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Preliminary Developing A Mathematical Model for Estimating Household Solid Waste Generation Rate: The Case of Ho Chi Minh City, Vietnam

Le Minh Truong, Tran Thu Trang and Tran Thi My Dieu†
Department of Environmental Technology and Management, Van Lang University, 45 Nguyen Khac Nhu Street, Co Giang Ward, District 1, Ho Chi Minh City, Vietnam
†Corresponding author: Tran Thi My Dieu

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ABSTRACT

Solid waste generation rate plays an important role in calculation and design different elements of a municipal solid waste management system of an urban area. The survey was carried out at 644 households living in 6 selected wards of 6 districts in Ho Chi Minh City (HCMC) that have different population densities to determine generation rates and main composition (food refuses and plastic bags) in domestic solid waste. Composition of household solid waste of HCMC determined from this study will help to develop a model to predict solid waste generation rate in the future. It is also found from the study that, in 2015 household solid waste generation rate of HCMC is 0.41 kg/capita/day (SD = 0.313), food refuse generation rate is 0.23 kg/capita/day, plastic bag generation rate is 0.032 kg/capita/day, and percentages of food refuses and plastic bags in domestic solid wastes of HCMC are 61.63% and 7.67%, respectively. Statistical data indicate that generation rates of household solid waste, food refuses, and plastic bags are inversely proportional to the number of people in a family and directly proportional to the household income. The rank correlation shows no significance between the household solid waste generation rates and the urbanization levels as well as between household solid waste generation rates and days of a week. A linear regression model proposed to determine generation rates of household solid waste, household food refuse, and household plastic bags shows that household size and household income explain only 14.2% of solid waste generation rate (R^2 = 0.142) and 11.9% of plastic bag generation rate (R^2 = 0.119). Generation rate of food refuse (within the scope of this study) can only be estimated based on household size (R^2 = 0.08).

INTRODUCTION

With more than 2 million households; 10 thousand hotels, restaurants, guesthouses; hundreds of education centres; hundreds of healthcare centres, more than 10 thousand clinics and about 12 thousand industrial enterprises, total amount of household solid waste (HSW) generated in Ho Chi Minh City (HCMC) is in the range of 10,000-11,000 tons/day (DONRE 2013). Of which, the amount of solid waste generated from residential areas, commercial areas, offices, schools, canteens of enterprises and industrial zones, non-infected medical centres is about 9,000 tons/day, and about 6,400-7,200 tons/day (equivalent to 2.34-2.64 million tons/year) is collected, the remaining is separated, traded and reused or recycled (Dieu et al. 2014).

In recent years, though a great effort has been put on development and implementation of different policies (socialization and investment incentive), infrastructure investments (of solid waste transfer stations, solid waste treatment complexes), capacity building and administrative management structure as well, there have been big challenges for HCMC to fulfil the strategy of integrated solid waste management of 2015 with a vision of 2025, promulgated by Vietnamese Prime Minister, especially about solid waste separation at sources, reducing waste to landfill and management of private solid waste collection system (Viet 2013).

Researches on public health and environmental sanitation related to solid waste have shown that ineffective and non-scientific management of solid waste at landfills will attract birds and rodents, create unsanitary environment, cause nuisance, disperse air-born diseases, and emit greenhouse gases. Therefore, effective solid waste management tools are necessary to minimize the above mentioned negative impacts, and evaluation of characteristics and generation rate of solid waste is one of the important initial step towards an effective solid waste management (Gidarakos et al. 2006, Medina 2000, Qu et al. 2009, Thanh et al. 2010). In addition, Suthar et al. (2015) identified that quantity and characteristics of municipal solid waste are indicators of sustainable development of urban areas as well as social - economic conditions of society and household. High reliability solid waste management parameters will be efficient supporting tools for assessment and selection of effective management alternatives of solid waste management programs (Qdais et al. 1997, Chang & Davila 2008, Hancs et al. 2011). In fact, collection, updation and management of statistical data on solid waste management, however, are usually insufficient, especially in developing countries (Buenrostro et al. 2001). In the case where data are available, it might be contradictory because of being gathered from different sources or measured by different methods or instruments (IPCC 2006, Couth & Trois 2011, Ranjith 2012). One of the most significant influences of this problem is opportunities of investment in solid waste management (Miezah et al. 2015). Lack of data on solid waste generation rate and composition leads to difficulties on determination of solid waste collection routes and incomplete collection of solid waste generated from areas which differ from social-economic conditions. So far, several researches have been carried out to estimate solid waste generation rate, composition and characteristics. Gu et al. (2015) used a multiple linear regression model to estimate solid waste generation rate from 240 households living in Suzhou, the East region of China, during different seasons in 2011 and 2012 as well as evaluating opportunities and predicting benefits of solid waste reuse from the households. Two important conclusions withdrawn from the research of Gu et al. (2015) include (1) solid waste generation rate of household is 208.5 g/capita/day, of which, 89.3% is recyclable and compostable materials and (2) educational level is a key factor that influences on solid waste generation rate. A study of Miezah et al. (2015) on evaluation of generation rate, composition and efficiency of waste separation at sources in Ghana shows that solid waste generation rate is 0.47 kg/capita/day, of which biodegradable solid waste is 0.318 kg/capita/day, non-biodegradable and reusable material is 0.096 kg/capita/day, and the remaining is 0.055 kg/capita/day. The highest value of solid waste generation rate is found from households living in the capital of the country (0.63 kg/capita/day), lower values are from households living in urban areas (0.40 kg/capita/day) and lowest values are from households living in undeveloped areas (0.28 kg/capita/day). Suthar et al. (2015) reported that the solid waste composition is an important parameter to develop an effective solid waste management system for an urban area. A research on solid waste generation rate and composition from 144 households living in different social-economic conditions in Dehradun, India indicates that solid waste generation rates vary in a large range from 24.5 g/household/day to 4147.1 g/household/day with a mean value of 267.17 g/household/day (SD = 38.13) and more than 80% of food refuses were found in the household solid waste. Dennison et al. (1996a) presented that precision data on solid waste generation rate plays an important role in management of solid waste management infrastructure. A study in Dublin, Ireland showed that solid waste generation rate reduced from 0.69 kg/capita/day in 1970s to 0.53 kg/capita/day in 1996. In other words, continuously updating data on solid waste generation rate as well as estimating solid waste generation rate based on changes in social-economic conditions is essential for waste management. Benitez et al. (2008) has developed a mathematical model to estimate domestic solid waste generation rate of Mexican City by determining variables as education level, household income, and household size. A linear and multiple regression model has been developed for each variable to describe the influences of proposed variables. It is found from this research that education level, household size and household income are significant factors affecting HSW generation rate. The multiple linear regression model accounting for all these variables reached highest R^2 value of 0.51. Thanh et al. (2010) also developed a multiple linear regression model to estimate solid waste generation rate in Can Tho, Vietnam. Results from surveying 100 households during rainy season and dry season indicate that solid waste generation rate in Can Tho was 285.3 g/capita/day, and 80% compostable materials and 11.7% recyclable materials were found in household solid waste composition. The multiple linear regression model of Thanh et al. (2010) also showed that household income and house-hold size influence the generation rate of commingle solid waste and food refuses from households. R^2 values of commingle solid waste and food refuses are 0.361 and 0.374, respectively. In HCMC, Vietnam, it is found from the research of Dieu et al. (2014) that solid waste generation rate from households living in District 1 was in the range of 0.53 -0.63 kg/capita/day. The composition of the separated food waste comprises about 80.1%-90.0% of biodegradable food refuse. So far, very few researches on methods estimating solid waste generation rate in HCMC have been published. In order to contribute to effective management of solid waste in HCMC, Vietnam, this study aims at: (1) determining generation rate of commingle waste, food refuses and plastic bags in HSW in HCMC; (2) developing a multiple linear regression model to estimate the generation rate of solid waste, food refuses and plastic bags in HCMC; (3) assessing factors that influence the generation rate of solid waste, food refuses and plastic bags from households, including population density, household size, household income and days of a week.

