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Otoniel Buenrostro [a] , Gerardo Bocco [b] & Javier Vence [c]
[a] Instituto de Investigaciones sobre los Recursos Naturales, Universidad Michoacana de San Nicolás de Hidalgo , Morelia , Mexico
[b] Departamento de Ecología de los Recursos Naturales , Instituto de Ecología, Universidad Nacional Autónoma de México , Morelia , Mexico
[c] Centro Regional Universitario Centro Occidente, Universidad Autónoma de Chapingo , Morelia , Mexico
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Otoniel Buenrostro
Instituto de Investigaciones sobre los Recursos Naturales, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Mexico

Gerardo Bocco
Departamento de Ecología de los Recursos Naturales, Instituto de Ecología, Universidad Nacional Autónoma de México, Morelia, Mexico

Javier Vence
Centro Regional Universitario Centro Occidente, Universidad Autónoma de Chapingo, Morelia, Mexico

ABSTRACT
Based on a study of the composition of urban solid waste (USW) and of socioeconomic variables in Morelia, Mexico, generation rates were estimated. In addition, the generation of residential solid waste (RSW) and nonresidential solid waste (NRSW) was forecasted by means of a multiple linear regression (MLR) analysis. For residential sources, the independent variables analyzed were monthly wages, persons per dwelling, age, and educational level of the heads of the household. For nonresidential sources, variables analyzed were number of employees, area of facilities, number of working days, and working hours per day. The forecasted values for residential waste were similar to those observed. This approach may be applied to areas in which available data are scarce, and in which there is an urgent need for the planning of adequate management of USW.

IMPLICATIONS
Linear regression models based on socioeconomic variables are proposed to forecast USW generation. These models can assist solid waste management planners with efficient and easily applicable statistical instruments to describe and forecast the generation of solid waste. This is relevant in the development of solid waste management plans. Accurate and detailed forecasts of solid waste generation allow municipal authorities to plan capacity requirements for waste-treatment systems and collection and transportation systems, and to select sites and predict landfill lives. For policymakers and lawmakers, this approach contributes to improving regulations about solid waste generation.

INTRODUCTION
The amount and composition of the waste generated are essential for adequate decision-making regarding the management of urban solid waste (USW). Both characteristics of waste vary with time and are affected by socioeconomic conditions. This aspect is most important for planning management programs of USW in developing countries, because the effect of socioeconomic variables associated with the generation of solid waste is poorly understood. Here, the effect of socioeconomic variables such as income, level of consumption, and cultural and educational environment on the generation of USW are specific and vary from place to place.[1,2]

Most cities in developing countries undergo accelerated urbanization. One of the consequences of this process is the transformation of the habits of consumers. This change in consumer habits results in an increased generation of waste, such as plastics and glass, that is difficult to break down.[3] The inadequate disposal of this waste in the neighborhoods of the urban centers creates a strong, negative environmental impact on soil, groundwater, the surrounding flora and fauna, and public health.

In order to understand the USW generation, as well as to propose management plans, it is necessary to consider social and economic aspects. In developing countries, poverty of large sectors of the population is an instrumental cause of the increase of social underdevelopment and marginality.[4] The generation of USW is more complex, and governments face difficulties in implementing adequate waste management programs.

To understand, describe, and predict the unit waste generation rate and the composition of USW, various researchers have studied the influence of socioeconomic factors. The variables more commonly analyzed are community size; population density; monthly wages per capita; number of persons per dwelling; percentage of urban population; annual average temperature; age, sex, and ethnicity of the population; size of housing; geographical characteristics; land use; productive activities; and communications.[5-7] The overriding variable influencing unit waste generation rate is population.[2]

Solid Waste Generation Models

Solid waste generation models may be grouped into two large classes:

(1) Descriptive generation models. These models provide information about the generation of solid waste by different sources, such as residential, commercial, institutional, and industrial sectors. In general, these models are expressed in terms of unit waste generation rates, which are factors or multipliers relating the amount of waste generated with certain characteristics of the community, such as total population size or number of persons employed.[7] Basically, generation data are obtained by means of four different types of sampling:[8,9] sampling of waste generated by representative sources (direct waste analysis), sampling of the products derived from a given process of waste management (waste product analysis), sampling of the materials used for the production of commodities by means of the enumeration of supplies (market product analysis), and weighting of representative samples of the loads of solid waste collection vehicles (tonnage estimation models).

