

Households as Sources Contributing the Most to Urban Solid Wastes Production: Implications for a Better Management and Disposal

Otoniel Buenrostro Delgado^{1,2*}, María del Consuelo Hernández Berriel^{2,3},
Iván Yassmany Hernández Paniagua⁴, María del Consuelo Mañón Salas²

¹Instituto de Investigaciones en Ciencias de la Tierra, Universidad Michoacana de San Nicolás de Hidalgo, Ciudad Universitaria, Morelia, México

²Sociedad Mexicana de Ciencia y Tecnología Aplicada a los Residuos Sólidos, A.C. (SOMERS), Ciudad de México, México

³Tecnológico Nacional de México, Instituto Tecnológico de Toluca, División de Estudios de Posgrado e Investigación, Metepec, México

⁴CONACYT-Consorcio CENTROMET, Querétaro, México

Email: *otonielb@umich.mx, mhernandezb@toluca.tecnm.mx, hberriel_1999@yahoo.com, ivan.hernandez@centromet.mx, consuelomanon@gmail.com

How to cite this paper: Delgado, O.B., del Consuelo Hernández Berriel, M., Paniagua, I.Y.H. and del Consuelo Mañón Salas, M. (2019) Households as Sources Contributing the Most to Urban Solid Wastes Production: Implications for a Better Management and Disposal. *Journal of Environmental Protection*, 10, 1072-1084.
<https://doi.org/10.4236/jep.2019.108063>

Received: July 18, 2019

Accepted: August 19, 2019

Published: August 22, 2019

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Abstract

Households are the sources contributing the most to the production of urban solid wastes in developing countries. The present study analyses the generation of domestic solid wastes in a settlement in Mexico in two different years. The goals were to compare composition and rates of generation into the periods to assess changes and the influence of socioeconomic variables. In 1998 and 2004, wastes from households were sampled of three socioeconomic levels randomly selected, and a survey was applied. Data obtained were analyzed with descriptive and multivariate analysis. Results of generation rate and composition of domestic solid wastes showed a negative correlation between generation and income in the first one, but positive in the second one; in both, composition did not show correlation. Rates of per capita generation, per household, population and density of inhabitants per dwelling increased, and the generation of wastes were more with respect to population growth, which emphasizes the influence of economic and demographic variables. This study corroborates that households are the principal sources of urban solid wastes and it is emphasized that management strategies must preponderate households to be successful. In addition, this information is important to establish strategies for an integral management of urban solid wastes in developing countries.

Keywords

Waste, Dwellings, Management, Recycling, Survey

1. Introduction

The generation of urban solid wastes (USW) represents a severe problem for the environmental authorities of Mexico, as for the majority of developing countries [1]. USW are composed of a mixture of heterogeneous materials that are by-products inescapable of production and consumption patterns of contemporary societies [2]. The design and implementation of efficient programs for improving current USW management systems are urgent challenges that must be addressed by urban authorities in short-time. Deficient technical and operational structures at local and national scales are reflected frequently in an insufficient USW collection together with an inadequate disposal [3]. Furthermore, limited or null data for generation and composition of USW also contribute to limit for predictions that could help to better design collection policies [4] [5].

The lack of updated and precise data of USW generation is related to the rapid change in generation rates and composition. Such changes are strongly linked to variations in population lifestyle and consumption patterns. In economically developing countries, increases in household income, urbanization, and spread of more manufactured products clearly influence both generation rates and composition of USW [6]. These rapid changes also contribute to low efficiencies of USW collection and management systems, that when coupled with bad design and outdated policies such as the lack separation and recycling operations result lately in waste of economic resources [7] [8]. All these led to social, sanitary and environmental issues for urban authorities that should provide services for a growing population. Moreover, most cities should deal with a growing vulnerable population that operates irregularly collection and separation services as a way to obtain economical resources.

