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Mathematical modeling to predict residential solid waste generation

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ABSTRACT

One of the challenges faced by waste management authorities is determining the amount of waste generated by households in order to establish waste management systems, as well as trying to charge rates compatible with the principle applied worldwide, and design a fair payment system for households according to the amount of residential solid waste (RSW) they generate. The goal of this research work was to establish mathematical models that correlate the generation of RSW per capita to the following variables: education, income per household, and number of residents. This work was based on data from a study on generation, quantification and composition of residential waste in a Mexican city in three stages. In order to define prediction models, five variables were identified and included in the model. For each waste sampling stage a different mathematical model was developed, in order to find the model that showed the best linear relation to predict residential solid waste generation. Later on, models to explore the combination of included variables and select those which showed a higher R^2 were established. The tests applied were normality, multicolinearity and heteroskedasticity. Another model, formulated with four variables, was generated and the Durban–Watson test was applied to it. Finally, a general mathematical model is proposed to predict residential waste generation, which accounts for 51% of the total.

1. Introduction

Municipal solid waste (MSW) generation and management is an issue of worldwide interest; it constitutes a cycle made up of several stages which are closely related.

Solid waste generation also represents a socio-environmental problem and is the result of a production and consumption cycle. In this way, all manufactured, commercialized and consumed products are finally converted – at least partially – into waste. Since consumption is unstoppable and ever increasing, waste production is becoming gradually more important and its disposal is a problem that seriously threatens the sustainable development of society today. When analyzing material flow, from the moment raw materials are extracted to manufacture goods until they turn into waste, it is observed that the problem of solid waste arises at the very moment that the raw materials are extracted. Waste still is produced throughout the manufacturing process and it becomes even worse when consumers discard the remaining part of the product, which is no longer useful to them.

The cycle starts with the production of consumer goods and continues with the generation, storage, sweeping, collection and final disposal of solid waste. Studies conducted on solid waste management are focused on the complete cycle or only on some stages. Generally, the purpose of the studies is to obtain benefits, such as introducing a more sustainable management of municipal solid waste, promoting citizen participation and well-being, contributing to environmental conservation, among others. This work is focused on the generation and characterization of residential solid waste, since those parameters are very important for decision-making in regard to the planning and design of solid waste management systems and final disposal.

Like many other countries, Mexico faces a great challenge in managing its (MSW) due to its industrial growth, population increase, habits, improvement of family welfare, and migration from rural to urban areas. For such reasons, the Federation, through its Secretariat of Environment, Natural Resources (*Secretaría del Medio Ambiente, Recursos Naturales*, SEMARNAT), in coordination with the National Institute of Ecology (*Instituto Nacional de Ecología*, INE), set the regulations, laws, and goals to control contamination in the country.

The problem of MSW generation is a cause for concern in Mexico, because the management and control of MSW has been inadequate for years and management and disposal of municipal solid waste has never been under full control.

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The management of MSW has been extensively discussed and reported in a large number of studies, trying to find relationships and the best plans to solve the problem of MSW, from its collection to its final disposal.

Modeling is a tool used for the planning and management of municipal waste. Tanskanen and Melanen (1999) propose a mathematical model for the planning of solid waste management; Fabricino (2001) proposes a mathematical model to be applied to the integrated management of municipal waste, from its generation to its transportation and final disposal, emphasizing the percentage of material that can be recovered.

There are many researchers who have carried out simulations and have modeled MSW management systems in several parts of the world using mathematical models; among them we can mention Mac Donald (1996) who examined the state-of-the-art of solid waste (SW), analyzing 14 mathematical models based on economic optimization criteria. The problem is that such models require large quantities of data and, as a result, they are more suitable to be applied during the stages of planning and set up. In another study conducted by Lund (1990), he analyzes the alternatives for final disposal in a sanitary landfill through a linear optimization model.

Jacobs and Everett (1992) proposed mathematical models to analyze the recovery of recyclable components. In a more recent research study, Everett and Shahi (1996) proposed an administration model for the setting up of compost plants. Meanwhile, Everett and Modak (1996) also developed a general model aimed at specifying the more convenient methods for MSW collection and disposal for each region.