(2) Predictive generation models. In general, these models are based on unit waste generation rates.[7] The forecasting models are developed using several statistical methods, such as the correlation of the socioeconomic variables with the generation of solid waste and the application of linear regression models,[5] principal component analysis to suggest indicators of potential generation of solid waste,[10] the use of nonparametric statistics to determine probability distribution for daily solid waste generation data,[11] and the retrospective analysis by time intervals to know the simultaneous influence of the variables involved in the generation of solid waste (geometric lag time series analysis techniques).[12]

Applicability of Forecasting Models in Developing Countries: A Critical Review

The models and variables that have been shown to be significant for developed countries have been extrapolated to developing countries. In general, these models do not consider the differences in behavior of the explaining variables involved, nor the scarcity of data about the amount and composition of solid waste. Likewise, in developing countries, they do not account for the existence of informal practices, both in the generation and in the collection of solid waste. Nevertheless, with respect to developed countries, in developing countries the level of recovery of components is higher.[13] The recovery of waste in developing countries is mainly carried out by marginal sectors of the population, by means of a diversified range of informal activities, such as the handpicking of materials during the collection of solid waste, at the source of generation and at the dumping grounds. This accounts for the difficulties involved in precisely determining the volume of USW that is recovered and recycled in these cases.

Despite the environmental problem posed by the increasing generation of USW in developing countries, the published research in this regard is scarce.[14] Notwithstanding the demographic growth, the expansion of industries, the modification of food habits, and the process of urbanization in developing countries, the corresponding authorities have not been urged to promote the development of research leading to an understanding of the patterns of generation of USW. This paper contributes to this type of research; we present a case study aimed at forecasting the generation of USW in the city of Morelia (Michoacan) in Mexico. As every major city in developing countries, Morelia is undergoing fast urban growth, mostly driven by the immigration of rural population. This is reflected in land use speculation, a chaotic expansion of the urban areas at the expense of agricultural land, and a sustained increase in the generation of USW. This waste is becoming increasingly similar in its composition to that generated in developed countries. However, the management of USW remains to be dictated by obsolete and inadequate criteria, something common to all developing countries. As a result, USW is disposed of in inadequate dumping grounds, following deficient planning of USW management.[15]

The specific objectives of this research were (1) to analyze the effects of monetary income, density of dwellers per household, and educational level and age in the generation of residential solid waste (RSW); (2) to analyze the effects of the number of employees, the size of facilities, and the number of daily working hours and of working days in the generation of nonresidential solid waste (NRSW); and (3) to test the efficiency of these socioeconomic factors in the development of regression models for the forecasting of USW generation in fast-growing urban areas.

CONCEPTS

In this research, USW is defined as all solid waste generated within any human settlement. According to the sources of generation, USW is divided into RSW, which is produced by households, and NRSW, which is produced by commerce, industries, and institutions/services. Each one of these sources generate different waste, which is defined accordingly, as follows:

(1) RSW: the solid waste generated in either single-family or multifamily dwellings.
(2) CSW: the solid waste generated in commercial facilities, department stores, supermarkets, restaurants, markets, and temporal ambulatory markets (*Mexican tianguis*).
(3) Industrial solid waste: the solid waste generated in all processes of extraction, transformation, and production.
(4) Institutional and services solid waste: the solid waste generated in private and governmental offices, educational centers, museums, libraries, archaeological zones, and recreation centers, such as movie theaters and stadiums.
(5) Special solid waste: the solid waste requiring special techniques for control, because of either the relative hazard it represents or its particular condition or state, or because it is required by the standing legal regulations. This solid waste is generated in such sectors as research laboratories, medical institutions or facilities, automotive or industrial maintenance workshops, veterinary facilities, drug stores, airports, and terrestrial transportation terminals.[16]

The Urban Solid Waste in the Studied Area

In this city, the majority of the USW is generated by residential sources, thus corresponding to RSW. Table 1 presents the results of the sampling of waste in the studied area. The contribution of nonresidential sources to the generation of USW is due to the fact that, in general, the micro and small industries (usually workshops) are predominant in the urban centers of developing countries. Most of these sources mix their solid waste in the USW stream because they use the municipal solid waste collection service. The medium and large industries (considering the number of employees, the size of their facilities, and the volume of commodities production) are concentrated in industrial parks, which, in many cases, are surrounded by marginal residential settlements. The medium and large industries also transport their solid waste by their own means, but dispose of them in the dumping grounds used for all other USW.[15]

Table 1. Generation rates of urban solid waste (kg/capita/year).