MATERIALS AND METHODS

Sampling network: With total area of 2,095 km^2, of which 494.01 km^2 is urban area, 19 central districts and 5 suburban districts, population of 7.97 million people (2014), HCMC is considered as a key administrative economic centre in the southern region of Vietnam (Thanh et al. 2016). In the large area as HCMC, selection of sampling network plays an important role in ensuring representation of the research results. The studied locations were selected to ensure that sampling locations are distributed in the whole city, and represent the different social-economic characteristics of different districts in HCMC. Thanh et al. (2010) indicated that population density can be used as an indicator of urbanization level. Statistical data of HCMC (HCMC Statistical Office 2014) provided that it is possible to classify central districts of HCMC into different areas based on population density as follows: less than 5,000 person/km^2, 5,000-15,000 person/km^2, 15,000-25,000 person/km^2 and more than 25,000 person/km^2. In the other words, it is possible to classify the districts in HCMC into 4 groups: (1) District 1 and District 9 represent the area with population density of 2,495-2,823 persons/km^2; (2) District 7, District 12, Thu Duc District, Binh Tan District represent the area with population density in the range of 7,866-12,628 persons/km^2; (3) District 1, District 8, Tan Binh District, Tan Phu District represent the area with population density in the range of 19,797-27,932 persons/km^2; and (4) District 3, District 4, District 6, District 10, District 11, Phu Nhuan District represent the area with population density in the range of 36,979-44,452 persons/km^2. For each group, one or two districts were selected for carrying out field surveys. Districts chosen for surveying and sampling were District 9 (represented to group 1), District 7 (represented to group 2), District 1 (represented to group 3) and District 10 (represented to group 4). Besides, Binh Thanh District (belonged to group 3) and District 5 (belonged to group 4) were also selected for surveying and sampling because these two Districts participated in "Plastic bag reduction" program organized by HCMC Environmental Protection Fund. Results on composition of household solid waste generated in these districts were used to assess the influence of propaganda and training program on reduction in usage of plastic bags, in comparison to other Districts.

There are 83 wards of 6 selected districts. For each selected district, a ward is selected by the percentile rank of the population density, 10th; 30th; 35th; 50th; 60th and 80th percentiles, respectively, which defined 6 levels as: level I correlates to percentile of 10th and population density of 1,803 persons/km^2; level II correlates to percentile of 30th and population density of 14,500 persons/km^2; level III correlates to percentile of 35th and population density of 17,323 persons/km^2; level IV correlates to percentile of 50th and population density of 33,444 persons/km^2; level V correlates to percentile of 60th and population density of 40,956 persons/km^2, and level VI correlates to percentile of 80th and population density of 49,996 persons/km^2. Calculated results are described in Table 1. At each ward, 25 households are chosen for delivering plastic bags to collect solid waste samples and for gathering related information. Thus, total samples needed to be collected for each time of survey were 25 households/ward × 6 wards = 150 households. In order to avoid insufficient number of samples needed, in case some households received sampling bags but did not separate solid waste at source, actual number of households surveyed were 162 households (27 households/wards × 6 wards). The surveying and sampling was conducted for 2 working days of a week, also on Saturday and Sunday. Therefore, total number of samples are 648 samples [(162 samples/day × 2 days)$_{\text{working days}}$ + (162 samples/day × 1 day) Saturday + (162 samples/day × 1 day) Sunday]. Besides, in order to avoid concentration of sample locations in some places, in the same street of the same ward, samples were taken from maximum 5 households. Surveyed streets of each ward of each selected district were randomly chosen. Selected wards for surveying are described in Table 1.

Survey procedure: For each household, two different colour plastic bags were delivered, of which the blue one was for food waste (food refuse, fruit peel, bulb peel, fish intestine, shrimp cover, etc.) and the red one was for other wastes. The sample bags were labelled with detailed information about household, including: (1) district name; (2) street name; (3) number and (4) sampling date. In fact, there are several households not following the sampling requirements. Hence, 14 plastic bags (7 blue bags and 7 red bags) were randomly delivered to 7 households in 2 working-days of a week, from 8:30-10:30, and sample bags were collected at the same time next day. In order to assess the

Table 1: Sampling locations.