For several decades households have been increasing their contribution to the generation of USW in urban areas of developing countries [9] [10]. For instance [11] reported a contribution of households of around 87% to USW for metropolitan areas of Mexico. Existing studies for domestic solid wastes (DSW) and USW made during the 1990s reported that composition and generation depend significantly on demography [12], socio-economic conditions [13], perception and behavior of population [1] and, individual and family consumption patterns [14]. The above highlight the need for precise and updated composition and generation rates of DSW, which could be used to design efficient management programs that must include valorization and recycling operations but also an adequate confinement of heterogeneous solid wastes [15].

This study addresses changes in composition and generation rates of DSW in the city of Morelia, Mexico, during two different periods, which allows identifying variations of by-products and the influence of socio-economic variables in composition and generation of these wastes. Because households are keys in the USW generation route as observed in most cities of developing countries, updated information of composition and production of wastes from households, is

vital and urgently required by environmental authorities for a better design of clean and efficient policies with respect USW management. Morelia City is the capital of Michoacán State and experiences a growing population and rapid urbanization rates similar to those observed in most cities of developing countries. The above, confronts the urban authorities with serious problems to provide efficient urban services, among the most pressing are the water supply and the collection service for a growing generation of USW, which is reflected in an inadequate provision of these, among other environmental problems. Urban authorities in Mexico experience typically must operate with reduced funding to provide an efficient collection of USW and water and electricity supplies. The results presented here provide both statistical information and evolution of composition of DSW through time.

2. Materials and Methods

2.1. Selection of Households and Application of Survey

Sampling of DSW was carried out in 1998 and 2004. The generation analysis of DSW was made per household and the sampling sites were selected randomly following a random categorization and the socio-economic classification designed by the Mexican Bureau of Census [16]. Overall, three representative neighborhoods of each socio-economic stratum (low, middle and upper) were selected. The households were selected according with the acceptance of inhabitants to participate in the study and a survey was applied to heads of the households to obtain socioeconomic and demographic data and DSW samples were collected only at households where inhabitants provided data and accepted to participate in the project. In both studies, the number of samples was determined by the level of participation of the selected dwellings. **Table 1** presents the survey applied in the studies of 1998 and 2004.

2.2. Sampling and Characterization of DSW

In the studies of 1998 and 2004, the sampling of DSW was made during seven days, prior notification to all selected household inhabitants to ratify their collaboration in the study and the number of inhabitants in each home. Samples of DSW were collected in plastic bags where waste produced during periods of 24-h were placed. After collection of DSW, the bags were weighted and labelled on a daily basis and socio-economic strata, data were captured on a daily basis according to **Table 2**; the characterization of samples of DSW was made following the method cited in [17]. **Table 3** presents some key data from the studies carried out, as the amount of DSW and households sampled in the studies of 1998 and 2004.

Samples were prepared through the quartering official standard norm (NMX-AA-015-1985) [18], and DSW was sorted according to the official standard norm NMX-AA-022-1985 [19]. Briefly, such standard establishes that DSW samples must be weighted, and then separated into by-products which are sub-

sequently weighted. All individual components weights were compared to the overall weight of the sample to verify a correct separation. A database was compiled using the survey and generation data; statistical analyses, ANOVA test and variance analysis were made with the software STATGRAPHICS 25.

Table 1. Survey for economic and demographic data collection.

I.D.: _____

Date (dd/mm/yyyy): _____.

Interviewer: _____.

1. Member of the family that was interviewed (mark where appropriate):

_____ Mother _____ Son/Daughter

_____ Father _____ Others

2. Number of inhabitants at the household during the sampled period of DSW:

Age (range): _____. Gender (M-F): _____.

3. Schooling, only for mother and father (mark where appropriate):

Mother: _____. Father: _____.

a) Primary school. b) Secondary school. c) Secondary/Technical level.

d) High school. e) Bachelor (BA., BSc.). f) Postgraduate.