Source	kg/Capita/Year (Wet wt)
Residential	230
Commerce	219
Markets	2646
Institutions/Services	304
Industry	569
Specials	259

In most urban centers in these countries, with the exception of the capital cities, large shopping malls are few or absent. Additionally, these sources do not dispose of their solid waste by means of the solid waste collection services but, in general, they hire or own collection services to transport their solid waste to dumping grounds. Usually, this solid waste is highly appreciated by the marginal groups of the population because of its high content of metal and paper. The decomposing fruits and vegetables in this solid waste are normally used to feed domestic animals and, not infrequently, are also used for human consumption.[15]

METHODS

Sampling and Data Sources

During March and April 1998, a stratified sampling of 243 dwellings was randomly selected out of a total of 123,000 households. The number of samples per stratum was determined by the Stein's procedure.[17] The sampling sites were chosen by socioeconomic level following the classification of the Mexican bureau in charge of the census (INEGI, by its Spanish acronym). This socioeconomic stratification establishes three levels of monetary income:[18]

(1) low socioeconomic class: monthly income of less than one minimum wage [about $90 (U.S. dollars) per month in 1999];
(2) middle socioeconomic class: monthly income between one and two minimum wages [up to about $180 (U.S. dollars) per month in 1999]; and
(3) upper socioeconomic class: monthly income between two and five minimum wages [up to about $450 (U.S. dollars) per month in 1999].

In all cases, a questionnaire was simultaneously applied in order to obtain precise data about the monetary income (income), the density of inhabitants per household (density), the age and educational level (education) of inhabitants of the households, the land tenancy regime of the household, and the availability of automobiles. The questionnaires were grouped by socioeconomic level, and the answers were captured and analyzed in a database (Excel version 1997).[19] Further data were subjected to a descriptive statistical analysis. Tables 2 and 3 show the results of the questionnaires for these sources.

Likewise, 32 nonresidential sources stratified by type of economic activity were sampled. The total number of samples included in the statistical analysis was determined by the amount of samples retrieved from each selected source. Nonetheless, the Stein's procedure determined that this number of samples was enough for the statistical analysis. The samples of solid waste were taken during visits to the facilities. In these cases, the questionnaires were aimed at knowing the number of employees (employees), the area of the facilities (area), the number of daily working hours (hr), and the number of working days (days).

For forecasting the generation of these sources, the land tenancy regime of the household and availability of automobiles were not included in the analysis because these were highly correlated with income. Nonetheless, it was observed that the availability of automobiles in the low stratum might not correspond with income because the majority of cars reported were old models. Also, it was difficult to consider the age of all inhabitants of the households; thus, it was decided to select the age of the heads of the household only. Table 4 contains the number of nonresidential samples analyzed and the results of the questionnaires applied to these sources.

The socioeconomic data were considered as independent variables, and data on generation of solid waste were considered as dependent variables. Table 5 contains, for residential and nonresidential sources, the names of the analyzed variables together with their description. The variables analyzed in this study were assessed simultaneously with the sampling of the solid waste generated by each one of these selected sources. This was assumed to be important to ensure a better relation between variables; it has been shown that if the solid waste is not assessed simultaneously with the socioeconomic data, model development may be affected.[7]

Predicting Models

The differences in socioeconomic conditions are reflected in the composition of solid waste and in its generation rate. Thus, an association between the generation of USW and the corresponding socioeconomic variables is to be expected.[10] Based on this assumption, the Pearson product moment correlation coefficient was initially applied to find the coefficient of determination (R^2) between the independent variables. Subsequently, to test the hypothesis of independence between the selected explanatory variables, the Student *t* test[17] was applied on the R^2 coefficient of the socioeconomic variables. Because the analysis included more than two variables, and these variables displayed a linear distribution, a multiple linear regression (MLR) analysis was

Table 2. Socioeconomic data for residential sources.

