A Dissertation for the Doctor of Philosophy in Environmental Science

Analysis and Modelling of Household Solid Waste Generation, Handling and Management in Phnom Penh, Cambodia

By

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Abstract

The amount of total disposed waste in Phnom Penh has increased annually. It grew from 1.12 to 1.86 Gg/day between 2010 and 2015. Per capita, waste generation rate (WGR) was about 0.762 kg/day. Household solid waste (HSW) shared about 55.3% of the total generated waste in 2013. As population and gross domestic product (GDP) rose, the generation of solid waste also increased gradually. Phnom Penh City Hall, a responsible authority for solid waste management (SWM), has worked closely with relevant institutions and waste collection company, CINTRI (Cambodia) Ltd. to provide cleaning, collection and transport service to residents. However, the collection service covered only 76 of 96 communes in the city that was expected to approximately 82.1% of the total generated amount in 2011. About 78.4% of the total household has accessed the service while the others could not. Therefore, self-treatments and illegal dumping of waste became common handling methods in the non-service area that would result in environmental pollutions and impacts on public health. Integrated solid waste management (ISWM) was recommended to enhance the present management system. Organic composting and material recovery seemed to be the most suitable options for ISWM. Source segregation of waste and 3R (reduce, reduce and recycle) are required to enable the treatment potentials. The Royal Government of Cambodia has promoted these practices throughout the country, especially in Phnom Penh. However, it seemed not practical since solid waste was still disposed of mixed. The householders only segregated such valuable materials for self-treatments, primarily for sale. Therefore, it is necessary to understand the public perspectives before introducing any alternative management systems to satisfy their preferences.

This study mainly aimed to assess the HSW management based on public behaviours by using system dynamic modelling in Phnom Penh, the capital of Cambodia. We developed four-step research to achieve the objectives including 1) estimation of the generation of HSW and determinants, 2) evaluation of the current management practices and handling methods used for HSW, 3) assessment of the public's knowledge, attitudes, practices (KAP) and willingness to pay (WTP) for improved management service and 4) assessment of the future trend of HSW generation and scenario-based management. Phnom Penh was divided into four areas of rural (Zone1), suburban (Zone2), urban (Zone3) and central (Zone4) for data collection and evaluation started from August 6 to September 4, 2016, and August 5 to 31, 2017. A total sample of 1,280 households was interviewed, and generation of HSW from 480 families was manually observed for seven days. Greenhouse gases (GHGs) emitted from the handling of HSW were calculated using the IPCC 2006 model, and system dynamics of HSW generation were modelled to project the future trend in the target year of 2025.

The first case study quantified the generation rate and compositions of HSW. Multiple linear regression models were developed to assess how 11 independent socio-economic factors influenced the waste generation. The variables were income, household size, a fraction of children, adults and elders, employment rate, engagement in home business and agriculture, home garden, access to SWM service and urbanisation level. The best subset regression was

analysed to choose the best suitable variables for multiple linear regression modelling. The data of waste generation were grouped into 70% of training dataset and 30% of the testing dataset. As a result, the average WGR was approximately 2.382 kg/household/day or 0.502 kg/capita/day. Food waste was the largest composition, sharing about 52.49% on average while plastic was about 18.37%. The other compositions were garden waste (11.7%), paper (5.89%), nappies (3.23%), textile (1.95%), metal (1.62%), glass (1.27%), leather and rubber (0.92%), wood (0.68%), ceramic and stone (0.29%), hazardous waste (0.21%) and other residues (1.38%). To be noticed, the hazardous waste referred to harmful materials such as batteries and medical and electrical waste. The best subset regression selected five variables (engagement in home business, household size, employment rate, income and fraction of children) to develop five different models. Two of the models were then evaluated with the testing dataset. The multiple linear regression models made clear significant factors that affected the waste generation. They validated the significant and positive effects of income, household size, employment rate, and engagement in home business. Waste management planners and policymakers should pay attention to the future trends of these four variables as determinants of household waste estimation.

The second case study evaluated waste management practices and handling methods. The householders were grouped into registered households of collection service (HH_UCVs) and non-registered households (HH_NCVs). Questionnaire interview was performed to collect data of management status, access to collection service, collection frequency and satisfaction as well as handling methods and pre-segregation of HSW. A flow diagram of HSW was drawn in the software of STAN 2.6, GHG emissions were estimated in the IPCC 2006 model. The study found that most of the HH_UCVs reside in the urban and central area in the city, and about 40.44% of the total households could access the collection service on a daily basis. However, the service seemed to run every other day or twice a week or even less frequent in the rural and suburban area. About half of the HH_UCVs and two-thirds of HH_NCVs were aware of the waste segregation, yet none of them has put it in practice. In response to the question about willingness to segregate waste, more than two-thirds of the total respondents presented their positive willingness, but mostly only segregation into two groups of organic and inorganic waste mainly was chosen. The total HSW in 2017 was estimated to be about 907.98 Mg/day, and about 546.05 Mg/day (60.14%) were discharged for collection. About 101.25 Mg of food and garden waste were locally recycled into animal feeds and organic fertiliser for farming and gardening. Reuse and sale of valuable materials (wood, paper, plastic, metal, textile, leather and rubber, glass, rechargeable batteries and electrical waste) to the informal sector also took place, especially in the central area. Reuse weighed about 17.46 Mg/day and sale amounted to about 49.69 Mg/day of the generated waste. Practices of illegal dumping happened in all zones, which totalled up to about 193.53 Mg/day including 123.37 Mg/day of open burning, 52.81 Mg/day of littering to open space, 5.99 Mg/day of burying, and 11.36 Mg/day of scattering to water bodies. Nonetheless, illegal dumping was a common handling method of a waste of HH_NCVs. Also, the total emissions of GHGs of handled HSW were approximately 219.40 Gg/year of CO_2 equivalent, and 182.23 Gg/year (83.06%) was from the dumping site.