The model proposed by Chang et al. (1996) addresses the problems of collection vehicles and traffic control, which includes models of non-linear equations and solves them by using interpolation and division algorithms.

In another study, Fabricino (2001) points out that the complexity of models lies in the need to understand the large quantity of parameters and data used, which can not be immediately quantified to do the initial planning of MSW. The proposed model solves or tries to solve the problem of preliminary decision-making prior to the planning phase and its economic optimization. Its application proves how it can be used to assess the economic advantages of MSW collection and disposal.

Salhofer (2000) designed a model aimed at trying to estimate industrial and commercial waste generation in Vienna. This model is based on a matrix, which is applied to sort the type of business that generates the waste by commercial/industrial sector, and is based on the number of employees. The results are comparable to data from similar studies.

In a study conducted in Chile by Orccosupa (2002), he analyzes the relationship between the production of residential solid waste per capita and socio-economic factors. In his model, Orccosupa links economic income against electric power consumption and applies the theory of the Environmental Kuznets Curve, which relates per capita income and the pressure exerted on the environment, all this aimed at reducing residential solid waste (RSW). Beigl et al. (2004) developed a model to identify the parameters that help to account for the current situation and to estimate the generation of MSW in various European cities. Results have shown that this model can be a useful tool to support decision-making regarding municipal solid waste; however, they also showed that the proposed model must be statistically refined (especially the composition modulus) for its application in other contexts.

Beigl et al. (2008) conducted a review of the literature regarding the models developed to estimate waste generation in order to classify the models according to the following criteria: regional scale, modeled waste streams, independent variables and method.

The use of mathematical models can be an alternative to deal with the problem of municipal waste management. In this sense, Sheshinski (2001) emphasizes the importance of creating a mathematical model to deal with the problem of solid waste and the care one should take when creating it.

The mathematical relationship among the amount of solid waste, its transport, cost, treatment, etc., is difficult to construct due to the large quantity of variables involved, and the changing nature of such relationships, which were analyzed by Fabricino (2001) and Sheshinski (2001). The importance of the different parameters in the analysis must be clearly stated in detail so as to ensure that we are using optimal values; otherwise, we would document a wrong relationship between functions and wrong estimates.

For all those reasons, this paper will deal with the problem of solid waste generated per day in an urban community and the need to formulate a mathematical model so as to explain the variables related to this problem. Therefore, the purpose of this research is to develop a mathematical model that explains the variables that determine the generation of residential waste.

2. Methodology

The research was carried out in Mexicali, capital city of the state of Baja California located in the northwest part of Mexico. According to the II Population and Housing count 2005, Mexicali has a population of 855,962, which represents 30% of the state's population.

Mexicali's weather is arid-dry with scarce annual rain; its location on the Tropic of Cancer makes this region a place with extreme climate. This municipality is characterized by its agricultural, industrial and tourist activities; prominent are those activities of the tertiary sector (commerce, services and tourism) that provides employment to about 52% of the population.

In order to carry out this research, we assessed the waste generated by households of a community in Mexicali; for such purpose, a study on the generation and quantification of waste through sampling was conducted. Waste sampling was carried out in three stages corresponding to three different years. A survey was also conducted to obtain demographic data of the population under study. For the development of this research work, data from the three stages of the original research study were assessed and taken as a starting point.

After analyzing the data stored in the database of the original project, the required information was generated so as to characterize the community's residential solid waste (RSW) in the three stages, establishing weight, composition, consumption habits, number of children, educational level, family income, and number of residents per house.

The results obtained from the database were interpreted to identify the study variables and the mathematical model to be used, so as to try and implement such model in the planning, reduction and transport of RSW.

In this stage, the level of correlation with the data generated from the three sampling processes was assessed. It is worth mentioning that the sampling carried out in each stage was different: the sample included 53 households in the first stage; in the second stage, 52 households; and in the third one, 76 households.

The community that this research covered does not reflect a representative sample of the city's population; it only reflects the behavior of three neighborhoods, each representing a defined socio-economic stratum. For the waste generation analysis, the annual seasonal variations were not considered.