Parameter	Socioeconomic Class					
	Low		Middle		High	
Total number of households	61		125		57	
Total number of persons	285		522		237	
Average number of persons per household	4.7		4.2		4.1	
Age distribution	**(%)**		**(%)**		**(%)**	
Under 3	14		7		2	
4 to 12	24		18		17	
13 to 18	13		15		10	
19 to 30	26		24		23	
31 to 59	20		29		40	
60 or over	2		7		8	
Sex	**(%)**		**(%)**		**(%)**	
Men	49		43		42	
Women	51		57		58	
Education level	**Men**	**Women (%)**	**Men**	**Women (%)**	**Men**	**Women (%)**
Elementary school (not finished)	32	46	10	6	0	2
Elementary school	34	34	10	13	0	0
Junior high	17	15	7	9	2	6
High school	8	3	18	32	10	34
College	9	2	55	40	88	56
Graduate school	0	0	0	0	0	2

Table 3. Income data in residential sources.

Parameter	Socioeconomic Class		
	Low (%)	Middle (%)	High (%)
Income[a]			
$86 or less	33	0	0
$86–$91	12	2	0
$92–$264	53	18	4
$265–$609	2	28	13
$10–$965	0	27	21
$966 or more	0	25	62
House			
Rent	10	14	17
Own	61	58	79
Paying	26	24	4
Lending	3	4	0
Car			
Yes	7	75	93
No	93	25	7

[a]Monthly household income.

applied to determine the probable shape of the relation between variables and to estimate the generation of solid waste, which corresponds to the values of the analyzed socioeconomic variables. From this, it may be ascertained that the generation of USW may be explained by a multiple linear equation having the form of eq 1.

$$Y = ß_o + ß_1X_1 + ß_2X_2 + ß_3X_3 + ß_4X_4 ..... + \varepsilon \qquad (1)$$

where Y is the dependent variable; $ß_o$ is the intercept; X_1, X_2, X_3, and X_4,....are independent variables; $ß_1$, $ß_2$, $ß_3$, and $ß_4$ are regression parameters; and ε is residuals.

The required statistical analyses were performed with the Statistical Analysis System program (SAS).[20-22] In order to determine the forecasting model, which was most appropriate for the generation of solid waste, the following criteria were applied:

(1) Portion of sample variation explained (R^2). An ideal value of 1 for this coefficient indicates a good fit of the model.

(2) Mean square deviation regression (MSDR). The lower the value, the better the fit of the model.

(3) The level of significance of the model ($Pr > F$). For the model to be considered as significant, F must have a value of less than $\alpha = 0.05$.

RESULTS AND DISCUSSION

Forecasting Generation of Residential Solid Waste

The estimated values of the R^2 of the selected socioeconomic variables were under 0.7, indicating poor multicolinearity and independence among them.[23] The latter suggests that these variables are suitable for predicting the generation of solid waste with this data set. However, the Student t test showed dependence between the variables age versus income, educational level versus income, and educational level versus age (Table 6). The above facts had the effect of decreasing the significance of the regression model when the four variables were included. The analysis of variance (ANOVA) of the regression gave an F value of 4.89, a $Pr > F$ of 0.0008, an R^2 of 0.075, and an MSDR of 2.59. However, the variables age and educational level had nonsignificant regression coefficients, with respect to their value of t (0.83 and 0.87, respectively), indicating that these two variables did not explain variability in per capita waste generation. This fact confirmed the results of the test for the hypothesis of independence by means of the Student t distribution; likewise, it corroborated the results of the questionnaires with respect to the socioeconomic analysis. It was found that the educational level increased with income, and this latter variable was inversely related to the number of dwellers per household.[15]

Because of the behavior described above, another model was tested including the two variables whose values of t were significant (income and density). This model did not show an increase in the R^2 coefficient, but the level of significance showed a sensitive increase (0.0001), and a decrease in MSDR was observed (2.57). These facts lead to the decisive consideration of this model as a better fit than the model with the four variables. The hypotheses stating

Table 4. Economic data in nonresidential sources.

