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# Study on the generation and composition of household solid waste in Ciudad Valles, S.L.P.

# Estudio sobre la generación y composición de los residuos sólidos domiciliarios en Ciudad Valles, S.L.P.

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**Abstract**

The problem of the generation and composition of household Urban Solid Waste (RSU) in Ciudad Valles, San Luis Potosí was addressed. The information obtained could be used in making decisions about management and treatment for final disposal. To define the dwellings under study, the city was divided into socioeconomic strata with the support of the kmz tool, to visualize the Basic Geostatistical Areas (AGEB) according to the percentage of poverty. The generation of waste in the study area was determined through the NMX-AA61-1985 standard. For seven days, the selected dwellings were sampled, the quartering method was applied to the waste generated by means of the NMX-AA-15-1985 standard, and the samples were obtained for the physical-chemical analyses. The quantification of the by-products was carried out according to the NMX-AA-22-1985 standard. The organic fraction residues were the predominant in all the strata, being the medium marginalization stratum (EMM) the one that presented the highest percentage (49%). The physical-chemical characterization of the residues showed a moisture content of 52.48% and organic matter of 61.28%, results derived from the high composition of food residues that provide a higher percentage of water.

**Quarting method, Volumetric weight, By-products, Organic fraction, Physicochemical analysis**

**Resumen**

Se abordó el problema de la generación y composición de Residuos Sólidos Urbanos (RSU) domiciliarios en Ciudad Valles, San Luis Potosí. La información obtenida podría utilizarse en la toma de decisiones sobre la gestión y tratamientos para su disposición final. Para definir las viviendas objeto de estudio, la ciudad se dividió en estratos socioeconómicos con apoyo de la herramienta kmz, para visualización de las Áreas Geoestadísticas Básicas (AGEB) según el porcentaje de pobreza. Se determinó la generación de los residuos en el área de estudio a través de la norma NMX-AA-61-1985. Durante siete días se muestrearon las viviendas seleccionadas, a los residuos generados se les aplicó el método de cuarteo mediante la norma NMX-AA-15-1985 y se obtuvieron las muestras para los análisis físico químicos. La cuantificación de los subproductos se llevó a cabo de acuerdo a la norma NMX-AA-22-1985. Los residuos de fracción orgánica fueron los predominantes en todos los estratos, siendo el estrato de mediana marginación (EMM) el que presentó el mayor porcentaje (49%). La caracterización físico-química de los residuos mostró un contenido de humedad del 52.48% y materia orgánica de 61.28%, resultados derivados de la alta composición de residuos alimenticios que aportan un mayor porcentaje de agua.

**Método de cuarteo, Peso volumétrico, Subproductos, Fracción orgánica, Análisis fisicoquímicos**

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## Introduction

In Mexico, the General Law for the Prevention and Integral Management of Waste (LGPGIR) classifies waste according to its characteristics and origin into municipal solid waste (MSW), special management waste (SMW) and hazardous waste (HW). MSW are those generated in households when disposing of materials used in domestic activities, those coming from activities carried out inside establishments or on public roads, with household characteristics, and those resulting from public roads and places, as long as they are not considered as other types of waste (LGPGIR, 2003).

The increase in the generation of MSW is related to human activities and is potentiated by factors such as population growth and changes in consumption habits, migration to cities and poor waste management by waste management agencies and society itself (Buenrostro & Bocco, 2003).

Likewise, the accumulation of MSW causes environmental risk factors associated with the generation of "biogases" classified as greenhouse gases (GHG), such as methane (CH4) and carbon dioxide (CO2) mainly (Kiss and Encarnación, 2006). Most of these accumulated wastes also generate liquids (leachates) during their degradation process, and although they are leachates of organic origin, they represent a source of contamination of soil and adjacent water bodies, which can cause problems of toxicity, eutrophication and acidification (Allen, 2001; Torres, et al., 2011). In addition to these environmental problems, there is also the proliferation of harmful fauna and the consequent transmission of diseases to the population (Jaramillo, 2002; Hernández-Rejón, 2014).