2.1. Predictor variables to be included in modeling

The behavior of RSW generation is impossible to explain by using a single predictor variable. Thus, to find the mathematical model that best explained RSW generation, we analyzed data and identified the variables involved. In order to define prediction models, five variables were identified and included in the model; for such purposes, a symbol was assigned to each variable, and the type of dependence, as well as the unit of measure, was set. The information in Table 1 shows the variables included in this work.

The variable "average education per household" (X_{EDU}) was determined based on the number of people older than 18 years living in the particular house. In order to estimate the average education, values from 1 to 4 were given to the different levels of education (Table 2). To assign the corresponding level of education to each individual, the following requirement was established: the individual must have completed the education level assigned, from secondary level to professional one. If a non-completed level was recorded in a given person, the level assigned to such individual was the level immediately below the incomplete one.

To construct the variable "Income per household", the number of household members who work and earn an income was considered; then, the incomes of all the members were added and divided by the total number of household residents who work. Once the variables to be studied were found, a matrix with the data of bag sampling, as well as another matrix with the information collected from the interviews was constructed.

2.2. Definition of matrices based on waste composition data

Based on the results of the sampling in each stage, three matrices were constructed in order to study the variables identified to develop this model. The matrices were defined, including the information for each household-family participating in the sampling in the three stages of the research work. The categories analyzed were the following: total weight of sampled bags, education, number of residents per household, daily income per household and amount of RSW generated per person.

For waste quantification and characterization purposes, the community studied was divided into two areas so as to facilitate the handling of sampled waste. The first stage was sampled during October and November. The second stage was implemented during the months of May and June.

For the third stage, the households sampled were those who agreed to go on participating in the solid waste project; this means that the households included in the third stage had already participated in the previous stages.

To find the relationship between the RSW generated and the defined variables, data of the matrices constructed with the information from the three stages was studied to analyze the behavior of waste generation throughout the years. After concentrating the data in each matrix of results, the relationship among all the pairs of variables was explored, especially the relationship between RSW per capita and each of the predictor variables. To observe such relationship, the software *Statistica Version 6* was used to plot matrix graphs.

For each waste sampling stage, a different mathematical model was developed, so as to look for the model which showed the best linear relation to predict residential solid waste generation. Later on, seven models that explored the combinations of included variables were established, and those which showed the higher R^2 were selected. The first three models were generated with two variables. Normality and homoscedasticity tests were applied to these models in order to generate a linear model. Following that, three models were generated with three variables, and the tests applied to them were normality, multicolinearity and heteroskedasticity. Finally, a seventh model was generated, formulated with four variables, and the test applied to it was the Durban–Watson test. Using the results obtained for these models, a general mathematical model is proposed, which will enable prediction of residential waste generation.

Table 1
Definition of variables for the mathematical model and information analysis

Variable name	Symbol	Type	Unit of measure
Average education per household	X_{EDU}	Independent discrete	Education/household
Number of residents per household (density)	X_{HAB}	Independent discrete	Persons/household
Income per household	X_{INC}	Independent continuous	Income/household
Per capita production of residential solid waste (RSW) per day	Y_{RSWpc}	Dependent continuous	g/person-daily

Table 2
Determination of numeric values for the different levels of education

Education level	Value	Observations
No education	0	Those individuals who have not attended primary school or any other education level
Primary (elementary school)	1	Only those who indicated that they have completed primary education
Secondary (junior high)	2	Only those who have completed secondary education were included in this level. Those who have incomplete secondary studies were included in the immediately preceding level
Preparatory (high school)	3	Only those who indicated that they have completed preparatory school. Those who have incomplete preparatory studies were included in the secondary education level
Professional degree	4	Only those who indicated that they have completed the professional education level were included. Those who have incomplete professional studies were included in the preparatory education level. (Both higher and postgraduate education levels are included here)

2.3. Modeling residential solid waste generation

This modeling started out as a model of linear function, following the steps indicated by Mendenhall (1990). A regression model was determined for each of the variables included in the model: education, income per household and number of residents, aimed at calculating the generation of RSW per dweller. The model of linear function used is represented in the following equation:

$$Y = \alpha + \beta X_1 + \varepsilon \qquad (1)$$

α is the intercept and it indicates the mean value of the response variable when = 0; β is the slope and it indicates the average change in the response variable, when the random variable rises; ε is the term of the average random error or the expected value equals zero $E(\varepsilon)$.

