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Tax calculation proposal for waste collection based on the amount of residential solid waste

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ABSTRACT. This study aimed to elaborate a mathematical model to estimate the amount of residential solid waste (RSW) generated and thus, to propose an alternative methodology for calculating the waste collection tax (WCT) for the city of João Pessoa, in Northeast region of Brazil, based on the estimated amount of RSW generated rather than on the constructed area of the residence, as is the case for this city. The methodological procedures consisted of daily weighing of the RSW along with readings of water and electricity consumption in three multi-family buildings and two single-family houses in the city of João Pessoa. Results have shown that the RSW generation rate was 0.526 kg capita^{-1} day^{-1} in apartments (multi-family buildings) and 0.794 kg capita^{-1} day^{-1} in houses (single-family residence). Results also indicated that water consumption was highly correlated with RSW generation and that it is possible to estimate the amount of RSW generated in a residence considering its population and water consumption. Based on this model, a new methodology for the WCT calculation was proposed: an alternative which relies on the estimated amount of RSW rather than on the constructed area.

Keywords: RSW collection tax, case study in João Pessoa.

Proposição do cálculo da taxa de coleta de resíduos, pela quantidade estimada de resíduos sólidos domiciliares: estudo de caso da cidade de João Pessoa, estado da Paraíba

RESUMO. Este trabalho objetivou a elaboração de um modelo matemático para estimativa da quantidade gerada de resíduos sólidos domiciliares (RSD) e propor uma metodologia alternativa para o cálculo da taxa de coleta de resíduos (TCR) para a cidade de João Pessoa-PB, com base na quantidade estimada de resíduos e não na área construída da residência, como é o caso desta cidade. O procedimento metodológico consistiu em se pesar diariamente a quantidade de RSD, bem como efetuar a leitura do consumo de água e de eletricidade em três edifícios multifamiliares e duas residências unifamiliares na cidade de João Pessoa. Os resultados indicaram que a taxa de geração per capita de RSD foi de 0,526 kg hab^{-1} dia^{-1} em apartamentos e 0,794 kg hab^{-1} dia^{-1} em casas. Os resultados também mostraram que o consumo de água é fortemente correlacionado com a geração de RSD e que é possível estimar a massa de RSD, pela população e pelo consumo de água da edificação. Com base neste modelo, uma metodologia alternativa para o cálculo da TCR foi proposta, levando em conta a massa estimada de RSD e não a área construída da edificação.

Palavras-chave: taxa de coleta de RSD, caso de João Pessoa.

Introduction

This study deals with a matter in evidence in present days: solid waste. Domestic or residential solid waste (RSW) corresponds to a considerable part of urban solid waste (USW) from daily activities at household level. Food leftovers, deteriorating products, packing, magazines and bottles are a few examples of RSW. Governmental data (SNSA, 2012a) reports a generation rate of USW of 0.93 kg capita^{-1} day^{-1} as the mean value for Brazilian cities in the year 2010.

According to Dangi et al. (2008), few studies were carried out to characterize solid waste at household level (RSW), making available data for such type of waste scarcer than those for USW. Still according to these authors, the household approach also allows for consideration of socio-economic conditions, level of waste generation, geography and demography. In the city of Morelia, Mexico, according to Buenrostro et al. (2001), the generation rate specifically for residential source (RSW) was reported to be 0.629 kg capita^{-1} day^{-1} and represented 87% of USW generation.

For the solid waste collection, municipalities generally charge the population a waste collection tax (WCT). However, in Brazil, WCT is currently a deep issue, since it is calculated considering another factor instead of the real amount of waste generated in a given house, which is generally the constructed area, based on the premise that large families live in large houses, whereas small residences house only a few people. Because of this, it may happen that a larger house will be charged a high WCT while it will not necessarily have produced a larger amount of waste, which makes this tax unfair. Pickin (2008) emphasized that charging household waste collection per unit volume, weight or collection frequency, or even a combination of these parameters is becoming more popular.

This paper aims at proposing a mathematical model for the estimation of the amount (mass) of waste generated at household level, so that the estimated amount can be used for calculating the WCT instead of the constructed area of the house, for example, as is the case in João Pessoa, Paraíba State, Brazil.