4. ¿Car membership?

a) Yes b) No

5. Household property:

a) Rent b) Own c) Under payment d) Lend e) Other

6. Overall family income by month (grand total for all members):

a) Lower than \$750 MXN (Mexican pesos) b) From \$750 to \$799 MXN

c) From \$800 to \$2299 MXN d) From \$2300 to \$5299 MXN

e) From \$5300 to \$8399 MXN f) More than \$8400 MXN

7. ¿Frequency of waste collection from the neighborhood?

a) Daily (including Sunday) b) Almost daily (5-6 days per week)

c) Three times per week d) Two times per week

e) Once per week f) More than a week

8. ¿Frequency of waste collection from the household?

a) More than 7 days b) Three times per week

c) Once per week d) From 4 to 6 times per week

e) Two times per week f) Daily (7 times per week)

Table 2. Format for capturing survey data.

No. of household	Address	No. inh.	Day 1	Day 7	Average generation	
			Date:	Date:	kg d ⁻¹ fresh weight	Per inh. (g inh ⁻¹ d ⁻¹)
			DSW (kg)	Generation (kg/inh)	DSW (kg)	Generation (kg inh ⁻¹ .)	

Table 3. Data of total households and samples sorted.

Strata	Total of households		Sample sorted (kg d ⁻¹ fresh weight)	
	Year of study			
	1998	2004	1998	2004
Low	65	80	183	208
Medium	101	80	342	200
High	96	80	172	256
Total	262	240	697	664

3. Results

Sampling of DSW was carried out in 1998 and 2004; the number of samples of DSW was determined by the volunteers' participants.

In 1998, Morelia had around 510,463 inhabitants and an annual population growth of 2.2%. A total of 123,307 households were estimated to generate 321 t·d⁻¹ of DSW. Composition analyses made, revealed 31 different by-products in the DSW, with an organic fraction representing 58% of the total and significant contributions of packing, plastic and glass containers [11]. The generation per inhabitant of DSW was estimated in 0.629 kg·d⁻¹·inh⁻¹. However, although the coefficients of generation per capita showed an increasing generation with monthly income, there was no statistical significant difference ($p > 0.05$) among generation rates for all socio-economic strata ($F_{c, 2, 242, 0.05}$), the homogeneity of variances was corroborated with the C-test of Cochran (3, 242, 0.05). We observed that the number of kids and the density of inhabitants per household showed a growing tendency as income decreased, in contrast, schooling decreased as income declined.

In 2004, Morelia had around 549,996 inhabitants and 133,634 households but a similar population growth rate of 2.2% as in 1998 [20]. In 2012, the population was estimated in 829,625 inhabitants and 184,601 households, but the population growth rate remained without change (2.2%) [21]. A demographic projection of 2012 is shown, since we made another study of DSW generation different from the methodology previously used, however, the samples were taken from the truck that provides the service in the selected suburb.

Table 4 shows the population dynamics and DSW production for the two years studied. Between 1998 and 2004, population grew by 7.7% while the number of dwellings increased by 8.4%. This corresponds to a decrease of one tenth in the inhabitants' density per household during this period. For 2012, the population increase by 50.8% and the number of households only 38.1%, with the consequent increase in density of inhabitants per household comparing between the years of 2004. In addition, daily and per inhabitant DSW generation rates exhibited a growth of 37.7% and 27.8% in 1998 and 2004 respectively, while between 2004 and 2012, those grew by 60.6% and 6.5%. These suggest an increase in the collection of USW around 30% and >50% during these years. The

Table 4. Population, households and domestic solid waste generation in Morelia city.

Year	Total inhabitants	Total households	Inhabitants per household	DSW generation	
				(t·d ⁻¹)	(g·inh ⁻¹ ·d ⁻¹)
1998	510,463	123,300	4.1	321	628.8
2004	549,996	133,634	4.1	442	803.6
2012*	829,625	184,601	4.5	710	855.8

*Results from this study come from a study made with different sampling methodology.

above is important to take into account, since the number of years between the first and second sampling varied only six years, the Per capita increase of DSW generation is remarkable with respect to population growth. Indeed, the study made in 2012 resulted in generation rate of 855.8 g·d⁻¹·inh⁻¹, which may suggest the influence of other factors upon the generation rates rather than those considered previously.

