals or events throughout the year. Finally, urbanization also affects waste rates, since the greater the urbanization, the greater the access to new products or services that reach the communities and affect these waste production patterns.

Table 5

Waste production by generating source in Chiapilla, Chiapas

Source	Chiapilla		Promedio nacional[a]	Chiapa de Corzo[b]	Las Margaritas[c]	Berriozábal[d]	Villaflores[e]
	kg/hab-día	ton/día			kg/hab-día		
Household	0.615	2.684	0.653	0.487	0.346	0.456	0.495
Non-household	0.118	0.516	0.291	0.300	0.300	0.163	0.212
Total	0.733	3.200	0.944	0.787	0.646	0.619	0.707

Source: a SEMARNAT (2020); b Alvarado et al. (2009); c Araiza et al. (2015); d Araiza et al. (2017a); eAraiza et al. (2017b)

Spatially, the sources of waste production (household and non-household) are located from the northeast to the southeast, along the main road that crosses the municipal capital (**Figure 3a**). The area with a low presence of waste production sources (**Figure 3b**), is characterized by the existence of vacant lots, scattered houses, lack of paved roads, etc. This influences the fact that the most representative economic units are small grocery stores. On the other hand, the areas with a high presence of waste production sources are highly concentrated in the middle part of the municipal capital (**Figure 3c**), very close to the central park. This area is characterized by the presence of typical houses, administrative offices, large and small commercial establishments, as well as medical and school units. Finally, the zone with moderate (medium) presence of waste production sources of all types covers most of the study area (**Figure 3d**).

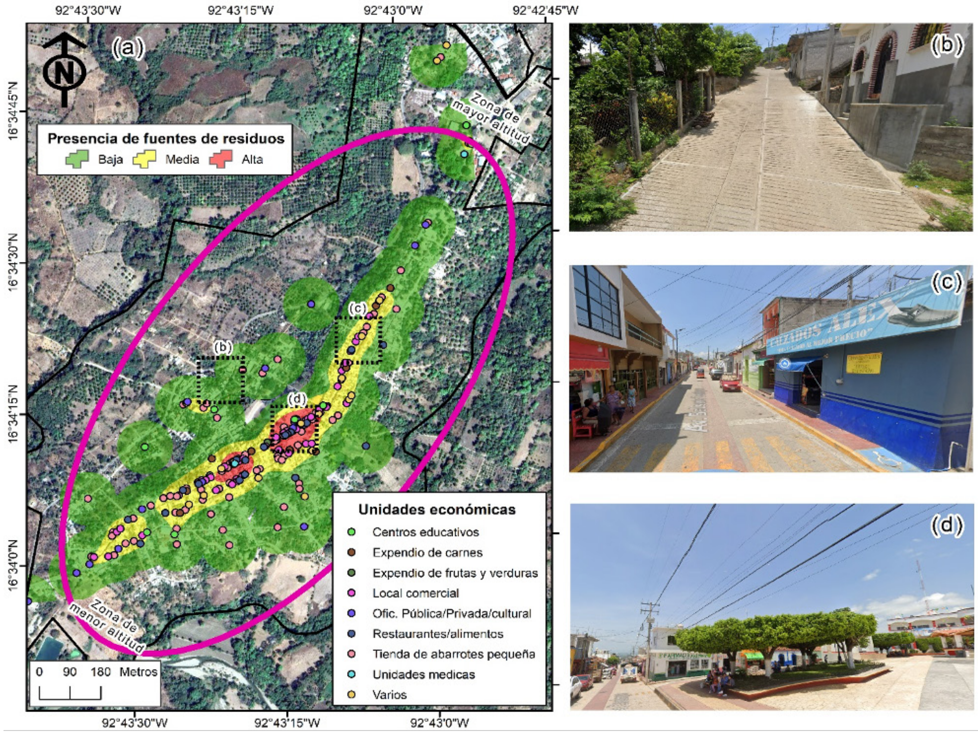

Figure 3. Sources of waste production: a) distribution of sources, b) area with low presence, c) area with medium presence, d) area with high presence

Waste composition

Figure 4 and **Table 6** show the typology of sub-products generated in the municipality of Chiapilla. It is observed that the organic fraction has the highest percentages, particularly food waste at 35.50%, followed by garden waste at 22.91%. Other sub-products such as plastics (7.38%) continue to increase, particularly PET (1.02%), HDPE (1.50%), and LDPE (2.83%). Paper and cardboard fractions, as well as glass and metals, have a very low presence, with percentages ranging between 1 and 3%.