Source	Samples per Source	Number of Employees	Size of Facility (m^2)	Schedule (hr)	Working Days (days/week)
Commerce	10	2.1	32.33	9.46	6.27
Institutions/Services	2	1.5	35.5	9.25	6
Microindustry	4	2	62	9.5	6.25
Special	16	2	28.7	8.6	6.06
Average		2	36	9.19	6.17

Table 5. Variables explaining the generation of USW in Morelia.

Variables	Description
	Independent Variables
Residential Sources:	
X_1	Income: total monthly income per household (U.S. \$).
X_2	Density: total number of dwellers per household.
X_3	Age: average age of heads of households (years).
X_4	Educational level: average number of years in an educational institution attended by the heads of the households.
Nonresidential Sources:	
X'_1	Employees: the number of workers employed by the business.
X'_2	Area: the total area in m^2 occupied by the facilities in which economic activity takes place.
X'_3	Hr: the total number of daily working hours.
X'_4	Days: the total number of working weekdays.
	Dependent Variables
Y	RSW: the solid waste generated in households.
Y'	NRSW: the solid waste generated in the industrial, commercial, institutional/services, and special sectors.

Table 6. Values of *t* from the test for the independence hypotheses (Ho: $\rho = 0$ vs. Ha: $\rho \neq 0$) among explanatory variables (n–2 degrees of freedom, $\alpha = 0.05$).

Compared Variables	Standard Value of *t*	Estimated Value of *t*
	Residential Sources	
Density vs. income	1.96	–0.627[a]
Age vs. income	1.96	3.76[b]
Education vs. income	1.96	10.17[b]
Age vs. density	1.96	0.91[a]
Education vs. density	1.96	–1.76[a]
Education vs. age	1.96	2.39[b]
	Nonresidential Sources	
Area vs. employees	2.04	–1.26[a]
Hr vs. employees	2.04	1.34[a]
Days vs. employees	2.04	0.144[a]
Hr vs. area	2.04	0.341[a]
Days vs. area	2.04	–0.623[a]
Days vs. hr	2.04	0.845[a]

[a]Significant (Ho is not rejected ∴ independent); [b]Not significant (Ho is rejected ∴ not independent).

that the regression coefficients of the variables are equal to zero (Ho: $\beta_I = 0$ vs. Ha: $\beta_I \neq 0$) were rejected for estimators β_o, β_1, and β_2 at $\alpha = 0.05$. This suggests that the proposed model using the variables income and density may be applied to explain the MLR relation, and to forecast the generation of RSW, as shown in eq 2:

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \qquad (2)$$

Replacing values:

$$\mathrm{RSW} = 1.02 + 0.000072X_1 + 0.236X_2$$

According to eq 2, the predicted value of RSW generated is 2.46 kg, very close to the observed value of 2.49 kg. Although the model is highly significant, the low value of R^2 (0.075) indicates that the variables suggested for forecasting RSW generation are yet of limited value in explaining the total variation in the data. However, in previous studies using MLR to predict RSW components, R^2 coefficients between 0.26 and 0.57 have been reported.[5]

The models developed in this study provide a basis to narrow the analysis of other factors involved in the generation of USW, such as temperature. In a previous study,[24] a marked seasonal pattern in the generation of USW in urban areas was reported. This was explained by the predominance of some foodstuffs in certain seasons of the year, and as drops and surges in consumption, which derive from seasonal and economic fluctuations such as the Christmas season. The data used in the present study were gathered during a single season (spring), which undoubtedly should affect the forecasting capability of the model, although the socioeconomic variables selected may be suitable. Yet, compared to the literature, these data remain relevant.

Forecasting Generation of Nonresidential Solid Waste

The test for the hypothesis of independence by means of the Student *t* distribution with n–2 degrees of freedom and $\alpha = 0.05$ showed that all selected socioeconomic variables were independent (see Table 6). This suggests that the optimal model for predicting the generation of solid waste for the nonresidential sources is the one including the four variables considered (employees, area, hr, and days). However, the ANOVA of the MLR of the model with all four variables was not significant ($\Pr > F = 0.17$). Consequently, runs were made using different models to determine which was more adequate in terms of the level of significance. From this analysis, it was determined that the model including the variables X'_3 (hr) and X'_4 (days) was optimal for the forecasting of NRSW. Inclusion of these two variables increased the significance level to 0.05 and the R^2 to 0.177, and decreased the value of MSDR to 591; thus, the model including the variables X'_3 (hr) and X'_4 (days) was adopted (eq 3).