Waste generation

Generation is the first and most important phase for a waste management system (DYSON; CHANG, 2005; TCHOBANOGLOUS et al., 1993). The amount of RSW generated is a function of the amount of people living in a given house, but it depends on other factors, such as eating habits, hygiene, wealth and education level of the population, as well as on the economic status (DANGI et al., 2008; TENÓRIO; ESPINOSA, 2004). A positive correlation (r^2 = 0.95) between RSW generation and the Gross Domestic Product in Hong Kong was reported (KO; POON, 2009), although these authors have stated that recycling practices may change such correlation.

Vicentini et al. (2009) have emphasized that estimating waste generation is important not only for charging purposes, but also for optimizing collection services. These authors proposed a sensorized container which could remotely send information on the amount of waste that is inside the container. Although interesting, cost aspects were not discussed in their paper. Vijay et al. (2008) proposed a GIS methodology for waste generation estimation in a given bin of waste collection, based on population density, income rate and waste generation rate. However, a mathematical model was not mentioned in their paper. Karadimas and Loumos (2008), based on the assumption that the municipal solid waste (MSW) generation rate in the city of Athens (Greece) is 1 kg capita $^{-1}$ day^{-1}, have estimated that the daily MSW generation rate may vary from 0.011 to 0.419 kg m^{-2} in the city, depending on the degree of commercial activity in residential areas.

Although the cases above reported (KARADIMAS; LOUMOS, 2008; VICENTINI et al., 2009; VIJAY et al., 2008) are more related to collection purposes, they show the importance currently given to the matter.

Afon and Okewole (2007) carried out a study in the city of Oyo, Nigeria, to estimate the amount of waste generated in the houses of the city. This study lasted 1 year and collected information on the socio-economic profile of 648 families through questionnaire. Subsequently, 2.5% of these families had their waste weighed for 1 week in each of the twelve months of the study. These authors elaborated a mathematical model to predict RSW generation in which the coefficient of determination was 0.888, significant at the level of 0.001. Six variables were identified as independent: household income, household size (population), educational background, social status, occupation and season of the year.

Waste estimation from consumption indicators

Slomp (1999) reports on a case study in the city of União da Vitória, located in the southeast region of Brazil, and the idea of charging waste collection based on water consumption was proposed. The premise for this was that the larger the population, the higher the water consumption and the higher the waste generation. Therefore, the relationship between waste generation and water consumption is indirect, through the population variable. Although no data collection or statistical analyses have been performed — in spite of being suggested by the author —, the idea was implemented in the city of União da Vitória.

The case of the city of Mairinque, located in the southeast region of Brazil and reported by D'Ella (2000), investigated a relationship between water consumption and waste generation. In this city, waste collection and water supply were managed by the same company, which made the study easier. Three sectors of water distribution were selected in the city and sectors of waste collection were set to match these sectors. Data were collected from July to September 1998. Results showed a ratio (kg of wastes m^{-3} of water) of 2.18, 1.96 and 1.88 in each of the three sectors studied. D'Ella (2000) concluded that there is a relationship between waste generation and water consumption. However, correlation analyses were not performed.

From the reported studies of Slomp (1999) and D'Ella (2000), it can be concluded that a relationship between waste generation and consumption indicators is possible. The relationship is not believed to be of cause-effect nature, but an indirect one, based on how intensely the population uses the house.

Material and methods

The study was conducted in the city of João Pessoa (07º06'57" South; 34º53'14" West), capital of the state of Paraíba, located in the Northeast region of Brazil (Figure 1), which had a population of 723.514 in 2010.

Figure 1. Location of the city of João Pessoa in Brazil.

Data were collected in three residential multi-family buildings (BA, BB and BD) and two residential single-family houses (HA and HB). All these apartments/houses were of medium-high socio-economic level. Wastes were weighed daily, at the same time every day, during the period of data collection, followed by water and electricity consumption readings. Electricity consumption readings were not possible in BA due to researcher restriction to the place the meters were installed. Population was also recorded on a daily basis. Data from these buildings are presented in Table 1.

Table 1. Details on the houses/buildings studied.