Of all the waste generated in Chiapilla, 81.41% is material that can be recovered or used through some recycling mechanism so as not to be sent directly to final disposal and thus extend the useful life of the local sanitary landfill.

Finally, the fraction of hazardous and technological waste appears to a lesser extent, with a share of 1.15%. This type of sub-product, according to Araiza et al. (2017a), will require some kind of control or treatment mechanism in the future, especially due to the degree of hazardousness they add to the mixture with conventional or household waste.

Table 6
Percentage composition of domestic solid waste from Chiapilla, Chiapas

Fraction	Percentage %	Components	Percentage %
Organic	65.70	Food waste	35.49
		Garden waste	22.91
		Wood	0.35
		Animal bones	0.35
		Seeds and hard shells	6.60
Paper and card-board	4.31	Cardboard	2.57
		Waxed cardboard/Tetrapak	0.52
		Waxed paper/magazine	0.40
		Printing paper	0.48
		Newspaper	0.34
Plastics [a]	7.38	HDPE (high-density polyethylene)	1.50
		LDPE (low-density polyethylene)	2.83
		PET (polyethylene terephthalate)	1.02
		PP (polypropylene)	1.00
		PVC (polyvinyl chloride)	0.07
		PS (styrofoam)	0.28
		Miscellaneous plastics	0.68
Glasses	2.94	Stained glass	0.52
		Transparent glass	2.42
Metals	1.08	Aluminum (cans and paper)	0.42
		Cans of other metals	0.25
		Ferrous materials	0.41
Hazardous	0.61	Hazardous Waste (syringes, batteries, medicines)	0.61
Technology	0.54	Technological waste	0.54
Not usable	17.44	Disposable diapers / sanitary napkins	6.71
		Toilet paper	5.16
		Leather shoes	0.51
		Rag (natural and synthetic)	1.93
		Earthenware and ceramics	0.40
		Rubber	0.01
		Construction waste	0.18
		Fine waste	2.45
		Hair	0.09
			0.00
Total	**100.00**		**100.00**

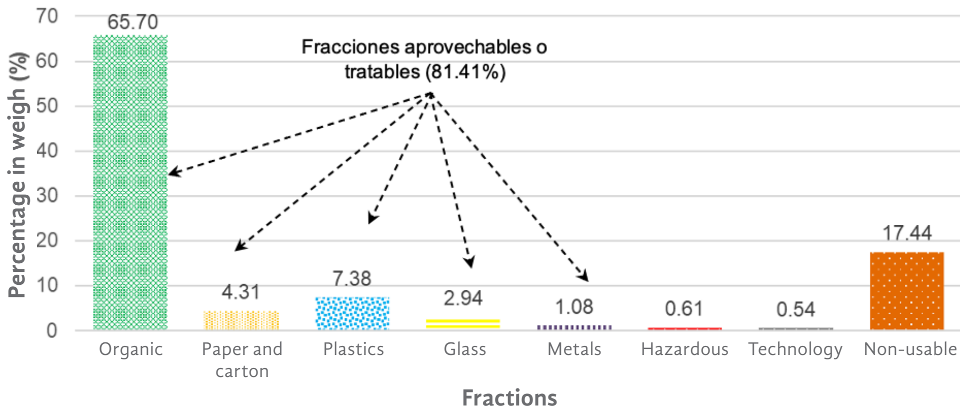

Figure 4. Main solid waste fractions generated in Chiapilla, Chiapas

As for the volumetric weight, the value obtained was 234.07 kg/m^3, which is a high value compared to the 140.44 kg/m^3 and 128.06 kg/m^3 reported by SEMARNAT (2020), as a national average and for small towns (<10,000 inhabitants). This is possibly due to the time of year in which the study was carried out, which was when the first heavy rains appeared, which incorporated water or humidity into the samples, regardless of the humidity contributed by the organic matter present in the waste. According to Colomer and Gallardo (2007), the humidity of the waste ranges between 35 and 65% and the factors that mainly influence the percentage of water in the waste are the content of organic matter, the origin, how they are presented, and the climate of the region.