$$Y' = \beta'_o + \beta'_3 X'_3 + \beta'_4 X'_4 \qquad (3)$$

Replacing values:

$$\mathrm{NRSW} = 0 + 0.19217X'_3 + 0$$

The forecasted value of 1.77 kg is almost twice the observed value of 0.925 kg; however, the model was highly significant for forecasting the generation of NRSW. The low value of R^2 in the tested models indicates, as is the case for RSW models, that the proposed variables for the forecasting of generation are yet of limited value to explain the total variability of the data. One possible explanation for this inadequacy of the forecasting models is that the number of samples in the analyzed database, despite being statistically significant, does not reflect the total variation of the population studied. To improve the forecasting capability of the models, the samples must be expanded to a larger number of sources. It is important to include additional socioeconomic variables, such as sales volume. This variable is instrumental to assess the real dimension of the economic activity of the sources. Indeed, consideration of the size of the facility and the number of employees may lead to underestimating the degree of economic activity of the source. However, data regarding total sales volume are troublesome to obtain. In addition, sampling nonresidential sources is a difficult task because of lack of cooperation from owners. The database analyzed in this paper must be regarded as an initial approach to the forecast of the generation of USW in urban areas that may be similar to that described here, and of the variables that may be affecting their generation.

CONCLUSIONS

Adoption of adequate management measures to couple with the environmental and public health impact caused by the inadequate refusal of increasing urban waste is urgent. The analyses of socioeconomic variables influencing the generation of waste enable the forecast of their quantity and are useful for planning their adequate management. The models forecasting solid waste generation are useful analytic tools in the design of management programs. In the international range, a number of models have been proposed that are based on the analysis of several statistics and socioeconomic variables. These models have shown to be efficient for the forecasting of solid waste generation in developed countries. However, the applicability of these models is troublesome because of their theoretical complexity, as well as the large data requirements. The use of linear regression with efficient statistical instruments can explain and forecast the generation of solid waste, based on data obtained through relatively simple sampling designs, and can do so at a low cost.

Such tools are used in this research; their efficiency in forecasting was assessed in a case study in Mexico. This approach may be extrapolated to similar cases in other cities in developing countries. Although the models proposed by this study are regarded as an initial approximation to the explanation of these processes, they do offer an alternative with analytical value.

Our results indicate that, in Morelia, the generation of residential waste differs significantly from that of nonresidential sources. In the case of the former, the variables which were found useful for forecasting the generation of waste were monetary income and density of dwellers per household; for the latter, the useful variable was the number of daily working hours. The analysis of these sources was difficult because of the restrictions imposed by environmental legislation and policies. To improve the forecasting power of the models, it is necessary to expand the sampling to a larger number of sources. It should be highlighted that the low number of samples analyzed here followed the limited level of participation of the sources. As a result, it is necessary to precede the sampling with environmental education programs related to the objectives of the analyses of generation of solid waste. To this end, the different social sectors involved in solid waste generation must work in coordination with governmental agencies, chambers of commerce, services, and industries. Emphasis must be on the confidentiality and professionalism with which the volunteered information will be utilized.

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About the Authors

Otoniel Buenrostro (corresponding author) has a Ph.D. in biology from the Universidad Nacional Autónoma de México (UNAM). He is a junior researcher at the Instituto de Investigaciones sobre los Recursos Naturales (INIRENA), Universidad Michoacana de San Nicolas de Hidalgo. His address is Apartado Postal 2-10, Morelia, Michoacán, Mexico; phone: (4) 3272351; fax: (4) 3272350; e-mail: otonielb@zeus.ccu.umich.mx. Gerardo Bocco is a senior researcher at the Departamento de Ecología de los Recursos Naturales (DERN), Instituto de Ecología, UNAM, Campus Morelia, in charge of the Laboratory of Geoecology. His address is Apartado Postal 27-3 (Xangari), 58089, Morelia, Michoacán, Mexico. Javier Vence is an assistant professor in Statistics at the Centro Regional Universitario Centro Occidente, Universidad Autónoma de Chapingo. His address is Periférico Independencia Poniente No. 1000, Colonia Lomas del Valle, Morelia, Michoacán, Mexico.