Table 5 shows the results for the DSW generation analyses made in 2004. A detailed description of the DSW composition in 1998 can be found elsewhere [11]. A comparison of the composition of DSW between the years of 1998 and 2004 shows a homogenization in the solid wastes produced by the three socio-economic strata, which makes possible to identify the influence of the monthly income variable. A comparison with the study made in 1998 suggests an increase in the generation of around 67% in the by-products founded. For instance, cardboard in the upper stratum increased by around 3-fold from 2.27% in 1998 to 6% in 2004. Nevertheless, only the generation of some by-products is determined by income, as other components such as transparent glass exhibited similar composition for the three strata, suggesting that composition is influenced by other socioeconomic factors, as in this case, due to the change in consumption patterns, since glass has been replaced as packaging by plastic material.

Table 6 shows the generation rates per inhabitant and household for the two years studied. From 1998 to 2004, such rates increased to 10.34% and 21.41%, respectively. In addition, the composition of DSW changed significantly; for instance, the organic wastes decreased by 17% while inorganic wastes increased. The results show an increasing tendency in the DSW generation per inhabitant between 1998 and 2004 for the three socio-economic strata, which corresponds to an overall increase of 49%. Interestingly, the ANOVA analyses performed in 1998 study suggested a non-significant difference between monthly income and DSW generation, despite the coefficients of generation per inhabitant showed an increasing tendency from the low to the upper stratum (Fc 2, 242, 0.05). By contrast, the results of the ANOVA analysis for the year of 2004, showed significant differences between the monthly income and DSW production (Fc 2, 283, 0.05). In the 2012 study, the ANOVA analysis was not performed by stratum because the experimental design of the sampling was different with respect to the studies made in the years of 1998 and 2004.

Table 5. Average of domestic solid waste composition in Morelia by socio-economic stratum in 2004 (% humid base).

By-product	Socio-economic strata			
	Low	Middle	Upper	Average
Food waste	35.88	45.99	43.76	41.88
Baby diaper	16.62	3.99	3.82	8.14
Hard plant fibre	7.99	7.37	3.28	6.21
Garden waste	4.49	7.00	6.09	5.86
Toilet paper	3.91	4.62	5.51	4.68
Snack packing	3.67	2.73	2.71	3.04
Cardboard	3.07	3.73	6.00	4.27
Paper	3.01	4.70	7.73	5.14
Dust	2.93	0.72	0.46	1.37
HDPE	2.34	2.58	3.43	2.78
Transparent glass	2.30	2.26	2.73	2.43
Plastic	1.83	1.46	1.61	1.63
Unidentifiable	1.80	0.76	0.61	1.06
Clothing	1.17	0.94	0.60	0.90
Synthetic fibre	0.61	0.49	0.49	0.53
Snack packing	0.61	0.37	0.37	0.45
Shoes	0.61	0.13	0.09	0.27
Wood	0.59	0.46	0.29	0.44
Tin	0.56	0.87	1.22	0.88
Tetra pack	0.46	1.16	1.28	0.96
Other ^a	5.55	7.67	7.92	7.08
Total	100	100	100	100

Other^a: ferrous material, polystyrene, ceramics, feminine towels, flasks, ash, diaper, stone, colour glass, polypropylene, aluminium, hazardous waste, construction materials, polyvinyl chloride, leather, tetra brick, cotton, electronic waste, coal, rubber, wax paper, batteries, laminate bag, wax, fine residues, metallic paper, flour, polyurethane, wax cardboard, stool, cellophane paper, butts, broom, clay, detergent, viscera, hair, animal hair, feathers, filters, latex, straw, eraser and laminated paper.

Table 6. Domestic solid waste generation per inhabitant and household by socio-economic strata in 1998-2004 (humid base).

Socio-economic strata	1998	2004	1998	2004
	Generation per inhabitant (g·inh ⁻¹ ·d ⁻¹)		Generation per household (kg·d ⁻¹)	
Low	578.13	766.48	2.300	2.685
Middle	625.33	688.08	2.450	2.693
High	691.32	956.34	2.740	2.695
Average	628.84	803.64	2.490	2.777

Table 7 shows the DSW composition in the low stratum between 1998 and 2004. Although the food waste generation decreased during this period, it still remains as the predominant component of the overall USW. This highlights the importance of introducing biological treatment instead of its current disposal at landfills, because they are mainly responsible for the production of biogas, which is mainly composed of CH₄ and CO₂.