Building/ house	Number of apartments	Period of data collection		Number of days data were collected
		start	end	
BA	96	02/20/2005	05/14/2005	84
BB	13	07/04/2005	10/02/2005	84
BD	28	02/17/2006	05/11/2006	84
HA (1st period)	-	09/20/2007	12/12/2007	84
HA (2nd period)	-	05/18/2009	08/14/2009	89
HB	-	09/28/2009	03/31/2010	185

Data collected were analyzed through ANOVA according to the GT-2 graphic method (SOKAL; ROLHF, 2012) for simultaneous comparison of several means of unequal sample size at the significance level of 1%. In this procedure, the intervals that have not overlapped have means significantly different from each other.

Correlation analyses were also applied to collected data. Correlation does not imply causation. The relationship between two or more parameters can be direct or indirect, especially in a situation in which the majority are mutually associated (SOKAL; ROLHF, 2012). Researchers have to carefully select the potential causal relationships. The statistical technique known as stepwise multiple regression, although not entirely satisfactory (KINNEAR; GRAY, 1997), can be employed to overcome this problem. In such an approach, the independent variables are added to (or removed from) the model one at a time — the order of entry (or removal) being determined by statistical considerations —, until the changes in the coefficient of determination (r^2) are not significant at a specified level. In this procedure, variables that are considered to enter the regression as independent ones are tested for correlation and in case of any pair of them presenting a correlation coefficient significant at a specified level, only one of the variables of such pair will remain in the model, because, in fact, they are not independent as previously assumed to be.

For mathematical modelling of RSW generation, the stepwise multiple regression method (KINNEAR; GRAY, 1997) was employed, at the significance level of 1%.

Results and discussion

The Table 2 lists central tendency measures (arithmetic mean, median and mode) for the population and arithmetic mean for RSW generation, water consumption and electricity consumption for the houses/buildings studied. Total (mode) population related to this study amounted 464 people.

Table 2. Descriptive statistics for population, mass of RSW, water consumption and electricity consumption.

Building/ house	Central tendency measure for population (capita)			Mass of RSW generated (AM)		Water consumption (AM)		Electricity consumption (AM)	
	AM	ME	MO	kg day^{-1}	kg cap^{-1} day^{-1}	m^3 day^{-1}	m^3 cap^{-1} day^{-1}	kWh day^{-1}	kWh cap^{-1} day^{-1}
BA	321.8	323	323	163.4	0.508	62.17	0.193	NM	NM
BB	37.4	37	37	19.7	0.527	10.61	0.284	85.0	2.27
BD	89.8	91	91	48.6	0.541	24.31	0.270	254.4	2.83
HA	6.57	7	7	5.2	0.797	1.09	0.166	16.2	2.47
HB	5.55	6	6	4.4	0.792	0.70	0.126	14.1	2.54

AM: arithmetic mean; ME: median; MO: mode; NM: not measured.

The RSW per capita generation rate found varied from 0.508 to 0.797 kg capita^{-1} day^{-1}. These figures are close to that for RSW reported by Buenrostro et al. (2001) of 0.629 kg capita^{-1} day^{-1} and to the value reported by SNSA (2012a) for USW relatively to the year 2010 for Brazilian cities with population in the range 250001 – 1000000 inhabitants, as is the case of João Pessoa, which was 0.90 kg capita^{-1} day^{-1}. It must be noted that SNSA (2012a) reports on USW, which is the sum of RSW and those from public areas collection.

SNSA (2012b) mentioned that the mean water consumption in the Brazilian cities, relative to the year 2010, was 0.159 m^3 capita^{-1} day^{-1}, while to the cities in the State of Paraíba was 0.111 m^3 capita^{-1} day^{-1}. According to EPE (2012), the residential consumption of electricity in Brazil was 1.59 kW capita^{-1} day^{-1}, relative to the year 2011.

The higher values herein found for water (0.126 – 0.284 m^3 capita^{-1} day^{-1}) and electricity (2.27 – 2.83 kW capita^{-1} day^{-1}) consumption as compared to those reported by SNSA (2012b) and EPE (2012), can be explained by the medium-high economic level of the population analyzed in this present study.