Studies on the subject have been carried out in Mexico; however, some of them have not been disseminated. Studies carried out in the 1980s and 1990s by agencies such as SEDESOL stand out; and more recently, the Basic Diagnoses for Integrated Waste Management, carried out by SEMARNAT and INECC in 2012 and the most recent one, carried out in 2020.

Likewise, there are some research studies carried out in some regions, such as in the Cuitzeo Lake Basin, in the State of Michoacán (Buenrostro and Israde, 2003); others, carried out in small cities, such as in Berriozábal, Chiapas (Araiza et al., 2017) and others carried out in the final disposal sites themselves, such as the one carried out in the Tepic Landfill, Nayarit (Saldaña et al., 2013).

In the State of San Luis Potosí, some studies related to the subject have been carried out. In the capital, a master's degree thesis was carried out by the Colegio de San Luis, A.C. (García, 2010). Likewise, in the Magical Town of Real de Catorce, a bachelor's degree thesis was carried out by the National Polytechnic Institute (Martínez, 2018); however, both works were not published as scientific articles.

The studies of MSW generation and quantification are based on methodologies to estimate the quantity and by-products generated in the localities. The resulting information can support municipal authorities in planning and management activities. Likewise, the physical-chemical characterisation allows to know the composition of the waste through the contents of: humidity, organic matter, ash, carbon, hydrogen, oxygen, nitrogen, caloric content, mainly; as relevant characteristics to evaluate the possibilities of utilisation (Tchobanoglous, et al., 1994).

Currently, in Ciudad Valles San Luis Potosí, there is no study of generation, quantification and physical-chemical characterisation; the only document that provides information on MSW is the Municipal Development Plan of Ciudad Valles 2021-2024, which only presents the national figures provided by SEMARNAT in the basic diagnosis for integrated waste management.

In this context, the present study was carried out, which shows the results of the generation, quantification of by-products and physicochemical characterisation of MSW of household origin, generated in the City, with the aim that these results are disseminated and can be considered by decision-makers in the municipality for better waste management.

**Methodology to be developed**

The study was carried out in Ciudad Valles, S.L.P., which is located at the geographical coordinates 21° 59' north latitude; 99° 01' west longitude and an altitude of 70 m above sea level. Its population is 179,371 inhabitants according to information from INEGI, 2020. The main economic activities are livestock, agriculture and services, with tourism services predominating in recent years.

The objective of this research was to carry out a study on the generation of household MSW in Ciudad Valles, S.L.P., the quantification of by-products and their physical-chemical composition, so that the results generated can support the design and orientation of public policies in decision-making on the management, use and/or treatment for their final disposal. To this end, three specific objectives were established: to determine the generation of household MSW in the study area by socio-economic strata, to quantify the by-products of MSW and to carry out the physico-chemical characterisation of MSW.

The following research questions were also posed: Is the per capita generation of household waste in Ciudad Valles lower than those registered in the state of SLP and at the national level? What are the percentages of organic fraction waste and usable inorganic waste by stratum? What is the physical-chemical composition of the waste? In order to answer these questions, the following methodology was applied:

**Statistical sampling**

In order to obtain the study sample, proportional stratified sampling was used. The population was defined as the 53,323 urban dwellings of Ciudad Valles, S.L.P. reported in the Population and Housing Census, 2020, and the socioeconomic strata of that population were considered according to the CONEVAL (2019) classification: low, medium and high marginalisation strata. To determine the sample size, a confidence level of 95%, an estimation error level of 10% and a population variance value of 0.04 $kg^2$ /inhab/d of waste, considering a standard deviation of 200 g/inhab/d, were used.

The population variance value was estimated according to previous studies on per capita waste generation, therefore, the per capita value of 0.663 kg/inhab/d of waste from the State of San Luis Potosí reported in the Basic Diagnosis for Integrated Waste Management (SEMARNAT, 2020) was considered. The equation used to estimate the sample number for the study was as follows:

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

Where:

N= population size

n= sample size

Z_(1-α/2 )^2=confidence coefficient

E= permissible error

σ^2= variance

Therefore:

$$n = \frac{(1.96)^2(53323)(0.04)}{(53323-1)(0.0663)^2+(1.96)^2(0.04)}$$

$$n = \frac{8193.82}{234.35}$$

$$n = 35$$

Consequently, the study sample consisted of 35 dwellings, and was distributed proportionally, with 8 dwellings for the Low Marginalisation Stratum (LMS), 11 for the Medium Marginalisation Stratum (MMS) and 16 for the High Marginalisation Stratum (HMS), as shown in the table below 1:

| Strata | Number of dwellings | % | Number of dwellings to be sampled |
|---|---|---|---|
| EBM | 12,129 | 22.75 | 8 |
| EMM | 16,879 | 31.65 | 11 |
| EAM | 24,315 | 45.60 | 16 |
| Totales | 53,323 | 100.00 | 35 |

**Table 1** Statistical sampling by socio-economic stratum
*Source: Own elaboration*

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For the sampling, the Google Earth programme and the kmz tool were used to visualise the Basic Geostatistical Areas (AGEB) with the ranges according to the percentage of poverty, available on CONEVAL's official website. In this way, it was possible to identify the neighbourhoods of the municipality by socio-economic stratum (Figure 1). These tools made it possible to choose the classification in the following levels

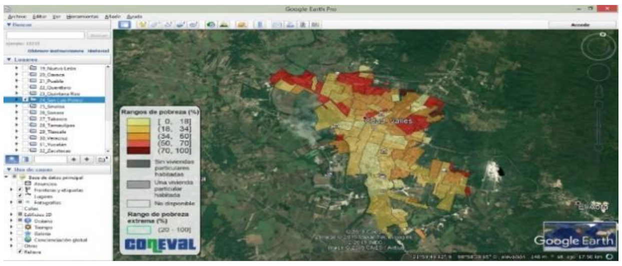


**Figure 1** View of the Municipality of Ciudad Valles in kmz file at AGEB level in the Google Earth interface
*Source: INEGI, CONEVAL, (2015)*

The selection of households to be sampled was made using a weighting matrix with three selection criteria: ease of access, knowledge of the locality and current risk situation.

The selection of houses to be sampled was made using a weighting matrix with three selection criteria: ease of access, knowledge of the locality and current risk situation. For the EAM, the selected households were located in the colonias: El Consuelo, Emiliano Zapata, Santa Lucia and Vista Hermosa. For the EMM the dwellings were located in the colonias: Bugambilias and Nelly Zulaiman. For the EBM, the homes selected were located in the colonias Mirador and Rotarios. A work plan was drawn up for the presentation of the field survey form to the inhabitants of the dwellings sampled, and a daily sampling procedure was established for the delivery of polyethylene bags identified by dwelling, as well as the timetables established for the collection of samples from 14 to 21 October 2021, contemplating a first day for the cleaning operation in each dwelling and on the following seven days the collection of household waste for its quantification and characterisation.

*Collection and quantification of solid household waste*

In accordance with the work plan, household waste was collected and taken to the TecNM Campus Ciudad Valles to determine the physical composition and physical-chemical characterisation. For the waste obtained for each of the strata, the procedure of the NMX-AA-015-1985 Municipal solid waste, quartering method (SECOFI, 1985) was applied; once the bag with waste arrived at the place of analysis, its weight was recorded in the logbook; this weight represented the total amount of daily waste (Wt) generated in the dwellings sampled by strata. Based on the data collected on the number of persons per dwelling (ni), the total number of persons involved (Nt) in the sampling per stratum was determined and the total weight of the bags (Wt) was divided by the total number of persons (Nt) to obtain the average daily per capita generation of the sampled dwellings (kg/inhab/d). According to formula 2:

$$Per\ capita\ waste\ generation = \frac{Total\ weight\ of\ waste\ (Wt)}{Total\ number\ of\ persons\ (Nt)} \qquad (2)$$

The bag was then torn open and the waste was dumped in a heap. With the help of hand tools, the bulky waste was chopped up to a size of 10 cm or less. The mound of solid waste was then shovelled into a homogenous heap. The mound was then divided into four approximately equal parts, and two of the opposing parts were separated, reserving them for volumetric weight calculation according to NMX-AA-019-1985 (SECOFI, 1985).

