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Household Solid Waste Characteristics and Management in Rural Communities

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Abstract: Globally there is a lack of knowledge about waste generation and composition in rural areas because these types of studies have been conducted mainly in big cities. This leaves the local sanitation authorities without information to properly plan its operations. Generally, characterization studies are carried out by using the technique of sampling taking at home level. This method requires human, material and economic resources that sometimes are limited for local sanitation authorities. This paper presents the results of a characterization study obtained by direct analysis of household solid waste generated in two rural communities in northern Mexico. The research also outlines a procedure for estimating the waste generation rate when financial constraints prevent the development of a characterization study at home level. This study attempts to fill the information gap on the generation and composition of solid waste in rural areas. The results indicate a waste generation of 0.631 kg/cap/day in San Quintín and 1.047 kg/cap/day in Vicente Guerrero. The specific weights of the uncompacted SW were respectively 145 kg/m^3 and 123 kg/m^3. The specific weight of the compacted SW was 229 kg/m^3 in San Quintín. Statistically, the composition of waste between these two rural communities differs in one fraction.

Keywords: Characterization, solid waste, rural communities, waste composition, waste generation.

INTRODUCTION

Solid waste (SW) constitutes a huge challenge for local governments due to its constant increase and the majority of the municipalities do not keep records on waste generation, origin and characteristics. This lack of information causes that the decisions regarding proper waste management are based on assumptions and inferences, which brings about its mishandling with serious consequences for the environment [1]. Examples thereof are river and groundwater contamination by landfill leachates, soil pollution, greenhouse gas emissions and fauna mortality.

It is necessary to know the intrinsic qualitative and quantitative characteristics of SW as its increase demands alternatives of handling and treatment [2]. The studies of characterization may include analysis such as: physical and chemical composition, volume and generation that provide information for the planning and management of waste for its beneficial use and final disposal. Therefore, these studies constitute the first step to successfully implementing a comprehensive waste management system [1, 3, 4].

The results of the studies of characterization cannot be generalized towards different regions and seasons of the year because there are many variants such as: eating habits, consumption patterns, population composition, season of the year and income, that can cause dramatic changes in the composition and generation of waste [1, 4-9].

Some studies of characterization have been carried out in Mexico [3, 7, 10-17], but mostly in cities. This could affect the way parameters are being estimated in rural zones by researchers, who run the risk of generalizing a behavior and overestimating due to the lack of data [14].

Economic constraints and the lack of information on waste generation in San Quintín and Vicente Guerrero, two rural communities in Ensenada, Mexico have caused a poor management of solid waste. The insufficiency of the waste collection system causes that the residents incinerate or discard the waste in sites near their homes. Similar situations have been reported in other rural communities of México, such as Santa Elena Canyon in Chihuahua [12] and Tulum in Quintana Roo [18]. In the latter was found that 86% of the residents use the municipal solid waste collection service, 8% burn the waste, and 3% dump it in the rainforest or alongside the highway.

In the studied communities, the waste collected by the municipality is disposed of in non-controlled dumpsites and incinerated outdoors, even though Federal and State laws prohibit such practices, and hence it is not possible to find large volumes and dimension the problem. Ojolo and

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Bamgboye [19] explain that most of the waste on landfills sites or in other dumping sites is usually incinerated.

In view of this, it was decided to carry out a study whose purposes were the following: a) to analyze and quantify the solid waste generated in two rural communities: San Quintín and Vicente Guerrero in Ensenada, Baja California, Mexico; b) generate information for the decision-making in programs about waste management and environmental education; and c) create a benchmark for further studies of characterization.

DESCRIPTION OF THE STUDY SITE

The towns of San Quintín and Vicente Guerrero belong to the municipality of Ensenada, Baja California, Mexico. They are located 195 km and 170 km south of the municipal seat, respectively, and 30 meters above sea level (m.a.s.l.). The main economic activity in these communities is the agricultural production of vegetables and flowers. The agricultural activity brings about a floating or migrant population that fluctuates depending on the season of the year and work quantity on the farms. The origins of this population are mainly from Oaxaca, Michoacán, and Sinaloa [20, 21].

As far as the climate is concerned, the annual average temperature is 17 °C, August being the hottest month of the year with an average temperature of 21 °C and February the coldest month with an average temperature of 14°C. The region's total annual precipitation ranges from 100 mm to 200 mm, December with 24.2 mm and January with 23.9 mm being the wettest months, and May with 0.5 mm and June with 0.1 mm being the driest months [21].