Urbanization level	Ward (District)	Area (km^2)	Population density (persons/km^2)	Percentile
I	Ben Thanh (District 1)	1,677	1,803	13.3th
II	Hiep Phu (District 9)	32,479	14,500	28.9th
III	Ward No. 25 (Binh Thanh District)	31,875	17,323	34.9th
IV	Tan Kieng (District 7)	33,444	33,444	49.4th
V	Ward No. 3 (District 5)	7,372	40,956	62.7th
VI	Ward No. 13 (District 10)	23,498	49,996	78.3th

difference in quantity and composition of waste between weekdays (Monday to Friday) and weekends (Saturday and Sunday), the sample bags were delivered on Saturday and Sunday and collected on the day after as well. The plastic bags are distributed right after the collection of city crew and before the time when they come next day. After transferring the bags, the necessary information to carry out the mathematical modelling for estimating HSW generation are: (1) household size and (2) household income. Two sample bags from each household (food waste and other wastes) is tied together and analysed in laboratory within the day.

Mathematical modelling for household solid waste generation in Ho Chi Minh City: The mathematical modelling for estimating HSW generation in HCMC is developed based on the analytical database of solid waste quantity and composition from household survey. It can be seen that solid waste generation rate depends on two factors of household size and household income (Ojeda et al. 2008). In this study, a multi-variable regression model also aimed at estimating the generation of solid waste per resident in HCMC by two variables as mentioned above. The variables and methods to identify variables are given in Table 2. The model of multi-variables linear regression is represented as follows:

$$Y_j=\alpha+\beta_1X_{hh}+\beta_2X_{inc}+\varepsilon$$

Where, α is the intercept and it indicates the mean value of the response variable when = 0; βj is the slope and it indicates the average change in the response variable, when the random variable rise, ε is the term of the average random error.

Analytical procedure: Solid waste amount and composition were analysed at the ambient laboratory by using analytical balance (accuracy of 100 g for solid waste and 0.01 g for plastic bag). The statistical analysis and multi-variables linear regression were analysed by SPSS ver.22.0 software (T-test, ANOVA, single-multi linear regression analysis).

RESULTS AND DISCUSSION

Waste Generation Rate in Ho Chi Minh City

644 households were selected to identify the composition and generation rate in Ho Chi Minh City (except for centralized generation sources as enterprises, facilities, hospitals and schools, etc.). Based on the analysis, the results indicate a wide range of HSW generation, ranging from 0.1 kg/capita/day (minimum) to 1.47 kg/capita/day (maximum).

In average, the waste generation is 0.41 kg/capita/day (SD = 0.313) (Fig. 1). Transferring to normal distribution, at 95% confidence interval of the difference, the generation rate is 0.39-0.43 kg/capita/day. This number is lower in comparison with the generation rate analysed by Dieu et al. (2014), the average HSW generation rate was 0.60 kg/capita/day which ranged from 0.53-0.63 kg/capita/day, due to two main reasons: (1) only 90 households in Dieu's study are selected to survey and almost located in central district with resident's income as uniform and higher than other areas and (2) Dieu'study assumed that the average household size is 4 members. This study, in fact measured that the household size ranges from 1 member/household to more than 8

Table 2: Variables definition.

Variables	Symbol	Unit	Definition
Household size	X_{HHS}	Persons/household	Number of members per household
Household income	X_{inc}	VND/person.household	Total income of all members divided by the total member of household
Generation rate	Y_j	kg/capital.day	Solid waste production per capita per day

Table 3: Waste composition and generation rate in Ho Chi Minh City.

	Min - Max	SD	Mean	95% confidence interval of the difference	References
Total waste generation (kg/capita/day)	0.10-1.47	0.313	0.41	0.39-0.43	This study 2015
	0.43-0.75	-	0.6	0.53-0.63	Dieu et al. (2014)
	-	-	0.28	0.15-0.3	Thanh et al. (2010)
Food waste(kg/capita/day)	0.00-1.25	0.216	0.23	0.22-0.25	This study (2015)
	-	-	-	0.25-0.34	Dieu et al. (2014)
	-	-	0.228	-	Thanh et al. (2010)
Plastic bag(kg/capita/day)	0.00-0.38	0.033	0.032	0.030-0.034	This study (2015)
	-	-	-	0.0243-0.0364	Dieu et al. (2014)
	-	-	$8.55.10^{-3}$-$9.067.10^{-3}$	-	Thanh et al. (2010)

member/household. By contrast, the amount of waste in Can Tho City, 0.28 kg/capita/day, (Thanh et al. 2010) is lower than that of this study (Table 3), and it might be due to GDP-an index playing a significant role in the difference of waste generation rates (Xu et al. 2013). Apparently, the GDP value of Can Tho City was 2800 USD/capita/year which is lower than GDP of Ho Chi Minh City (HCMC) with 5100 USD/ capita/year. Hence, it is possible to say that the solid waste generation rate not only depends on the GDP per capita but also other factors (Gu et al. 2015). The GDP of Beijing, Mexicali and Dublin is higher than that of HCMC, whereas the waste generation rate is lower or almost similar to HCMC (Table 4).

The food waste generation rate fluctuated dramatically, from 0.00-1.25 kg/capita/day with the average of 0.23 kg/ capita/day (Fig. 2). Similarly, in normal distribution, the generation rate is 0.22-0.25 kg/capita/day ranked the highest frequency. In terms of plastic bag, the generation rate averages at 0.032 kg/capita/day (Fig. 3), whereas, in normal distribution with 95% confidence interval of the difference, the generation rate is 0.030-0.034 kg/capita/day. The food waste amount of HCMC stays almost the same in several studies (Dieu et al. 2014 and Thanh et al. 2010) while the plastic bag quantity in Can Tho City is lower.