4. Discussion

The USW increasing generation in economically developing countries such as Mexico suggests the influence of economic growth, demographic changes, modifications in consumption patterns and lifestyles of the Mexican society. These are related to the overall change from a predominantly rural lifestyle during the

Table 7. Domestic solid waste composition for the low stratum in 1998-2004 (% humid base).

By-products	Year	
	1998*	2004
Food waste	40.88	35.88
Baby diaper	13.78	16.62
Hard vegetal fibre	0.3	7.99
Garden waste	0.0	4.49
Toilet paper	ND	4.68
Low density polyethylene	5.22	6.01
Cardboard	2.65	3.07
Paper	5.49	3.01
Dust	12.42	2.93
Transparent glass	3.83	2.30
Plastic	3.57	1.83
Non-separable material	0.0	1.80
Rag	4.1	1.17
Synthetic fibre	0.28	0.61
Snack packing	0.0	0.61
Shoes	0.0	0.61
Wood	1.76	0.59
Ferrous material	1.65	0.56
Tetra pack	0.20	0.46
Others ^a	3.82	5.55
Total	100	100

Others^a: ferrous material, polystyrene, ceramics, feminine towels, flasks, ash, diaper, stone, colour glass, polypropylene, aluminium, hazardous waste, construction materials, polyvinyl chloride, leather, tetra brick, cotton, electronic waste, coal, rubber, wax paper, batteries, laminate bag, wax, fine residues, metallic paper, flour, polyurethane, wax cardboard, stool, cellophane paper, butts, broom, clay, detergent, viscera, hair, animal hair, feathers, filters, latex, straw, eraser and laminated paper. ND: No determined.

first half of the twentieth century to a predominant urban one since the 1970's. This coincides also with the Mexican Bureau of Census (INEGI) data that reveals around 70% of the population of Mexico is located in urban settlements [21].

Results of the study conducted in 2004, it is interesting to note that the low stratum produced on average 25% less food wastes than the other two strata, while the presence of diapers was detected in all socioeconomic strata. However, the number of diapers founded in the low stratum was four times higher than in the other two strata, which confirms that income and population growth are the predominant factors in the changes in the composition of DSW. About the above, it is noteworthy that the number of diapers shows an inverse relation with the rest of residues from the consumption of goods, since the study carried out in 2004 showed a decrease of 10% of these with respect to 1998. The above also confirms the reduction of the birth rate as part of the demographic changes, which is more evident in the middle and upper strata, since the low stratum continues with birth rates similar to the 1980s, and increases in teenage pregnancies, with which Mexico has the first place among the Organization for Economic Cooperation and Development countries (OECD) [22].

The modification of consumption patterns and lifestyles of the urban population under study is basically confirmed by changes in the composition of the following byproducts: a) presence of diapers in the DSW stream, since the use of disposable diapers is already considered as a basic consumption item for babies and also the occurrence of adult diapers shows an increasing tendency in the two sampling periods; b) food wastes, the generation rate of this item in the low socioeconomic stratum between the two years of study verify the reduction of food wastes; c) yard and vegetable fiber residues increased, which makes it necessary to implement the collection of sorted wastes and reduce clandestine disposal. The percentages of fiber residues confirm the permanence of corrals and patios within the peri-urban zone, especially in zones of the low stratum; because the growth of the city has absorbed rural areas that continue with agricultural activities.

The quantity of sanitary paper founded (4%) is of critical interest in USW management due to the health implications of the exposure of fecal material to the workers and informal collectors. In Morelia, there are still factories of corrugated cardboard sheet that demand sanitary paper as raw material, which is separated by these people with the consequences of exposure to fecal matter. On the other hand, the disposal of sanitary paper within the drainage system is not feasible either, since although the city has a wastewater treatment plant, the drainage system is insufficient and obsolete.