San Quintín's dumpsite is located at +30° 31' 24.45", -115° 53' 40.26"; 3 km east of the town of Lázaro Cárdenas and sits on a 20-hectare ejido lot on a plateau close to Agua Chiquita Creek and a gorge. Vicente Guerrero's dumpsite is located at +30° 42' 43.58", -115° 58' 24.00"; 3 km east of Transpeninsular Highway and sits on a two-hectare private lot.

Waste collection is provided by the municipality, at no charge, and is not under concession in any stage of its process. The waste is collected at the curb, non-mechanized, once a week in one single shift. Residents are responsible for placing their garbage in bins at the curb on collection day and remove them once they have been emptied until the next collection day.

The waste collection vehicle fleet consists of waste-compacting rear loaders, and each one is operated by one driver and two waste collectors. Five collection vehicles with a capacity of 15.3 m^3 (20 yd^3) each and one with 19.11 m^3 (25 yd^3) provide collection service in San Quintín, whereas only two vehicles with a capacity of 15.3 m^3 (20 yd^3) each provide collection service in Vicente Guerrero. The average age of all of these vehicles is 10 years old and their mechanical conditions are good.

MATERIALS AND METHODS

To determine the need for stratified sampling, socioeconomic statuses were identified by taking the Basic Geostatistical Area (BGA) as a reference, through the database "Composition of stratification-BGA, 2005" [22], provided by the National Institute of Statistics, Geography, and Data Processing,. It was observed that out of the 13 BGAs considered for San Quintín, the 89% has level between 5 and 3. This same percent prevails in Vicente Guerrero for the nine BGAs considered. Therefore, due to the BGAs composition in these communities generally maintain a single socioeconomic status (median-low), it was decided to take a non-stratified sampling. Additionally, the waste collection trucks do not follow routes established by socioeconomic status.

The study was carried out in January, 2009, during a week in the dumpsites of Vicente Guerrero and San Quintín. The population considered to estimate the per capita generation was 10,632 for the first community and 19,800 for the second one. This last value includes the residents of Lázaro Cárdenas, whose waste is disposed of at San Quintín's dumpsite.

Daily samples were taken from the waste unloaded by the waste collection vehicles. Representative samplings of household waste could be: a) a truck load coming from a typical weekday collection route from a residential area, b) a mixed sampling taken from an incinerator storage pit, and c) a discharge pit of a shredder [23].

In order to draw a representative sampling in each site, the wastes daily analyzed were taken from a single waste collection truck. None of the samples were left out because the waste generated in these communities is collected once a week, and it was considered that they were representative of the generation of seven days.

Tchobanoglous *et al.* [23] explain that the measurements made in a 90-kg sampling do not change significantly from the ones made in samplings of up to 770 kg, taken out of the same waste load. CalRecovery [24] explains that the minimum weight per sample must be 100 kg; if it is less than 100 kg, the possibility of obtaining a representative sample reduces. Other authors establish that the optimum size of the sample ranges from 91 kg to 136 kg [25-28]. However, the Mexican Standard NMX-AA-015-1985 [29] indicates that a minimum of 50 kg of solid waste must be employed for the waste composition analysis. Therefore, to ensure representative results according to Mexican regulations, samples with a weight higher than 50 kg were taken.

Waste Generation Estimation

Determination of the Specific Weight of the Wastes

The specific weight of the un-compacted waste was determined following the procedure indicated by the Mexican Standard NMX-AA-019-1985 [30]. Waste from the loads disposed of by the waste collection trucks were placed in a container with a capacity of 0.2 m^3 to fill it, the container was slightly slammed against the ground three times by dropping it from an approximate height of 10 cm and again more waste were added to fill it. The procedure continued until it got completely full. No pressure was applied to the waste in the container to avoid altering the specific weight. The net weight of the wastes (gross weight-tare) was divided by the volume of the container.

The specific weight of the compacted waste was obtained by dividing the net weight of the waste by its capacity in m^3. Since only the garbage trucks of San Quintín were weighed, the specific weight found in this study corresponds to this community.