The other two parts of the residues were weighed and their weight was recorded in the logbook for the selection and quantification of by-products according to NMX-AA-022-1985 (SECOFI, 1985). For the determination of the volumetric weight by strata, a clean cylindrical container was selected, free of damage (dents or breakages), as well as a TORREY Model L-EQ scale. The empty container was weighed, taking this weight as the tare weight of the container ($W_1$). The volume was determined, using the height (h) of the vessel and the geometry of the vessel based on the formula 3:

$$V=\pi r^2 h \qquad (3)$$

The waste selected for this process was deposited homogenised in the container, hitting it against the ground three times to add waste up to the top, taking care not to press on it so as not to alter the volumetric weight that was determined. The container with the waste was weighed, gross weight ($W_2$) and the volumetric weight of the waste was calculated by strata using the formula 4:

$$Pv = P/V \quad (4)$$

Where:

$Pv$= Volumetric weight of solid waste (kg/m$^3$)
P = Net weight of the solid waste (gross weight

minus tare weight, kg)

V = Volume of the container occupied by the waste (m$^3$)

Once calculated, it was recorded in the corresponding logbook and a sample of this waste was set aside for physical and chemical characterisation tests.

For the selection and quantification of by-products by strata, these were classified by type in labelled bags. With the aid of a TORREY Model L-EQ scale. The waste was weighed and recorded in the logbook by weight of the sorted component. The percentage of each by-product was calculated taking into account the weight of the last heap resulting from the quartering (Wq) and the weight of each by-product (Pi) according to the formula 5:

$$\% \, Subproducto = \frac{Pi}{Wq} * 100 \quad (5)$$

Where:

$Pi$= weight of each by-product considered in kg (minus the weight of the bag used)

Wq= total weight of the sample

*Physico-chemical characterisation of household solid waste*

Proximal analysis was carried out in the Chemistry Laboratory of the TecNM Campus Ciudad Valles on the waste samples by strata; determining moisture, ash, organic matter, and percentages of C, H, O, N and S through gravimetric methods.

## Results

Table 2 shows the quantities of household solid waste used for quantification by the quarantine method according to the NMX-AA-015-1985 standard, for each of the strata:

| | Low Marginalisation Stratum Weight (kg) | Medium Marginalisation Stratum Weight (kg) | High Marginalisation Stratum Weight (kg) |
|---|---|---|---|
| Quantity harvested | 30.63 | 26.81 | 77.89 |
| Quantity intended for volumetric weighing | 16.24 | 13.62 | 37.73 |
| Quantity intended for laboratory analysis | 2.57 | 3.02 | 1.00 |
| Quantity intended for sorting and quantification of by-products | 8.62 | 7.95 | 9.54 |

**Table 2** Quantities used for the quantification of household MSW by stratum
*Source: Own elaboration*

Table 3 shows the per capita generation of household MSW in the urban area of Ciudad Valles, as well as the volumetric weight of this waste for each stratum.

| | Low Marginalisation Stratum | Median Stratum Marginalisation | High Marginalisation Stratum | P average |
|---|---|---|---|---|
| Household per capita generation in urban area (kg/inhab/d) | 0.828 | 0.725 | 0.980 | 0.844 |
| Volumetric weight (kg/m³) | 159.0 | 207.8 | 141.1 | 169.3 |

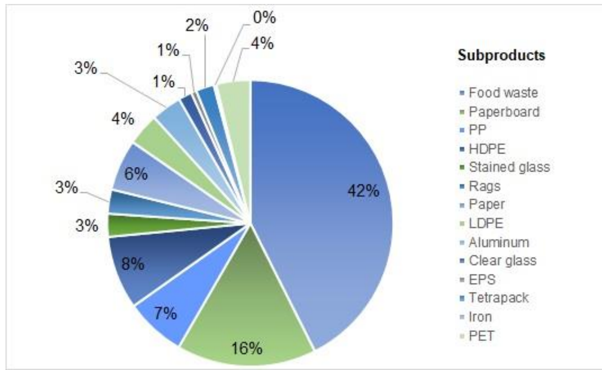
**Table 3** Per capita generation and volumetric weight of household MSW by stratum
*Source: Own elaboration*