On the other hand, the rate between food waste and total waste in this study is 61.63% (SD = 22.79). This result almost resemble to Dieu's study (68.8%) but smaller than that of Thanh's study (77.31% in dry season and 78.19% in rainy season). In addition, the mass of plastic bag per total solid waste is 7.67% (frequency distribution in range of 7.30 and 8.07%) higher than these rates of Dieu et al. (2014), 4.8%, and Thanh et al. (2010), 3.02% in dry season and 3.15% in rainy season, (Table 3). This result points out that there is a significant difference in waste generation between HCMC and Can Tho. The food to total waste ratio in Ho Chi Minh is lower than that of Can Tho, whereas the plastic bag to total waste ratio in Can Tho is lower than that of HCMC. Can Tho is a city integrated with urban and rural areas resulting in lower waste generation rate when compared with HCMC. This point of view is similar to Miezah's study (2015), the waste generation rate in developed areas is higher and vice versa. There is a large amount of food waste in the waste composition of urban-rural combined area due to the habit of residents, they often buy raw material while in urban area, and higher income people often buy fabricated food in supermarkets. Besides, the standard deviation of total waste, food waste and plastic bag generation rate is relatively high because of large sample size (644 households).

Factors Affecting Household Solid Waste Generation Rate

HSW generation between weekday and weekend: Table 5 and Fig. 4(a) present results of household waste generation rate among days of week. It can be seen that the largest quantity of total waste and food waste were both produced at weekends (0.44 and 0.29 kg/capita/day), but comparing to weekdays (0.42 and 0.26 kg/capita/day), the difference is not significant. By contrast, the generation rate of plastic bag on weekdays is higher than at weekends (0.039 and 0.036 kg/capita/day, respectively). Likewise, the total waste and food waste generation rate from Thanh et al. (2010) was

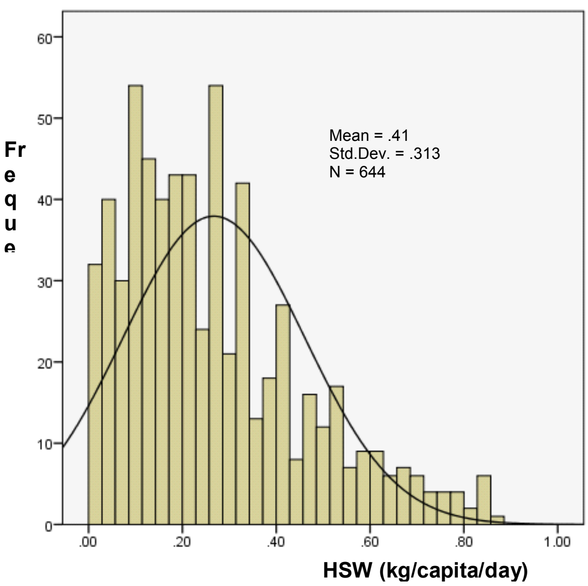

Fig. 1: Distribution frequency of HSW generation in HCMC.

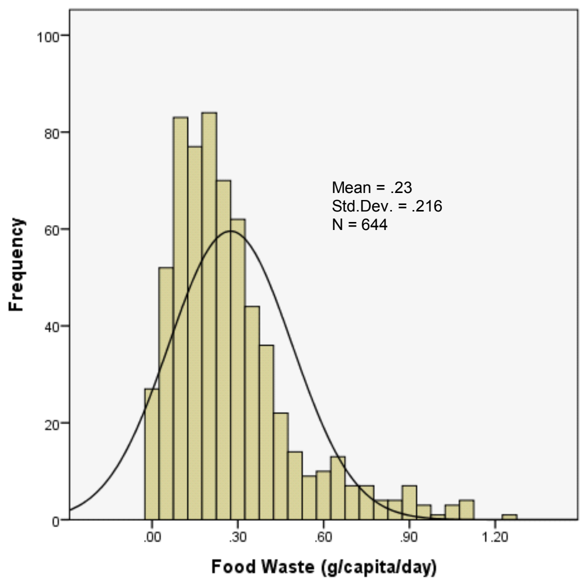

Fig. 2: Distribution frequency of household food waste generation rate in HCMC.

0.31 and 0.26 kg/capita/day and the rate of weekend is higher than its weekday that can be explained by living characteristic of HCMC residents. On weekdays, almost all members are in their offices, factories, companies and schools, only children and old/retired people are at home. Solid waste is only produced in the evening after they come back home. The residents often spend weekends together that results in the larger solid waste generation rate. Besides, several households are in the habit of buying and preliminary treating food at the weekends to preparing for next week, hence it leads to the increase in HSW at weekends. However, the plastic bags generation is higher on weekdays compared to weekends due to the habit of using cooked speciality and plastic bags. On the weekend, people do not buy the cooked

Table 4: GDP and waste generation rate in comparison with different studies.

	Studied area	Average(kg/capita/day)	GDP(USD/capita.year)	References
Total waste	Ho Chi Minh, Vietnam	0.41	5100	This study (2015)
	Can Tho, Vietnam	0.28	2800	Thanh et al. (2010)
	Mexicali, Mexico	0.59	14300	Benitez et al. (2013)
	Beijing, China	0.23	6000	Qu et al. (2009)
	Dublin, Ireland	0.53	45500	Denninson et al. (1996b)

Table 5: Waste generation rate between weekday and weekend.

Parameter	Sample size	Total waste		Food waste		Plastic bag	
		Mean	SD	Mean	SD	Mean	SD
Weekdays	319	0.4223	0.27720	0.2605	0.20093	0.0385	0.03353
Weekends	325	0.4422	0.28822	0.2876	0.22870	0.0362	0.03271
Sig.		0.372		0.111		0.377	

Table 6: Waste generation rate from different household size.