Determination of the Weight of the Wastes Disposed of at the Landfills

The existence of a public scale in San Quintín allowed the waste collection trucks to be weighed before and after discarding the wastes in the landfill site for final disposal. The difference between the gross weight and the tare of the truck was considered as the net weight.

It was not possible to weigh the waste collection vehicles in Vicente Guerrero due to three factors: a) there is no public scale in this community and the closest one is 25 km away; b) the time to waste collection is limited; and c) the operating costs of transporting the waste are high, so the total weight of the wastes was estimated by using the equation (1):

$$W_T = \left[\sum_{i=1}^{d}\left(N_i \times \upsilon_i \times \rho_i\right)\right](F_c) \quad (1)$$

where d= number of days analyzed, N = number of trips of the waste collection trucks, v = average in m^3 of the trucks, ρ = average specific weight of uncompacted waste, and F_c = compaction factor.

The compaction factor used (1.77) to infer the total weight in Vicente Guerrero was the one determined for the trucks of San Quintín. This was obtained by isolating F_c in the equation (1) and substituting in every variable the values found at the site. It was decided to use this factor because the operating conditions of the collection vehicles waste refuse body in both sites are similar.

Determination of the Per Capita Generation

The per capita waste generation in both communities was calculated by dividing the weight of the waste disposed of at the dumpsites (W_T) by the studied population (H) multiplied by seven days (equation 2).

$$G_{pc} = \frac{W_T}{H \times 7} \quad (2)$$

Analysis of Waste Composition

Waste Quantification

For the analysis of waste composition, 30 waste components were considered. 25 indicated in the Mexican Standard NMX-AA-022-1985 [31] and five more annexed in situ. These were aluminum, batteries, Tetra Pakpackaging, PET plastics and electronic waste (see Table **1**).

These waste components were divided into three groups: organics, non-organics and miscellaneous. Afterwards, a new classification (recyclables) was made with the waste components that have the possibility of being marketable in the communities nearby in order to define the selling potential of the wastes.

The weight measurements were performed in situ with portable electronic scales. These were an EQB 50/100 Torrey with a capacity of up 50 kg and readability of 10 g, and a 500/1000 Torrey L-EQM with a capacity of up 500 kg and readability of 100 g. For more accurate results, the specific weights were determined on the L-EQM 500/1000 and the weight of the waste components in the EQB 50/100.

Table 1. Waste Components Considered in the Study

Cotton	Non-ferrous material
Aluminum	Paper
Batteries	Disposable diaper
Cardboard	PET plastic
Leather	Rigid and film plastics
Waxed cardboard packaging	Polyurethane
Hard vegetable fiber (sclerenchyma)	Expanded polystyrene
Synthetic fibers	Food residuals
Bone	Yard trimmings
Rubber	Fine residue
Tin can	Electronic waste
Crockery and ceramics	Tetra Pakpackaging
Wood	Cloth rags
Construction material	Colored glass
Ferrous material	Transparent glass

Source: Adaptation from [34].

Differences in the Waste Composition

To identify if there were significant differences between the ratios of the main fractions of waste (those higher than 7.5%) from the two rural communities, the Z statistic was used within a 98% confidence interval. The MINITAB™ 14.1 statistical software was used to compare the ratios.

RESULTS

Per Capita Generation and Specific Weight

The waste generation per person per day was estimated in 0.631 kg in San Quintín and 1.047 kg in Vicente Guerrero. In San Quintín, the average specific weight of the compacted solid waste obtained in 24 samples was 229 kg/m^3 with a standard deviation of 53 kg/m, while the average of uncompacted solid waste in 32 samples was 145 kg/m^3 with a standard deviation of 31 kg/m^3. In Vicente Guerrero was obtained an average specific weight of uncompacted solid waste of 123 kg/m^3 with a standard deviation of 29 kg/m^3 by using 12 samples.

Waste Components Quantification

In total, 11 samples with a total weight of 883.35 kg were analyzed, out of which 617.37 kg corresponded to San Quintín (six samples) and 265.98 kg to Vicente Guerrero (five samples). Fine wastes and cloth rags were categorized as miscellaneous due to the diversity in their composition. The weights and fractions of every category are summarized in Table **2**.

The potentially recyclable waste generated in the state accounts for 42.15% in San Quintín and 38.69% in Vicente Guerrero (see Table **3**). Disposable diapers, Tetra Pak packaging, batteries and electronic waste can be recyclable, but there is no technology in the region to do it. Therefore, there is no secondary market for these wastes.