The increase in the amount of DSW generated by dwellings in Morelia is a serious challenge for the public cleaning systems, since implies an increase in budget for the collection and landfilled of the wastes. In Mexico in 2017, 102,895 Tons of USW were generated daily, of which 83.93% were collected and 78.54% landfilled, recycled only 9.63% and dumped around 11% [23]. In Morelia, the

landfill is eight years old, but in order to increase its useful life to another 10 years the extension of the area is contemplated, since generation rate of DSW has increased at 22% between the two study periods of 1998 and 2004 and 28% according to the 2012 study. This last fact, although not obtained from the methodology of the two previous studies, was done by taking the sample of DSW from the collection unit of a randomly selected suburb. Data confirm a growing tendency of waste generation in households, so this highlights the need to promote studies to locate facilities for the final disposal of solid wastes, which comply with environmental legislation, as well as increasing recycling and biological treatment to reduce the amount of wastes landfilled. In addition, having updated data on the composition of the DSW allows implementing strategies to improve the separation of wastes in dwellings. The results obtained in this study provide important data for municipal authorities and decision makers to implement management programs that include the separation of wastes in households and legislate to establish in these sources the polluter pay principle, and like so, recycling of sorted materials.

The management of the USW in cities such as Morelia, located in countries with economies in transition and/or developing countries, faces changes owed basically to demographic changes, consumption patterns and lifestyles. This has already been reported in various investigations such as [24] [25] and [26]. According to [27], the integral management of USW, also focuses on the improvement of the processes to optimize the physical, chemical and biological stability of the confined wastes, and on the valorization of the components to increase the rate of recovery and recycling in order to lengthen the time of useful life of landfills and as consequence diminish the costs of operation and post-closure, as well as of the impacts associated with the management of these facilities. The implementation of these measures involves the payment of economic resources, which is the main constraint that municipalities face. However, it is necessary that these strengthen the integral management of the USW, which must predominate actions and programs focused to prevent and minimize the generation of DSW; improvement of collection and transport of the USW by acquiring enough and adequate collection trucks which fit with the urban design of the cities and of the characteristics (composition) of the USW. Added to the above, the construction of transfer stations in cities of more than 100,000 inhabitants, it is a very important issue. These must be designed with a sufficient capacity, security measures and above all, that the facilities must not be built in the same place of the landfill, since this increases transportation costs of the USW. Finally, it is very important summarizing that all the measures that municipalities undertake, should include information to the population on measures to reduce the production of solid wastes in dwellings, since this study corroborates that these sources are the ones that contribute mostly to the generation of USW.

5. Conclusions

An increase in the production of DSW between the periods of study is observed,

both per capita and per household and the composition has tended to heterogeneity, reflected in a greater diversity of components and materials into solid wastes.

The methodological difference between sampling in the third study does not allow concluding about the generation rate and composition of DSW is determined by income. From the above, it is important to continue with the monitoring of these parameters as well as to expand the number of samples.

Notably, there was an increase in the generation of wastes derived of plastics and a reduction from the glass, which suggests that in addition to consumer demand, the prices of raw materials also affect the decision of manufacturers to develop packages and containers and, consequently, in the composition of DSW.

The increase in the generation of DSW faces to municipalities to provide a greater coverage by the collection systems and the construction of facilities to landfill the DSW.

The amount of food and sanitary wastes continues to be high; however, it is necessary to implement other disposal measures, different from drainage, since its implementation in developing and transition countries is not economically feasible because high costs that implies the construction of water treatment plants and modernization of drainage system. The differentiated collection of these wastes can be the best solution.

6. Absolute Recommendations

It is absolutely necessary to implement programs to encourage the separation of wastes in households and the recycling of sorted materials. The above reduces the cost of waste collection and disposal, as well as the environmental benefit due to the reduction of demand for raw materials.

Decision makers and politicians must achieve recovery of sorted materials to reach the zero generation. Circular economy is the axe which must transit the systems of municipal solid waste collection in developing countries.

Acknowledgements

This research was funded by The Coordination of Scientific Research of the Universidad Michoacana de San Nicolás de Hidalgo through project number 5.9.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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