Parameter	Sample size	Total waste		Food waste		Plastic bag	
		Mean (kg.capita^{-1}.day^{-1})	r	Mean (kg.capita^{-1}.day^{-1})	r	Mean (kg.capita^{-1}.day^{-1})	r
1-2 members	64	0.7019	-0.368*	0.4205	-0.278*	0.0684	-0.339*
3-4 members	275	0.4695		0.2993		0.0405	
5-7 members	260	0.3470		0.2263		0.0283	
>8 members	45	0.3144		0.1891		0.0256	

*Use the Spearman's correlation factor at significant level of 0.01

Table 7: Multiple comparisons between waste generation rate and household size.

Household size - I	Household size - J	Total waste Mean of difference (I-J)	Sig.	Food waste Mean of difference (I-J)	Sig.	Plastic bag Mean of difference (I-J)	Sig.
1-2 member	3-4 member	0.23242*	0.000	0.12116*	0.010	0.02793*	0.002
	5-7 member	0.35484*	0.000	0.19416*	0.000	0.04017*	0.000
	>8 member	0.38743*	0.000	0.23136*	0.000	0.04288*	0.000
3-4 member	1-2 member	-0.23242*	0.000	-0.12116*	0.010	-0.02793*	0.002
	5-7 member	0.12242*	0.000	0.07300*	0.000	0.01224*	0.000
	> 8 member	0.15501*	0.000	0.11020*	0.000	0.01495*	0.000
5-7 member	1-2 member	-0.35484*	0.000	-0.19416*	0.000	-0.04017*	0.000
	3-4 member	-0.12242*	0.000	-0.07300*	0.000	-0.01224*	0.000
	> 8 member	0.03259	0.851	0.03720	0.483	0.00271	0.951
> 8 member	1-2 member	-0.38743*	0.000	-0.23136*	0.000	-0.04288*	0.000
	3-4 member	-0.15501*	0.000	-0.11020*	0.000	-0.01495*	0.000
	5-7 member	-0.03259	0.851	-0.03720	0.483	-0.00271	0.951

*The mean difference is significant at the 0.05 level speciality so the amount of plastic bags reduces. In term of statistics, the difference of total waste, food waste and plastic bag generation rate between weekdays and weekend is not significant (p>0.05) and look similar to Qu et al. (2009). The standard deviation is large, meaning that there is unequal amount of waste quantity among different households, which is also showed in other studies (Thanh et al. 2010, Suthar 2015).

Difference of HSW generation in household size: In order to evaluate the influence of household size on waste generation rate, household size was classified into 4 categories which are (1) 1-2 members; (2) 3-4 members; (3) 5- 7 members and (4) 8 members and more. Household solid waste generation rate at different household size is illustrated in Fig. 4(b). The mean values of total solid waste, food waste and plastic bag generation rate are summarized in Table 6. It is apparent that almost all households in HCMC has 3-7 residents in which 275/644 households and 260/644 household are in the size of 3-4 residents and 5-7 residents, respectively. In addition, the results indicate that the generation rate of total waste, food waste and plastic bag from 1-2 household size are higher than 3 and more household size (accounted for 0.70; 0.42 and 0.06 kg/resident/day, respectively). The ANOVA results represented significant differences in total waste, food waste and plastic bag generation rate between 4 categories (p<0.05). However, there is no significant distinction between household in the size of 5-7 members and 8 members and more (p>0.05) (Table 7).

It can be seen that the household solid waste generation rate is inversely proportional to household size. The smaller the household is, the larger the waste generation rate is. These data are adequate to correlation statistical analysis between household size and waste generation rate. Also, similar phenomenon was found in other studies (Thanh et al. 2010, Dennison et al. 1996b, Bandara et al. 2007, Qu et al. 2009). The result of correlation analysis is presented in Table 6.

Difference of household solid waste generation in household income: Household income was divided into five groups to evaluate the influence of household income on waste generation rate, named (1) under 5 million VND/month.household; (2) 5-10 million VND/month.household; (3) 10-15 million VND/month.household; (4) 15-20 million VND/month.household and (5) more than 20 million VND/month.household with the waste generation rate of each group as shown in Fig. 4(c). The difference of household solid waste generation in household income is summarized in Table 8. The ANOVA results represented significant differences in waste generation rate between 5 groups (p<0.05). There are differences in total waste generation between household with income of under 5 million VND/month and household with income of 10-15 and more than 20 million VND/month (p < 0.05). Similarly, differences in plastic bag generation rates were also found between the household with income under 5 million VND/month and household with income more than 20 million VND/month. However, in terms of food waste generation, significant difference cannot be found (p>0.05). It can be seen from the result of rank correlation analysis (p<0.01) that household income is proportional to the quantity of total waste, food waste and plastic bag. This result is same to that of the results from the studies of Thanh et al. (2010), Denninson et al. (1996a,b) and Bandara et al. (2007). Plastic bag generation rate is in correlation with household income (rank correlation coefficient is 0.177) which is higher than rank correlation coefficient of total waste generation rate (0.169) and food waste generation rate (0.120). It is noted that the study conducted by Thanh et al. (2010) in Can Tho could not provide the correlation between HSW generation and household income.

Household income of 10-15 and 15-20 million VND/month ranked the highest ratio of food waste and total waste with 65.49% and 61.18%, respectively, whereas income of under 5 million VND/household.month occupied the lowest ratio (56.08%). Hence, it is apparent to conclude that food waste is the main composition of total waste, and the ratio of food waste and total waste among 5 groups of house-

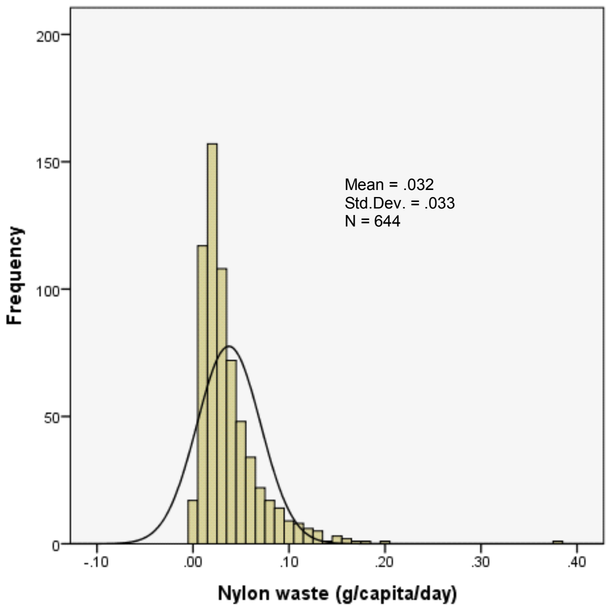

Fig. 3: Distribution frequency of household plastic bag generation rate in HCMC.