Table 2. Composition of Waste in San Quintín and Vicente Guerrero

Classification	San Quintín			Vicente Guerrero		
	Weight	% Fraction	% Total	Weight	% Fraction	% Total
Organics						
Food residuals	209.44	60%	34%	81.38	57%	31%
Paper and cardboard	120.84	35%	20%	47.41	33%	18%
Yard trimmings	11.8	3%	2%	14.89	10%	6%
Wood	4.62	1%	1%	0.15	0%	0%
Hard vegetable fiber	1.8	1%	0%	0	0%	0%
Leather	0.22	0%	0%	0.12	0%	0%
Total	**348.72**	100.00%	56%	**143.95**	100.00%	54%
Non-organics						
Rigid, film and PET plastics	91.1	45%	15%	31.78	32%	12%
Disposable diaper	48.06	24%	8%	37.34	37%	14%
Transparent and colored glass	22.3	11%	4%	16.14	16%	6%
Tin can	14.31	7%	2%	5.35	5%	2%
Expanded polystyrene	5.28	3%	1%	2.69	3%	1%
Aluminum	5.03	3%	1%	1.23	1%	0%
Tetra Pak packaging	4.66	2%	1%	2.13	2%	1%
Construction material	3.4	2%	1%	0.6	1%	0%
Crockery and ceramics	2.19	1%	0%	0.95	1%	0%
Electronic waste	2.08	1%	0%	0.98	1%	0%
Ferrous material	2.02	1%	0%	0.83	1%	0%
Batteries	1.08	1%	0%	0.12	0%	0%
Total	**201.51**	100.00%	33%	**100.14**	100.00%	38%
Miscellaneous						
Cloth rags	45.77	68%	7%	16.3	74%	6%
Fine waste	21.37	32%	3%	5.59	26%	2%
Total	**67.14**	100.00%	11%	**21.89**	100.00%	8%
Total	***617.37***			***265.98***		

Table 3. Percentages of Recyclable Materials in San Quintín and Vicente Guerrero

Classification	San Quintín		Vicente Guerrero	
Recyclables	**Weight**	**% Fraction**	**Weight**	**% Fraction**
Paper and cardboard	120.84	46.44%	47.41	46.08%
Rigid, film and PET plastic	91.1	35.01%	31.78	30.89%
Transparent and colored glass	22.3	8.57%	16.14	15.69%
Tin can	14.31	5.50%	5.35	5.20%
Aluminum	5.03	1.93%	1.23	1.20%
Wood	4.62	1.78%	0.15	0.15%
Ferrous material	2.02	0.78%	0.83	0.81%
Total	***260.22***	100.00%	***102.89***	100.00%

Ratio Test

The ratio test was based on the total weight of the samples taken from each community and the results are exposed in Table **4**. The comparisons between the main waste components indicate a significant statistical difference only in the fraction corresponding to disposable diapers. The total organic and non-organic portions in both communities do not represent significant statistical differences.

Table 4. Results of the Ratio Test

Type of Waste	Test Statistic (Z)	Critical Value
Food residual	1.01	± 2.3267*
Paper and cardboard	0.69	
Plastic	1.11	
Disposable diaper	-2.58	
Cloth rag	0.80	
Total organics	0.67	
Total non-organics	-1.38	

*Obtained by interpolation of values in the table "area under the normal curve", for $\alpha = 0.02$.

DISCUSSION

Compaction factor used to calculate the generation in Vicente Guerrero (1.77) is consistent with what it was exposed by the Secretariat of Social Development (SSD)[6]. This indicated that MSW can be hardly compacted to less than half its volume in bulk. Other studies [32, 33] have indicated that the compaction in the waste collection trucks is affected by the density of the wastes and that in developing countries it normally gets volume reduction 1.5:1

The per capita waste generation in these communities is similar to what it was proposed by the SSD [6]. The value for San Quintín is similar to the one for the south of the country (0.697 kg) and the value for Vicente Guerrero is similar to the one for the north border (1.048 kg). There are other generation rates reported for Mexico [7, 16, 34] but belong to a study carried out over seven years ago, since then the consumption patterns could have changed.