Variables more closely related among each other were looked for, and the regression model was created so as to subsequently calculate the coefficient of determination or the correlation between variables. However, if the coefficient of determination R^2 or the correlation coefficient R was low (less than 35%, Mendenhall, 1990), it was determined that the model was too "poor" to make any prediction.

In order to improve the model, the following alternatives frequently used in regression statistics were applied:

(a) Transformation of the independent or predictor variable (X = education, number of dwellers or income per household) or the dependent variable (RSW generation *per capita*) or both and use of a linear model.
(b) Usage of a polynomial variable with an independent or predictor variable or
(c) obtaining more independent or predictor variables and using multiple linear regression.

In the first case, it is meant to find the most appropriate transformation of the variables. A lot of time can be spent searching this transformation and, besides, we could find a very optimistic model, excessively satisfying the trend of the sampled data, also called "overfitting" (Mendenhall, 1990), though "poor" in making predictions as a standard deviation or an excessively large variance can be observed.

In the second case, the adjustment can be easier although it is also easier to be led into the optimistic model and many calculation problems may be generated as colinearity problems may arise.

The third case is the most widely used and convenient alternative of the research. The advantage is that is has an analogy with the first case (the case with two variables), but it requires the handling of vectors and matrices.

The third case was used in our study and the interactive use of the independent variables involved in regression models was shown. The study began with the exploration of the relationship between all the pairs of variables, mainly the relationship of RSW per capita with each of the previously found variables.

2.4. Analysis for modeling

The relationships of all the pairs involved in the dependent variable (Y_{RSWpc}) were explored with each of the predictor variables. In order to determine the model that could explain the predictor variables, seven tests were applied.

First, each data matrix was analyzed separately, i.e., by year of sampling to determine the goodness of fit measures. Then, the normality of each matrix was calculated to check the normality of data, to determine that the assumptions of the model are complied with, and, if necessary, to explain the reasons for a poor adjustment of a model.

The Kolmogorov–Smirnov was the third test applied. In this test, special attention was paid to the *p*-value or probability value. Then, multicolinearity was calculated since it is a problem which commonly arises in the analyses of multiple regression models. To assure that the multicolinearity is kept to the minimum, first some simple correlations were made between pairs of independent variables before setting out the problem of multiple regression.

The fifth test was the calculation of the heteroskedasticity, which means that the variance of errors is not constant, but rather changes. In order to identify the problem of heteroskedasticity, a diagram with the following values was drawn: $\hat{Y} = Y_{RSWpc}$ (estimated value of the regression model) with its corresponding residuals $e = (y_i - \hat{y}_i)$, y_i = RSWpc observed value.

The methodology to find the heteroskedasticity estimators was used to observe that residuals did not vary for the different $\hat{Y}_i$ values. In this study, it was only calculated for linear models with two variables.

The Durban–Watson test was the last one. This test was applied to detect the problems of first-order autocorrelation in residuals. The presence of correlations indicates that data is not independent.

3. Results

This section introduces the results concentrating the quantification of variables identified to build the mathematical models explaining residential solid waste generation.

In order to find a model for predicting the behavior of the waste generated, various analyses were carried out in each stage. In this case, the results incorporating the three stages in a single diagram for each variable will be shown, establishing certain important relationships from which we may infer some information.

3.1. Variable analysis

The results derived from variable concentration are:

1. *Education.* Concentrating the education variable in the three stages against the quantity of RSWpc generated, it was observed that there was an increase in the production of RSWpc for the third stage, mainly in households with primary education, followed by households with professional careers, though to a lesser extent. The information available regarding the two previous stages indicated that the primary levels of education were the ones generating more RSWpc and the ones generating less were those belonging to the professional levels. This trend remained up to the last study, which showed an increase in waste generation (see Fig. 1).
2. *Population density.* Information in Fig. 2 presents the population density per household in the three stages against the quantity of RSWpc generated. The diagram shows that there was an increase of the generation of RSWpc in the third stage in those