Table 8: Waste generation rate from different household income.

Parameter	Total waste		Food waste		Plastic bag	
	Mean ($kg.capita^{-1}.day^{-1}$)	Rank correlation coefficient[a]	Mean ($kg.capita^{-1}.day^{-1}$)	Rank correlation coefficient[a]	Mean ($kg.capita^{-1}.day^{-1}$)	Rank correlation coefficient[a]
Under 5 million VND/month	0.5961		0.3618		0.0567	
5-10 million VND/month	0.4644		0.22970		0.0388	
10-15 million VND/month	0.3962	0.169**	0.19598	0.120**	0.0331	0.177**
15-20 million VND/month	0.4144		0.21110		0.0361	
More than 20 million VND/month	0.3862		0.17874		0.0360	

**p < 0.01; [a]correlation analysis using Spearman's correlation

Table 9: Ratio of food waste and total waste, plastic bag and total waste from different household income.

	Food waste/Total waste		Plastic bag/Total waste	
	Mean (%)	SD	Mean (%)	SD
Under 5 million VND/month	56.0807	25.47467	10.3667	5.67297
5 -10 million VND/month	60.4211	23.65518	8.9321	5.88868
10 -15 million VND/month	65.4923	21.91109	9.2395	8.47423
15-20 million VND/month	62.1791	20.95550	9.1973	6.08513
More than 20 million VND/month	58.5525	23.11676	9.4428	5.44233

Table 10: Waste generation rate from different population density.

Parameter	Total waste ($kg.capita^{-1}.day^{-1}$)			Food waste ($kg.capita^{-1}.day^{-1}$)			Plastic bag ($kg.capita^{-1}.day^{-1}$)		
	Mean	SD	Rank correlation coefficient[a]	Mean	SD	Rank correlation coefficient[a]	Mean	SD	Rank correlation coefficient[a]
Level I	0.4097	0.26716	**	0.2589	0.20588	**	0.0362	0.03037	**
Level II	0.4182	0.28661		0.2755	0.21585		0.0399	0.03262	
Level III	0.4803	0.29262		0.2988	0.22489		0.0416	0.03544	
Level IV	0.4862	0.30199		0.3011	0.23536		0.0407	0.02983	
Level V	0.4096	0.27817		0.2536	0.20544		0.0284	0.02703	
Level VI	0.3742	0.24935		0.2520	0.19880		0.0370	0.04421	

**p < 0.01; [a]correlation analysis using Spearman's correlation

hold size is not markedly different (p>0.05). Unlikely, the largest percentage of plastic bags in the total waste is from household income of under 5 million VND/month with 10.37% and the lowest is from household income of 5-10 million VND/month (8.93%). However, ANOVA results represented no significant differences in plastic bag percentile between 5 groups (p>0.05). The results of these ratios are similar to the study of Suthar et al. (2015), and are indicated in Table 9.

Difference of household solid waste generation in urbanization level: The urbanization level is classified into 6 categories and their effect on household solid waste generation rate is described in Table 10 and Fig. 4(d).

The total waste, food waste and plastic bag generation rate among 6 urbanization levels range from 0.37-0.48 kg/capita/day; 0.25-0.3 kg/capita/day and 0.027-0.048 kg/capita/day, respectively. The result of rank correlation analysis show no relationship between urbanization level and household waste, food waste, and plastic bag (p > 0.01). The ANOVA results illustrate significant differences (p<0.05) existed between the household at level III-Ward 25, Binh Thanh District-having a population density of 17.323 capita/km^2 and HSW generation rate of 0.48 kg/capita/day, and household at level VI-Ward 13, District 10-having a population density of 49.996 capita/km^2 and HSW generation rate of 0.37 kg/capita/day. Besides, Ward 13, District 10 (belongs to level VI) shows the lowest HSW generation rate among surveyed districts. Results indicated no significant differences in the food waste generation rate among urbanization levels (p>0.05). However, there are significant differences in the plastic bag generation between household at level III-Ward 25, Binh Thanh District and house-