The per capita generation rates significantly differ between the two communities. According to what it was shown by the Municipal Research and Planning Institute of Ensenada (MRPI) [21], three possible explanations to this fact are: a) the economically active population of Vicente Guerrero is bigger by 9% than San Quintín's; b) the percentage of workers who get between one and five times the minimum wage is 4.24% higher in Vicente Guerrero; and c) Vicente Guerrero concentrates the population employed in the majority of the sectors, whereas San Quintín concentrates the largest population in tertiary activities.

Food residuals constitute the main fraction in the two communities. Its percentage is between 32% and 37% found by other authors for Mexico [13, 35], but differs from the percentages from other countries such as Macedonia (24%-Hristovsky [4]), Nigeria (12% -Afon and Afolabi [36]), Bangladesh (62%-Sujauddin *et al*. [37]), whose religious, economic, political, and environmental characteristics differ to the studied communities.

The fraction corresponding to textiles in both communities was superior by 1% proposed for the national mean [35, 38, 39]. However, it is consistent with what it was exposed by Tchobanoglous *et al*. [23] in middle income countries and with what it was found by Ojeda *et al*. [5, 40] and Ojeda [13] in Mexicali city. This situation may derive from the fact that in these communities is common the sale of second-hand clothes. Due to the quality and low cost, it is more likely to be acquired, as well as disposed of faster.

Only a small fraction of the potential recyclable materials is recovered at the dumpsites. In San Quintín, just aluminum, tin cans, and other ferrous wastes are collected and traded by local waste picker, whereas no material is recovered in Vicente Guerrero. According to Gutierrez [39], it is estimated that in Mexico, the materials recovered to be commercialized afterwards represent 8% to 12% out of the total generated.

Despite the contrasts in the generation rates between these two communities, there was only a statistical difference in the fraction corresponding to diapers, whose major proportion was in Vicente Guerrero. This could indicate that the residents from both communities share similar eating habits, but the consumption patterns differ. Regarding the diapers fraction, one could conclude that: a) family composition is not similar between these communities, Vicente Guerrero being the community with the most usage in diapers; and b) a greater purchasing power of Vicente Guerrero's people allow them to acquire this kind of products.

CONCLUSIONS

The lack of data on the generation and composition of waste in the region prevents the comparison of the data generated in this study. However, this information may serve as a reference for further studies in order to observe the behavior of waste generation over time.

Whenever it is not possible to weigh the waste collection trucks to determine waste generation in a direct manner, the procedure used in Vicente Guerrero can help to obtain an approximation. Trusting common sense or inferring based on data obtained under other contexts (by countries, socioeconomic stratification, among others) may lead to errors in waste estimation and/or seriously affect the credibility of the data generated.

The specific weights of the compacted and uncompacted solid wastes determined in San Quintín (229 kg/m^3 and 145 kg/m^3) can be used to: a) verify the efficiency of the waste collection vehicle fleet; b) plan the collection routes; and c) determine the size of waste bins in the households.

Because of the amount of waste generated and discarded by the residents in these rural communities, it is important to invest efforts and provide financial and technical resources in order to develop proper waste management systems that will ultimately improve the quality of life, boost the economy and preserve the environment.

The implementation of waste collection centers, along with waste treatments facilities such as biodigestion or composting in these communities, would be very beneficial to reduce the amount of solid waste. It would generate employment opportunities and help reduce the improper disposal of waste and, at the same time, valuable materials could be recovered. All these activities would therefore increase sustainability efforts. If only the organic fraction of waste, which is the largest in both communities, is reduced in the waste generation phase, this would lead to immediate positive impact on the system, such as: a) increased capacity of compaction and reduce the damage to waste collection vehicles; b) lower fuel costs in collecting waste; and c) lower amount of waste deposited in landfills, thus increasing its lifespan.

Joint work between the government and the academic sector may help to generate useful data for the decision-making and achieve an appropriate waste management. Integrating the academic sector into governmental projects ensures the sharing of resources and infrastructure, which in turn increases the efficiency of the public resources and raises the academic productivity.

This study is the first one carried out in these communities and its results will be given to the Department of Ecology of the municipality, the Secretariat of Municipal Public Works and the Secretariat for Environmental Protection of the state in order to support the decision-making on: a) the building of a sanitary landfill, which will provide service to three delegations of the southern region of the municipality of Ensenada, b) programs oriented to waste reduction and recycling and c) projects on the improvements of waste collection.

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