Figure 2 illustrates the simultaneous comparison for the means of RSW generation rate at BA, BB, BD, HA and HB. Means for BA, BB and BD were not different from each other. The same occurred for the means of HA and HB. On the other hand, any mean from the multi-family building group has differed significantly from any mean from the house group.

If the whole dataset from each group (multi-family buildings and single-family residences) is considered, the mean for RSW generation rate for apartments was 0.526 kg capita^{-1} day^{-1}, against 0.794 kg capita^{-1} day^{-1} for houses. ANOVA test evidenced significant difference at the level of 1%.

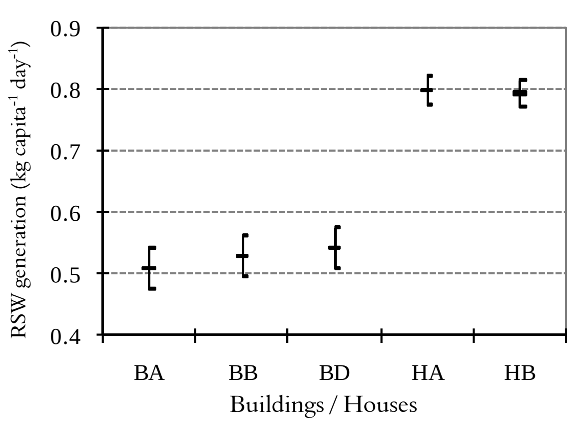

Figure 2. 99% confidence comparison intervals by the GT-2 method.

These results provided sufficient evidence that the relative amount of RSW generated in houses is significantly higher (1.51 times) than in apartments. The presence of gardens and backyards (associated with the generation of RSW in the form of leaves) in houses, but not in multi-family buildings (apartments) may contribute to this difference.

Table 3 shows correlation coefficients between RSW generation and water consumption and between RSW generation and electricity consumption, on a daily basis, for all the 5 cases of buildings/houses studied (BA, BB, BD, HA and HB) and for the 2 cases of whole data collected in each of the groups of buildings and houses, totaling a total of 7 cases.

Correlation coefficients between RSW and water consumption varied from moderate (0.523) to very high (0.960) and were significant at the level of 0.1%. Correlation coefficients between RSW and electricity consumption varied from very low (0.170) to high (0.875) and some of them were significant at 0.1%. The correlation coefficients between RSW generation and electricity consumption were always lower than the respective between RSW generation and water consumption.

Table 3. Coefficients of correlation, sample size and statistical level of significance.

	Building/house	Correlation coefficient	Sample size	Statistical level of significance
RSW and water consumption	BA	0.566	60	≤ 0.001
	BB	0.620	56	≤ 0.001
	BD	0.523	83	≤ 0.001
	whole data for BA, BB and BD	0.960	199	≤ 0.001
	HA	0.751	171	≤ 0.001
	HB	0.783	184	≤ 0.001
	whole data for HA and HB	0.736	355	≤ 0.001
RSW and electricity consumption	BB	0.189	56	0.091
	BD	0.430	83	≤ 0.001
	whole data for BA and BD	0.875	139	≤ 0.001
	HA	0.170	171	0.026
	HB	0.616	184	≤ 0.001
	whole data for HA and HB	0.410	355	≤ 0.001

Figures 3 and 4 are scatter plots for the whole data collected in the buildings (Figure 3) and in the houses (Figure 4) for RSW generation and water consumption. It is not difficult to accept that there is no cause-effect relationship between RSW generation and water consumption. However, a third factor, namely, how intensely the population uses the house, may account for these correlation coefficients. These results confirm the assumptions made by Slomp (1999) of a possible correlation between RSW generation and water consumption.

Figures 5 and 6 are scatter plots for the whole data collected in the buildings (Figure 5) and in the houses (Figure 6), for RSW generation and electricity consumption.

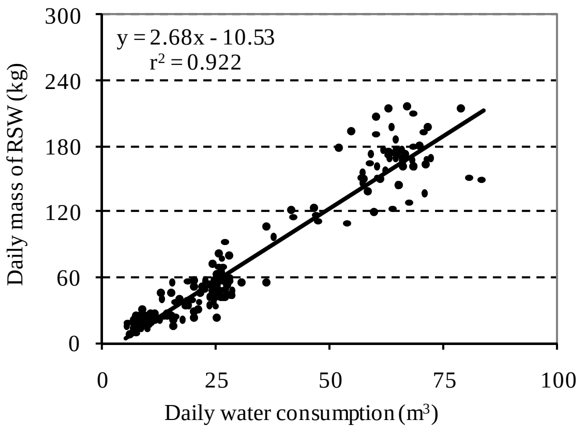

Figure 3. Scatter plot of mass of RSW generated and water consumption for BA, BB and BD.