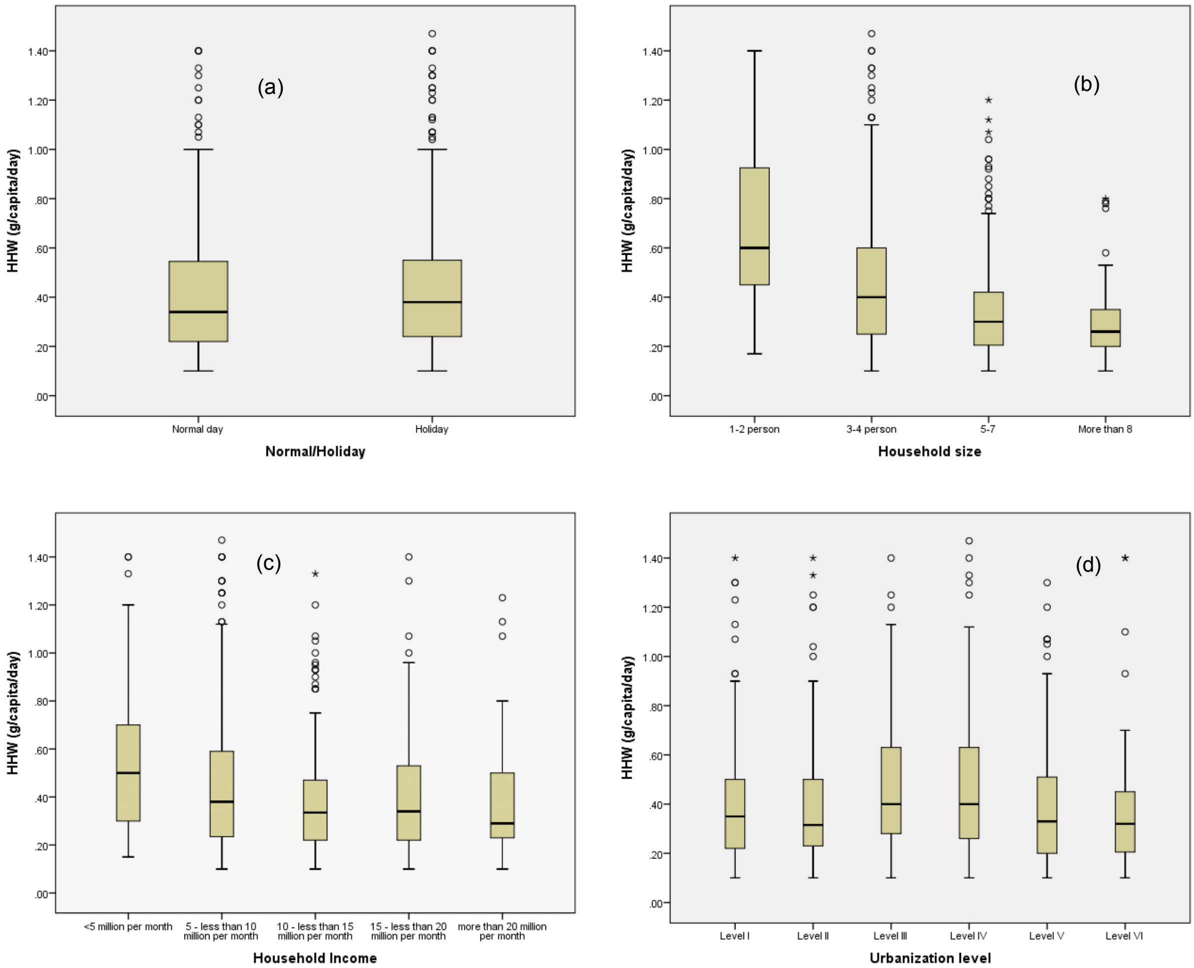

Fig. 4: Solid waste generation rate and (a) weekday and weekend; (b) household size; (c) household income and (d) urbanization level. In which, boxes indicate the inter-quartile range (1st inter-quartile - 25th percentile and 3rd inter-quartile - 75th percentile); line within boxes indicate medians; whiskers below and above boxes represent maximum and minimum values; o and * describe outliers and extremes.

hold at level V-Ward 3, District 5 ($p<0.05$) with 0.042 and 0.028 kg/capita/day, respectively. Besides, District 5 provided the lowest plastic bag generation rate among selected districts, following by District 10. Highest plastic bag generation rate was found in Binh Thanh Distirct. It is noted that the amount of plastic bag generated from District 5 is low due to "Plastic bag reduction" program of HCMC Environmental Protection Fund, residents are trained to reduce the usage of plastic bags. It appears that this program had a dramatic impact on people's awareness and need to be enlarged in Binh Thanh District to encourage the residents toward plastic bag reduction.

Modelling for Household Solid Waste Generation Rate

Based on the factors that affect total solid waste, food waste and plastic bag generation rate as mentioned above, the mathematical model to estimate the waste generation rate in HCMC is developed by single or multiple linear regression with an assumption of waste generation rate is a function of (1) household size; or (2) household income; or (3) both of household size and household income. Results showed a weak relationship between total waste, or food waste, or plastic bag generation rate and household size (R^2 = 13.4%). In addition, it is indicated a correlation being close to zero between food waste generation and household size. Besides, lower coefficient of determination exists between total waste, food waste and plastic bag generation rate and household income (Table 11).

Similar to Thanh et al. (2010), a multiple linear regression to calculate the waste generation rate is better with higher R^2 value. However, Mendehall et al. (1990) reported that the coefficient of determination is needed to be more

Table 11: Modeling for household waste generation rate.

Generation rate	**Household size**			
	Estimated model	R^2	R	p
Total waste	Y_{total}= 0.690 - 0.056X_{HHS}	0.134	0.367	<0.05
Food waste	Y_{food}= 0.425 - 0.033X_{HHS}	0.08	0.282	<0.05
Plastic bag	Y_{nylon}= 0.064 - 0.006X_{HHS}	0.101	0.318	<0.05
Generation rate	**Household income**			
	Estimated model	R^2	R	p
Total waste	Y_{total}= 0.329 + 3.404×$10^{-8}X_{inc}$	0.042	0.205	<0.05
Food waste	Y_{food}=0.221 + 1.766 × $10^{-8}X_{inc}$	0.019	0.139	<0.05
Plastic bag	Y_{food}= 0.024+ 4.511×$10^{-9}X_{inc}$	0.054	0.232	<0.05
Generation rate	**Household size and income**			
	Estimated model	R^2	R	p
Total waste	Y_{total}= 0.621 - 0.051X_{HHS}+ 1.547×$10^{-8}X_{inc}$	0.142	0.377	<0.05
Food waste	Y_{food}= 0.397 - 0.031X_{HHS}+6.468×$10^{-9}X_{inc}$	0.082	0.286	p_{inc} = 0.204 p_{hhs}< 0.05
Plastic bag	Y_{nylon}=0.051 - 0.005X_{HHS} + 2.753×$10^{-9}X_{inc}$	0.119	0.345	<0.05

than 35% to obtain a higher accuracy level. It can be concluded that the proposed modelling for generating total waste and plastic bag [$Y_n = (X_{hhs}, X_{inc})$] achieve higher confidence interval of the difference. However, it is announced that in term of household size, household member should range from 1 to13 members. Household of more than 14 members will result of waste generation rate going below zero. The formulas to calculate household solid waste generation are represented as follows:

$$Y_{total}= 0.621 - 0.051X_{HHS} + 1.547\times10^{-8}X_{inc} \quad ...(1)$$

$$Y_{nylon}= 0.051 - 0.005X_{HHS} + 2.753\times10^{-9}X_{inc} \quad ...(2)$$

The results given in Table 11 provide that household size and household income explain 14.2% of household waste generation, and 11.9% of plastic bag generation. Hence, there must be other factors contributing to HCMC HSW generation. A research carried out by Talalaj et al. (2015) phased out that waste generation rate (kg/capita/day) is more dependant on the number of unemployed women (R^2 = 0.70) and female to male ratio (R^2 = 0.81). Thus, further studies should consider these factors when estimating the household waste generation rate in HCMC. As per the equation (1) and (2), the interpretation of linear equation for each of its coefficient is as follows: (1) keeping variable X_{inc}unchanged means that, on average, household waste and plastic bag generation rate will decrease 0.051 kg and 0.005 kg, respectively, when the number of household member increases by one person; and (2) keeping variable X_{HHS} unchanged means that, on average, the quantity of household waste and plastic bag will increase 1.547×10^{-8} kg and 2.753×10^{-9} kg, respectively, when the household income per capita increases by 1,000,000 VND. Besides, regression coefficient (β) of all models means that there is a relationship existing among variables. This relationship, however, is very weak, especially the relationship with the household income variable shows the weakest ($\beta < 3.5 \times 10^{-8}$). On the top of that, household income variable must be considered carefully when seeking for an explanation of HSW in an area, especially in the Asian region. Similar to Thanh's (2010) point of view, people normally are not willing to answer the information or propose an imprecise answer. The household income variable in a multiple regression model for estimating food refuse generation shows no significance ($p > 0.05$). Hence, it is obvious to say that household income and household size demonstrate its statistical significance to predict food refuse generation when being explained separately, whereas, when combined together, only household size variable gets closer to a better interpretation of the food remnant generation rate of a household.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The average HSW generation rate in Ho Chi Minh (not accounted for centralized generation sources) is 0.41 kg/capita/day (SD = 0.313) with the 95% confidence interval of the difference of 0.39-0.43 kg/capita/day.
2. GDP is not a main driving force behind HSW generation rate in Ho Chi Minh. In fact, in terms of GDP, the HSW

generation rate in Ho Chi Minh is much higher when compared with other foreign regions (China, Mexico, Ireland).

3. The average generation rate of household food refuses in Ho Chi Minh is 0.23 kg/capita/day, and that of plastic bags is 0.032 kg/capita/day. The ratio of food refuses to total solid waste is 61.63% while that ratio of plastic bags and total waste is 7.67%.
4. Household habits give tremendous influence on the generation of HSW, food refuse and plastic bags.
5. Practically, household solid waste generation on weekdays is 0.422 kg/capita/day while the rate of weekends (Saturday and Sunday) is 0.442 kg/capita/day. For food refuses, the generation rate during weekdays and holidays is 0.260 kg/capita/day and 0.287 kg/capita/day, respectively. Similarly, the plastic bag generation rate is 0.0385 kg/capita/day (weekdays) and 0.0362kg/capita/day (holidays). However, the study found no significant differences of these rates between weekdays and weekends.
6. ANOVA analysis results provide the average significant differences for all household size categories. The differences, however, were not found for the household size of 5-7 residents and more than 8 residents. The study also phases out that the larger the household size is, the less the waste generation rate is.
7. Waste generation rate of different household incomes indicates the significant differences between household having an income of less than 5 million/household. month and those having an income ranging from 10-15 and more than 20 million/household.month. This means that the income can ever be considered as an important factor if the difference in income/capita.household is significant. In addition, the ANOVA test shows the significant difference in the plastic bag generation between household having an income of less than 5 million/month and household of income of more than 20 million/month. For food remnant generation among household incomes, however, the study found no significant difference. The results also figure that waste generation rate is proportional to the household income.
8. Rank correlation analysis shows no significant correlation between population density and household waste, food refuse, and plastic bag generation. When compared with Binh Thanh district in terms of plastic bag generation rate, the amount of plastic bag generated in Binh Thanh district (kg/capita/day) is much higher than that of District 5, and highest among the districts involved in the study, whereas District 5 shows the smallest plastic bag generation rate;
9. Models for estimating waste generation rate based on household size, or household income, or a combination of these two variables indicates a low relationship among the variables and household waste, food refuse, and plastic bag generation. Within the scope of the study, regression model indicates that changes in household size and household income can only explain for 14.2% of the changes in waste generation rate and for 11.9% of the changes of plastic generation rate. In other words, among the variables affecting waste generation rate, household size and income account for only 14.2% and 11.9%, and that of plastic bag is 11.9%. Hence, there are other reasons which can explain the waste generation in HCMC.

Recommendations: In order to improve the model for estimating household waste generation in Ho Chi Minh, following issues should be considered in the next study:

1. For establishing a sampling network, selection of the study areas should be based on the local socio-economic conditions or the city master plan.
2. Considering the method for gathering household income data. In this study, household income is obtained by face to face interview approach. Hence, the results are not close to the real, and that leads to a low reliability model. A proposal to approach a reliability study in the future is to know the job details of those who are considered as the main income earner of the household. Consequently, household income will be counted based on the basic salary regulated by the government.
3. Age structure (including age of working member, post-working age women/men) should be considered as a variable having strong relationship to the waste generation rate.
4. The model should regard a variable of female to household member ratio, number of female of age of less than 18, 18-64, and more than 64, and the number of unemployed women (including part-time working women). Talalaj et al. (2015) provided that the more women in the household is, the more waste the household generates due to various reasons (single woman, their habitat, etc.).
5. The model should view the effect of education level on waste generation. Education level is assessed as the number of years the main household income earner attended school. It is expected that the education level is proportional to the awareness, hence affects the household waste generation.

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