The per capita household waste generation in the urban area in Ciudad Valles, S.L.P. averages 0.844 kg/inhab/d (Table 3), which is above the national indicator reported in the Basic Diagnosis of Integrated Waste Management (DBGIR, 2020); which is 0.653 kg/inhab/d. It is considered that this difference may be due to the fact that the Ciudad Valles data considers only the urban area whose population is greater than 170,000 inhabitants and the national data comes from an analysis that includes different socio-economic strata in the different urban and rural regional areas. With respect to generation by socio-economic stratum, it was the high marginalisation stratum that presented the highest per capita generation and the medium marginalisation stratum that presented the lowest. These results confirm the socio-economic stratification of households in the City, but not the relationship of household income with the generation and composition of solid waste. There is no consensus on the influence of socioeconomic variables on solid waste generation.

On the one hand, some authors report that there is no statistical relationship between income and the rate of waste generation, although there are differences in the composition of solid waste (Getehun et al., 2012), (Monavari et al., 2012). Likewise, Xue et al. (2011) report that gross domestic product (GDP) has no significant correlation with production. On the other hand, there is a broad consensus that high-income population strata generate more solid waste (Gómez et al., 2009 and Ogwueleka, 2013), and also that the content of the organic fraction is higher in developing countries (Akinci et al. 2012) and in rural areas.

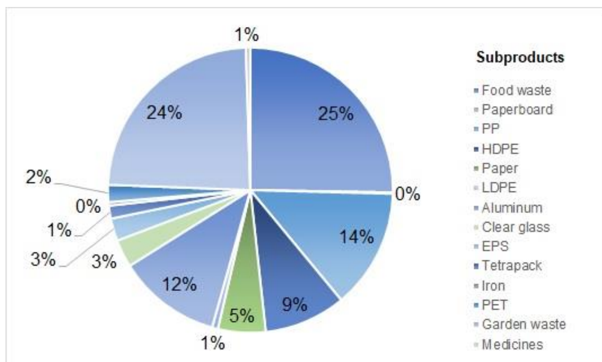
Now, with respect to volumetric weight, the average of the three strata was 169.305 kg/m³, a value above the national average weight which is 140.447 kg/m³ (SEMARNAT,2020). It is worth noting in Table 3 that the stratum of medium marginalisation was the furthest from the national average (207.8 km/m³); a situation that can be attributed to the fact that in this stratum there was a greater quantity of garden waste, such as leaves, which accumulated greater humidity and registered a higher weight.

Knowledge of the composition of waste is mainly used to determine which by-products or fractions of waste can be used or recovered, and which systems would be the most appropriate for this purpose. The quantification of the composition of household waste by strata, according to NMX-AA-022-1985, is presented in graphs 1, 2 and 3 below:



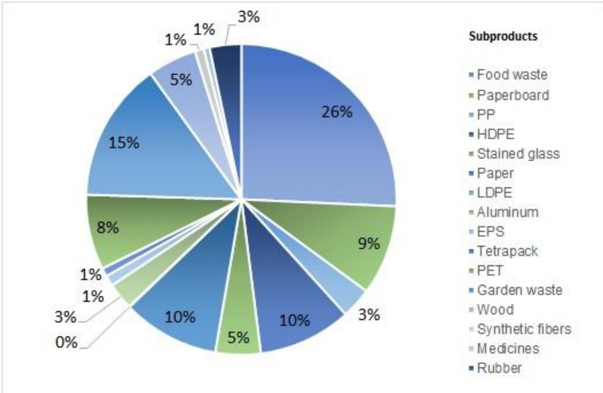

**Graphic 1** Waste composition (%) in EAM
*Source: Own elaboration*

In the case of EAM, food waste by-products made up 42% of the total quantified waste, cardboard 16%, high-density plastics 8%, polypropylene plastics 7%, paper 6%, PET plastics 4% and the rest of the other waste.




**Graphic 2** Waste composition (%) in MME
*Source: Own elaboration*

For the EMM, food waste by-products constituted 25%, around 24% was garden waste, polypropylene plastics 14%, aluminium 12%, high density plastics 9%, paper 5%, glass 3%, expanded polystyrene plastics 3%, PET plastics 2%, and the rest of other waste.