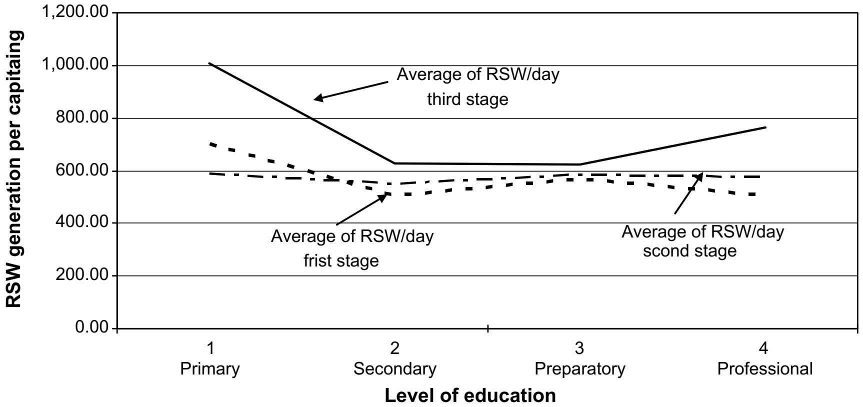

Fig. 1. Residential solid waste generation and education.

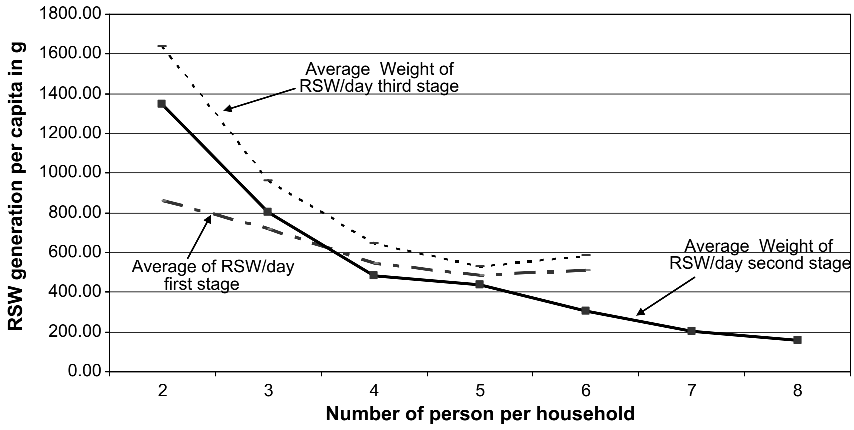

Fig. 2. Generation of residential solid waste and population density per household.

households with 2 and 3 residents, while in households with a larger number of residents, the generation of RSWpc decreases. This trend was observed in the three stages.

3. *Income per household.* Fig. 3 shows the income concentration per household in the three stages against the quantity of RSWpc produced. Here, it was observed that those people with a higher income are not the ones generating more RSWpc, as was observed in some other studies (Orccosupa, 2002). In this study, we found that the people with an income between 400 and 725 Mexican pesos (equivalent to \$34.78–\$63.04 US dollars) per week were the ones producing more RSWpc (between 400 and 1300 g/day).

In Figs. 1–3 it may be observed that a series of results and inferences may be produced for each variable but that the results are not enough to determine the variables that may predict the behavior of residential solid waste generation. Therefore, it is necessary to examine the relationship that exists between the variables. To do so, an option of analysis was to calculate a regression model to ensure a greater reliability of the results as the relationship that exists between the variables is not being analyzed and, consequently, a satisfactory interpretation cannot be given merely based on basic statistics. Due to this problem, we looked for the best option to calculate a regression model having greater result reliability.

The results for the average of sampled data of the three stages are shown in Table 3.

3.2. Statistical analysis of the models

In order to determine the predictions with the regression model, the relationship between what is known and the future event was established, finding the relationship of the variables involved in RSWpc generation. In this mathematical model with the regression analysis presented, an estimation equation was developed that links the variables found with the RSWpc variable and their degree of relationship.

Once the parameters of normality for the three samplings are calculated, the concentration of these samplings in a single one was made and, when they were within the parameters of normal-

Table 3
Averages of the samples performed in the three stages

Variable	*N*	Average	Minimum	Maximum	standard deviation
Education	56	3	1	4	0.97
Residents	56	4	2	6	
Income per week (Mexican pesos)[a]	56	262.27	60.51	966.57	189.39
RSWpc g/person-daily (g)/person-day)	56	627.08	291.37	1559.91	241.74

Source: Database of the three stages of the "Villa del Palmar" study.
[a] 11.50 Mexican pesos is the equivalent to US\$1.