Environmental improvement strategies for solid waste

Currently, the Chiapilla City Hall lacks much information on the elements involved in waste management, such as data on the urban population served by the cleaning service, the lengths traveled by the collection and sweeping routes, and the service times associated with the collection, among others. This prevents an in-depth analysis of aspects related to the efficiency, quality, and costs of those services. Therefore, one of the first strategies is precisely aimed at promoting municipal authorities to approach academia (educational institutions), to develop studies similar to this work, trying to update the figures of waste generation or carrying out environmental diagnoses. Today there are academic works that cover several small and large municipalities in Chiapas (González, 2021; Cirilo, 2021; Hernández, 2024), but there are still several more missing, given the number of existing municipalities and localities (124 municipalities and more than 20 localities). Much of the work to be carried out must also be focused on implementing emerging waste management technologies, such as large-scale treatment of organic waste or implementing unconventional methods of waste storage and collection, for example, using motorized equipment instead of specialized vehicles, and building high-volume containers with regional materials. On the other hand, it is necessary to promote the development of a municipal regulation related to the management of MSW, since currently according to Araiza (2019), in several municipalities of the state of Chiapas, including Chiapilla, there is a lack of any municipal regulation of constant application in terms of waste.

Another strategy that has gained relevance in recent years is the establishment of operating bodies for waste management. In the Official Journal of the State of Oaxaca POEO (2018) and SEMARNAT (2023), the functioning of such organisms has been reported, mainly paying attention to the stages of collection and final disposal. Through these operating agencies, what is sought is to have finances independent of the City Halls, but with the approval or partial control of them. This will allow it to operate similarly to how private companies do it, that is, through a payment or fee for the service, which makes self-financing possible.

Regarding the current situation of the municipality of Chiapilla, it is important to establish environmental education campaigns by the municipal government, which should be focused mainly on children and women, considering that they are the basis of academic and cultural formation in society. These campaigns must be aimed at the implementation of waste separation practices in homes and schools, as well as the reuse of the sub-products with the greatest presence in Chiapilla's solid waste, such as organic matter or plastics. These activities will allow the establishment of temporary storage mechanisms and also directly influence consumption habits and behaviors related to waste production.

Finally, it is important to seek a radical change in the way waste management policy or hierarchy is applied, not only in Chiapilla but in all municipalities in Mexico. According to the United Nations Environment Programme (UNEP, 2013) and Sáenz and Urdaneta (2014), these policies or hierarchies throughout Latin America are currently aimed at ensuring that conventional collection systems prevail, where organic and inorganic waste are mixed and are disposed of in landfills or open-air dumps, so minimization through recycling and waste treatment is left aside. However, a vision similar to the European one should be sought, where the waste management policy or hierarchy is reversed, that is, looking for minimization, having as a last stage or less favorable option, the final disposal through Sanitary Landfills. In addition, waste recovery and reuse as an energy source are also proposed.

CONCLUSIONS

In this work, the results obtained from a study of the generation and quantification of MSW sub-products prepared in the municipality of Chiapilla, Chiapas, were presented. The main objective of the work was to generate figures and data on solid waste, which municipal authorities can use to design works, plans, and programs on waste management.

The work carried out made it possible to meet the objective set since it was possible to determine the per capita generation rates for the source of urban (0.733 kg/inhabitant-day), domiciliary (0.615 kg/inhabitant-day), and non-domiciliary (0.118 kg/inhabitant-day) production. On the other hand, through the study of waste composition, it was found that the organic component presented the highest percentage (65.71%), followed by other sub-products such as plastics (7.38%), as well as paper and cardboard (4.31%). In addition, only 17.44% is non-usable material that should go directly to final disposal.

Some of the improvement strategies proposed in this work suggest that the City Hall seeks to collaborate with institutions of higher education to carry out more technical studies. In addition, it is also proposed to seek a radical change in the way of applying the waste management policy or hierarchy, in order to minimize and valorize waste. All these actions can serve to improve the current conditions in the municipality in terms of waste management.

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