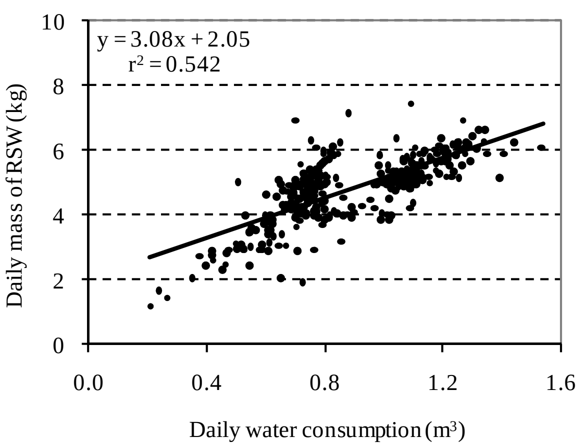

Figure 4. Scatter plot of mass of RSW generated and water consumption for HA and HB.

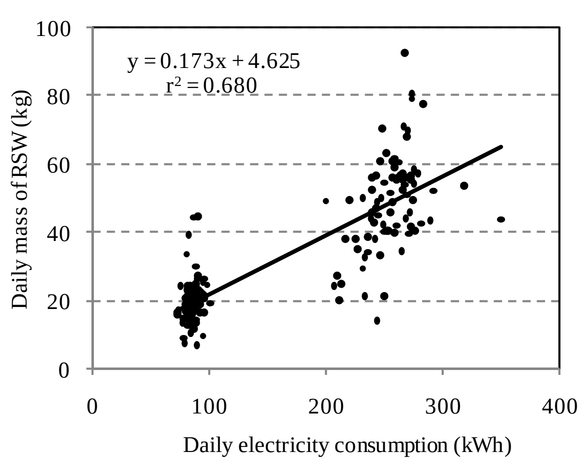

Figure 5. Scatter plot of mass of RSW generated and electricity consumption for BB and BD.

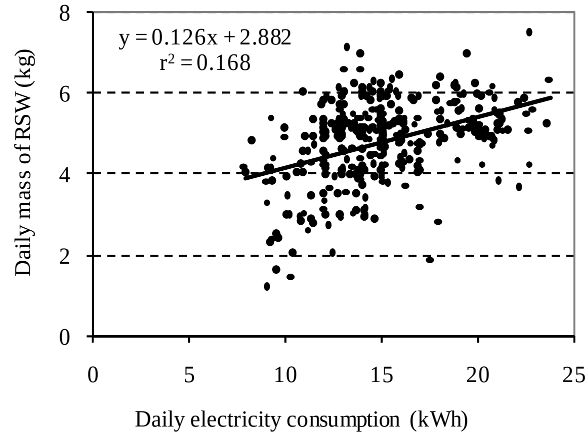

Figure 6. Scatter plot of mass of RSW generated and electricity consumption for HA and HB.

Waste generation estimation

The Table 4 shows regression coefficients and coefficient of determination (r^2) for each house/building studied and for the whole data for the group of BA, BB and BD and for the group of HA and HB. These coefficients resulted from the stepwise multiple regression technique. The water consumption remained in the model in all the seven possible cases studied. Subsequently, the population remained in the model in five out of seven possible cases. Electricity consumption remained in the model only in one out of six possible studied cases. If the whole data from the groups of buildings and the group of houses are considered, only population and water consumption remained in the model and Eq. (1) and Eq. (2) were proposed for them.

The reason why the variable 'electricity consumption' was excluded of the model in five out of six possible cases was due to a significant correlation between it and either the variable 'water consumption' or 'population' detected by the stepwise multiple regression technique. Importantly, the correlation coefficient between RSW generation and electricity consumption were always lower than the respective between RSW generation and water consumption.