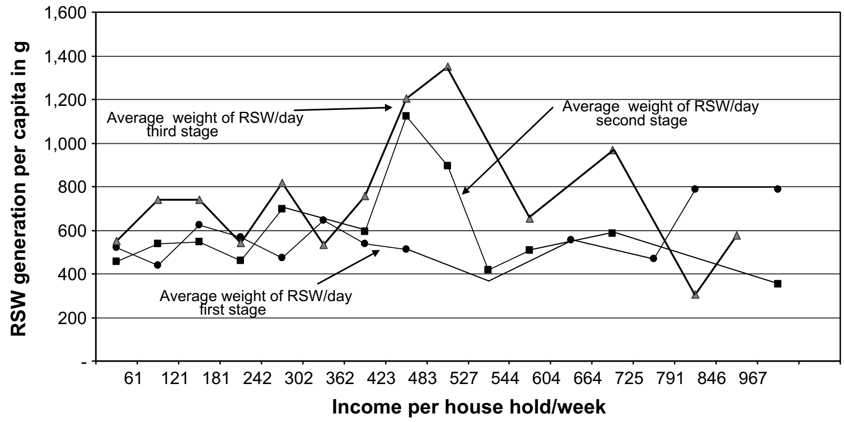

Fig. 3. Generation of residential solid waste and income per household/day. (*Note*: Income in Mexican pesos (US\$1 equals to 11.50 Mexican pesos)).

Table 4
Residential solid waste generation per capita

Model	Predictor variable	Generation in g RSWpc
Y_{RSWpc} = 1339.50 − 171.2 X_{HAB}	X_{HAB} = 4	654.7
Y_{RSWpc} = 1563.40 − 58 X_{EDU}	X_{HAB} = 4, X_{EDU} = 3	646.6
Y_{RSWpc} = 5505.3 − 3186.3X_{HAB}+ 744.91X^2_{HAB} − 74.04$^3_{HAB}$ + 2.49$^4_{HAB}$	X_{HAB} = 4, X_{EDU} = 3, X_{INC} = 262	644.6
Y_{RSWpc} = 1339.5 − 171.2X_{HAB}	X_{HAB} = 4	577.5

ity, the mathematical equations of modeling were calculated. In Eq. (2), the interpretation of the estimated regression coefficients for the linear regression model with two variables, shown in Table 5, whose equation with the best coefficient of determination R^2 is presented,

$$Y_{RSWpc} = 941.26 - 88.81X_{HAB} \quad (2)$$

Eq. (2) was considered the best estimation of the regression model compared to the other two models (Y_{RSWpc} vs. X_{EDU} and Y_{RSWpc} vs. X_{INC}).

The interpretation of this linear equation for each of its coefficients is the following: The *slope* −88.81 (named β, β_1 or degree of line slope) indicates the average change of the response variable, when the predictor variable increases an additional unit. The *intercept* 941.26 (called α) indicates the average value of the response variable when the predictor variable equals zero. However, it lacks practical interpretation if we consider that the range of X_{HAB} values includes zero. Consequently, it means that, the quantity of residential solid waste per person will decrease (on average, 88.81 g) when we add an extra person per household.

Observing the models calculated for the two variables, it was found that they are models that only work for a certain number of residents, between 1 and 8, because if we consider a household with 10 or 15 residents, the model would give a very low and negative generation of residential solid waste. This would be something illogical, even if the coefficient of determination may establish that there is a relationship between the variables. If the coefficient of determination for this model is interpreted, it would indicate that it can only explain 18% of the results. The coefficient is too low for the normal standards of interpretation (Mendenhall, 1990; Ostle and Malone, 1988) where it should be higher than 50%.