**Graphic 3** Waste composition (%) in EBM
*Source: Own elaboration*

In the case of EBM, the composition of by-products was 26% food waste, 15% garden waste, 10% paper, 10% high-density plastics, 9% cardboard, 8% PET plastics, 5% wood, 5% coloured glass and the rest other waste.

With regard to the composition of household MSW and its percentages, it is noticeable that the largest generation is the organic fraction derived from food waste, whose percentages are the highest in the three socio-economic strata analysed, and garden waste in the medium and low marginalisation strata.

Finally, the results of the physical-chemical characterisation of the sampled waste are presented in Table 4:

| Physical-chemical analysis | Percentage (%) |
|---|---|
| Moisture | 52.48 |
| Total solids | 47.51 |
| Working Moisture | 6.11 |
| Ash | 11.16 |
| Organic matter | 61.28 |
| Carbon | 35.54 |
| Hydrogen | 4.08 |
| Oxygen | 20.99 |
| Nitrogen | 0.66 |
| Sulphur | 0.2 |
| Calorific content (KJ/kg) | 12000.1 |

**Table 4** Results of the physical-chemical characterisation of waste
*Source: Own elaboration*

It can be observed that the waste contains a high percentage of moisture, on average 52.48%, due to the high composition of food waste, which contributes a higher percentage of water. The percentage of organic matter was 61.28%, as the presence of organic material is predominant, mainly due to the presence of food and garden waste. The ash content was 11.16%, which is related to the organic matter.

The nitrogen result was 0.66% and the theoretically calculated calorific value was 12,000 KJ/kg, which is mainly due to the amounts of carbon and hydrogen present.

**Acknowledgement**

We would like to thank the inhabitants of the colonies who actively participated in this study for their support.

**Conclusions**

The analysis of the composition of household MSW shows an interesting opportunity for recovery through composting, since the organic fractions are the ones with the highest percentage; in EAM about 42%, in EMM about 49% and in EBM about 41%, corresponding to food and garden waste.

There is also a diversity in the generation of plastics (PP, PS-E, HDPE, PET), paper, cardboard, glass and aluminium. The highest generation of plastics was found in the EMM with 28%, in the EAM with 19% and 18% in the case of EBM. Cardboard waste was identified in the high marginalisation and low marginalisation strata with 16% and 9% respectively. Paper generation was identified in all strata, with 6% for EAM, 5% for EMM and 10% for EBM. In the case of metals, aluminium accounted for 12% in the EMM and 3% in the EAM and EBM strata. Glass was 3% of the waste generated in the high and medium marginalisation strata, and 5% in the low marginalisation stratum. From the physical-chemical characterisation carried out in the Chemistry Laboratory of the Tecnológico Nacional de México Campus Ciudad Valles, it is observed that the percentages of moisture, total solids and organic matter of the samples are very uniform, due to the high percentage of food waste by-products detected in each of the strata.

However, when compared with results from other research, differences are apparent. For example, at the national level, the per capita generation of household MSW, the organic fraction and the usable fraction is 0.653 kg inhab/d, 46.42 % and 31.56% respectively (SEMARNAT, 2020). In Berriozabal, Chiapas, the per capita generation of household MSW, the organic fraction and the usable fraction is 0.619 kg inhab/d, 54.88 % and 78% respectively (Araiza et al., 2017).

Saldaña, et al. (2013) report a recoverable fraction percentage of 30.81% and organic matter content of 37.56%. While, for the present study, the per capita generation of household MSW obtained was 0.844 kg inhab/d, the organic and recoverable fractions were 44% and 50.7% respectively and the organic matter was calculated at 61.28%. The results obtained in Ciudad Valles, S.L.P. show significant percentages of usable waste (organic waste, various plastics, paper, cardboard, glass and aluminium). Currently, this waste arrives at the sanitary landfill without prior separation, and is collected in situ by the collectors for subsequent sale. This situation generates operating costs that the transfer of waste implies and a reduction in the useful life of the landfill. Therefore, collaboration between the municipality and academia is necessary to continue carrying out studies that provide data for the definition of relevant waste management strategies for the economy, the environment and, therefore, a better standard of living for the population, and thus contribute to the proper management of solid waste.

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