Table 4. Regression coefficients and respective coefficients of determination (r^2).

Building/house	Population (capita)	Water consump. (m^3 day^{-1})	Electricity consump. (kWh day^{-1})	Constant term	r^2
BA	-	1.73	-	52.832	0.320
BB	-	0.84	-	10.802	0.108
BD	2.645	1.63	-	-228.235	0.344
whole data for BA, BB and BD	0.204	1.62	-	-6.527	0.935
HA	0.374	2.58	-	-0.045	0.652
HB	0.357	3.14	0.075	-0.845	0.659
whole data for HA and HB	0.559	1.19	-	0.361	0.666

$$MRSW_A = 0.204POP + 1.62WC - 6.527 \quad (r^2 = 0.935) \quad (1)$$

$$MRSW_H = 0.558POP + 1.19WC + 0.367 \quad (r^2 = 0.666) \quad (2)$$

where:

$MRSW_A$: mass of residential solid wastes generated in apartments (kg day^{-1})

$MRSW_H$: mass of residential solid wastes generated in houses (kg day^{-1})

POP: population of the residence (capita)

WC: water consumption (m^3 day^{-1})

Concluding from these models, the waste generation can be estimated from the population size and the respective water consumption. Although water consumption is a function of population, it may reflect how intensely the population uses the house.

The case of the WCT in the city of João Pessoa

Nowadays, in João Pessoa, the WCT is based on 'Lei Complementar' 16/98 (PMJP, 1998). The annual value for this tax in João Pessoa is calculated by the Equation (3). The values for the *Fe* (waste generation factor) are those in Table 5 (PMJP, 1998), based on the constructed area of the building.

$$WCT = \{[(F_p + F_d) x U_i] x F_e\} x (12) \quad (3)$$

where:

Fp - Factor of periodicity of waste collection;

Fd - Factor of distance (to the landfill site);

Ui - Factor of utilization of the building (residential, commercial, services, industrial);

Fe - Factor of waste generation.

Table 5. Factor *Fe* of waste generation according to the constructed area of the building (currently used) and according to estimated mass of RSW (proposed).

Constructed area (m^2) (currently used)	*Fe* (currently used)	Mass of RSW (kg $month^{-1}$) (proposed in this article)
0.01-25	0.1290	0.01 - 12.5
26-50	0.2166	12.6-25.0
51-75	0.5314	25.1-37.5
76-100	0.6924	37.6-50
101-150	0.9279	50.1-75
151-200	1.3754	75.1-100
201-250	2.0359	100.1-125
251-300	2.6869	125.1-150
301-350	3.3698	150.1-175
351-400	4.1084	175.1-200
401-450	4.6352	200.1-225
450-500	5.5857	225.1-250

In Table 5, the first range for the constructed area of the building is 0.01 – 25 m^2, simulating very small houses, while the last one is 450 – 500 m^2, simulating very large houses or a multi-family building. Above 500 m^2, for each 100 m^2 of constructed area, 0.82 is added to the *Fe*.

In Table 5, the factor *Fe* is also associated with RSW ranges (proposed in this paper). In order to set equivalence between the ranges of constructed area and those for RSW mass, it was considered that a very large house of 500 m^2 (or an area equivalent to a multi-family building) would generate about 250 kg $month^{-1}$ of RSW. The limits of the other ranges were calculated proportionally.

By applying the models (Equations 1 and 2) herein proposed for RSW estimation for a given residence or multi-family building, it becomes possible to find the *Fe* according to the estimated amount of RSW (Table 5) and then apply it to the WCT calculation (Equation 3).

Although water consumption, used in the models, is a function of the population, with which the constructed area may also be associated, the first variable may provide an idea of how intensely the population uses the house, which is not expected from the constructed area of the residence.

Conclusion

A strong correlation was found between RSW generation and water consumption. Although the relationship between RSW generation and water consumption might not be a cause-effect one, a third factor, namely, how intensely the population uses the house, may account for the correlation coefficients between these variables found in this study. The RSW generation can be estimated from population and water consumption in the residence, so that the WCT can be calculated based on the estimated amount of waste rather than the constructed area of the residence, as is the case of the city of João Pessoa.

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