The linear model with three variables which produced the best coefficient of determination is shown in the following equation:

$$Y_{RSWpc} = 900.52 - 87.52X_{HAB} + 0.12X_{INC} \quad (3)$$

The interpretation of this linear equation for each of its coefficients is the following: keeping variable X_{INC} unchanged means that, on average, the quantity of residential solid waste per person will decrease 87.52 g, when we add one dweller per household, and keeping variable X_{HAB} unchanged means that the average of RSWpc will increase in 0.12 g for each *peso* of income that may come into the household. As the linear equation for two variables, this three-variable model is also restricted to a certain number of residents and amount of income.

A similar interpretation could be applied to the four-variable model and to the curvilinear model. In the results of the three models already averaged, it was observed that the coefficient of determination improved, when finding the average of the data, getting closer to a better interpretation of the results and to a better reliability than that obtained in the samplings separately. This is so because more information was obtained in order to calculate the models.

Calculating the results of the models in Table 5, with the average of residents per household, the average of education and the average of salary per household, we found the generation of RSWpc presented in Table 4.

Statistics is a tool that provides elements to build models and to identify variables that should be included in the modeling, regarding education, residents and income per household. This value may vary depending on the confidence interval that we assign to the model, normally estimated in a confidence between 95% and 99%.

In Table 5, linear models obtained for the sampling averages of the three stages are presented. In Eq. (4), the linear model with three variables (RSWpc vs. residents, income) is presented, the *F* distribution hypothesis testing is rejected, there is a relationship between the variables and the model explains 45% of the results,

$$Y_{RSWpc} = 1337.0 - 171.3X_{HAB} - 0.01X_{INC} \quad (4)$$

It was possible to put forward the model presented in Eq. (4), which explains 45% of the results. This model relates solid waste generation with the number of residents and their income; this shows that a relationship among variables exists, but the relationship with the variable income is very low (inhabitants $\beta = -0.67$ and income $\beta = 0.008$). Based on this, it is possible to say that it is not the most suitable model for our proposal; evidence shows that when the income variable, is included it is necessary to be very careful when the field data are obtained because people often omit this information or give it imprecisely.

In Eq. (5), the linear model with four variables (RSWpc vs. education, residents and income) is presented; the *F* distribution hypothesis testing is rejected and the model explains 51% of the results,

$$Y_{RSWpc} = 1560.0 - 64.1X_{EDU} - 187.5X_{HAB} + 0.1X_{INC} \quad (5)$$

where Y_{RSWpc} was considered a dependent variable of the variables education, residents and income per household.

4. Discussion and conclusions

Statistical analysis is a tool that provides elements to build models and to identify variables that should be included in the

Table 5
Linear models for sampling averages of the first, second and third stage (significance level α = 0.05)

Model	R^2	Distribution $F(1,54)$, $F(2,53)$, $F(3,52)$	*F* Probability $p<$	Distribution $t(54)$, $t(53)$, $t(52)$	*t* Probability $p<$
Linear model with two variables					
Y_{RSWpc} = 666.25 − 13.88X_{EDU}	0.00	0.17	0.6820	6.6	0.0000
Y_{RSWpc} = 1339.5 − 171.2X_{HAB}	0.45	44.55	0.0000	12.2	0.0000
Y_{RSWpc} = 627.06 − 0.00X_{INC}	0.00	0.00	0.9997	11.2	0.0000
Linear model with three variables					
Y_{RSWpc} = 1563.4 − 58.0X_{EDU} − 185.7X_{HAB}	0.50	28.86	0.0000	11.0	0.0000
Y_{RSWpc} = 663.89 − 15.08X_{EDU} + 0.02X_{INC}	0.00	0.09	0.9136	6.42	0.0000
Y_{RSWpc} = 1337.0 − 171.3X_{HAB} + 0.00X_{INC}	0.45	21.87	0.0000	11.60	0.0000
Linear model with four variables					
Y_{RSWpc} = 1560.70 − 64.1X_{EDU} − 187.5X_{HAB} + 0.1X_{INC}	0.51	18.00	0.0000	10.94	0.0000

modeling. In this research, statistical tests were applied to determine the models that better predict waste behavior. To do so, the tool used was modeling.

To determine the predictions with regression models, it is necessary to establish the relationship between what is known and the future event, finding the relationship of the variables involved in the generation of residential solid waste per capita (RSWpc).

In various research studies, regression and correlation analyses were used. Among others, the following may be mentioned: Orccosupa (2002), Jacobs and Everett (1992) and Fabricino (2001). In the mathematical model with the regression analysis developed in this paper, an equation that links the variables related to education, number of residents and income with the RSWpc variable and the degree of relationship was developed.

The quantity of solid waste generated by a family and by the population, as well as its final disposal, is relevant for the analysis of sustainability. The volume, weight, composition, time period of exposure and final disposal of the waste produce significant impacts on the physical-biotic environment and on human health, related to the atmospheric pollution, soil contamination, and groundwater and surface water contamination, threatening the planet's sustainability. It is worthwhile to bear in mind that the quantity of waste not only depends on the number of inhabitants of a population but is related to other factors as the process of urbanization, consumption patterns, cultural practices related to waste management, income, technology usage and industrial development.

One of the most relevant inadequacies concerning MSW management and final disposal is the existing unawareness on the phenomenon, both in conceptual and in factual terms. For example, in the majority of cities in Mexico, the quantity and the composition of all the generated waste are not identified and, therefore, decision-making is difficult. Thus, it is important to obtain support from modeling to explain the behavior of solid waste, especially when based on real data, as it is the case presented in this paper.

The model proposed in this work is the one presented in Eq. (5). The model is a four variables linear model with one dependent variable (per capita waste generation) and three independent variables (education, residents and income per household). From the models obtained in this work, this is the one that can explain the 51% of the results, showing that a relationship among variables exists.

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References

Beigl, P., Lebersorger, S., Salhofer, S., 2008. Modelling municipal solid waste generation: a review. Waste Management 28, 200–214.

Beigl, P., Wassermann, G., Schneider, F., Salhofer, S., 2004. Forecasting municipal solid waste generation in major european cities. In: Pahl-Wostl, C., Schmidt, S., Jakeman, T. (Eds.), iEMSs 2004 International Congress: Complexity and Integrated Resources Management. Osnabrueck, Germany. Available at: <http://www.iemss.org/iemss2004/pdf/regional/beigfore.pdf>.

Chang, N.B., Yang, Y.C., Wang, S.F., 1996. Solid-waste management analysis with noise control and traffic congestion limitations. Journal of Environmental Engineering 2, 122–131.

Everett, J.W., Modak, A.R., 1996. Optimal regional scheduling of solid waste systems. I: Model development. Journal of Environmental Engineering 9, 785–792.

Everett, J.W., Shahi, S., 1996. Curbside collection of yard waste II: simulation and application. Journal of Environmental Engineering 2, 115–121.

Fabricino, M., 2001. An integrated programme for municipal solid waste management. Waste Management and Research 19, 368–379.

Jacobs, T.J., Everett, J.W., 1992. Optimal scheduling of consecutive landfill operations with recycling. Journal of Environmental Engineering 3, 420–429.

Lund, J.R., 1990. Least-cost scheduling of solid waste recycling. Journal of Environmental Engineering 1, 182–197.

Mac Donald, M.L., 1996. Solid waste management models: a state of the art review. Journal of Solid Waste Technology and Management 17, 263–274.

Mendenhall, W., 1990. Statistics for Administrators. Edited by Grupo Editorial Iberoamericana, S.A. de C.V. México

Orccosupa, J., 2002. Relationship among the per capita generation of household solid waste and socioeconomic variables, Santiago de Chile Province. Master Thesis in Management and Evironmental Planning, Santiago de Chile, Provincia de Santiago de Chile.

Ostle, B., Malone, L.C., 1988. Statistics in Research. Basic Concepts and Techniques for Research Workers. Iowa State University Press, USA.

Salhofer, S., 2000. Modelling commercial/industrial waste generation: a Vienna, Austria case study. Waste Management and Research 18, 269–282.

Sheshinski, R.H., 2001. Indirect methods used for waste statistics and waste indicators. Statistical Commission and Economic Commission for Europe. Working Paper 17. Work Session on Methodological Issues of Environment Statistics, Ottawa, Canada.

Tanskanen, J.H., Melanen, M., 1999. Modeling separation strategies of municipal solid waste in Finlandia. Waste Management and Research 17, 80–92.