The third case study developed logistic regression models to analyse the relationship between observed variables on KAP toward SWM in five outskirt districts. Provision of collection service is a necessary element of municipal solid waste management. It is demanding to meet the users' affordability. We analysed the data of 800 households, including 200 HH_UCVs and 600 HH_NCVs. The determinants of how individuals are aware of, think of, and behave were assessed in the models based on the values of the estimated coefficient and probability of t-statistics. As a result, education level and knowledge of health effects have positive influences on knowledge of waste problems. Income is a decisive economic factor of knowledge and attitudes. The residents seem dissatisfied with the status of waste management and collection service if they are aware of the problems. The administration, therefore, needs improvements to satisfy knowledgeable citizens. Service provision to the non-service users is imperative to halt the practice of illegal dumping. However, the infrequent collection still leads to the improper practice of the service users. We also applied the contingent valuation method to assess households' WTP for the waste collection service. Some households could assess the service, yet some still could not. Therefore, the present service users were asked about WTP for improving the existing waste collection while the others were examined their willingness if a collection were served. Logistic regression and Tobit models were developed to evaluate possible factors that would influence public decisions. As a result, the service users were willing to pay between 731 and 783 Riel/month as an extra on their tipping fee for the improvement, and the mean WTP of the non-service users for the future collection would be between 3,438 and 3,550 Riel/month (about 0.85 to 0.90 USD/month). Income, age distribution, knowledge of waste problems and estimated waste generation rate seem to have significant effects on the public willingness and bid values. Importantly, satisfaction with waste management and tipping fee positively impact the way the service users present their willingness.

The final case study assesses the future projection of waste generation and management based on scenarios of source segregation using system dynamic modelling. Diagrams of the system dynamic modes were connected in Vensim PLE.3.5; the data were analysed using 'delSolve' package of the R Studio software. Three models were developed to project the future trend of HSW generation between 2017 and 2025 with a growth rate of the population at 1.02%. One of them was selected to simulate the waste flow and scenario analysis. In Model 1, the WGR per capita was supposed to be as same as in the base year, and Model 2 was based on historical growth rate of HSW generation at 1% per year. The waste amount was projected with economic data of income: 1727 USD/year at 7.7% growth rate in Model 3. In total, there were 12 stocks (state variables) and 11 auxiliary variables. The analyses showed that Model 2 seemed to present the most reliable data. As Model 2 chosen, the WGR per capita would grow from 0.502 kg/day in 2017 to 0.507 kg/day in 2018, 0.512 kg/day in 2019, 0.517 kg/day in 2020 and 0.54 kg/day in 2025. So that the annual HSW amount would be 926.44 Mg in 2018, 945.27 Mg in 2019 964.49 Mg in 2020 and 1066.59 Mg in 2025. As a business as usual (BAU), the amount of waste discharged for collection is estimated to be approximately 559.77 Mg/year in 2018, 574.07Mg/year in 2019, 588.7 Mg/year in 2020 and 666.88 Mg/year in 2025. It shows that this amount would stand out as the largest fraction, and the illegal dumping remains the biggest concerns toward SWM. BAU was the scenario

1, and then six more scenarios were additionally proposed to project waste segregation-based scenarios between monthly time step of zero (t = 0), and 96 (t = 96). The results show that discharged and dumped waste would greatly be reduced if a large number of the population participate in the sorting practice. In a scenario of 60% of people segregate the recyclables, up to 2.219 Gg/month of waste could be recovered in the 96th month. If the organics were also sorted, an additional recovery would be about 8.520 Gg/month. The recyclables and organics then can be sent to material recovery and composting facilities. The uncollected amount of waste can also be minimised if segregation is in place. Without segregation, it was estimated to be 8.627 Gg/month. It would be reduced to 7.773 Gg/month if the recyclables were pre-sorted and dropped to 4.493 Gg/month if organics were also another object for separation in further. The statistics show that the collection company has fully equipped collection truck to collect the uncollected waste. Cost recovery would not be a problem in the first few years of operation as expected about 71.11% of the household would pay the tipping fee. As the population increased, the required capacity also needs to increase. The available budget will be lower than expenses. The segregation scenarios present preferable values as it would recover a large number of recyclables, reduce the operation cost and raise the profit.

In conclusions, the generation, flow and projection of HSW were quantified, and the public KAP toward SWM were evaluated. The causes and effects of the illegal dumping were analysed. The public behaviours of willingness to pay for improved collection service and to segregate waste were assessed. It found that using different waste handling methods is not related to waste generation rate. Recycling, reuse and sale importantly contribute to the minimisation of waste disposal. A large amount of waste is illegally dumped where the collection is not served. Household size and economic factors significantly determine the waste generation rate. The quantity-based charge is a method used for tipping fee determination. Income is an economic factor to influence the public willingness to pay. Solid waste-related awareness positively determines public decisions and practices. The collection service needs to be frequent and affordable to all households. We suggest that the service is provided widely, efficiently, and regularly. The government and service providers should provide satisfying waste management at the desired tipping fee. If the collection service would be increased in price, it should be reasonable and affordable. General knowledge of waste problems and management should also be raised in the area.

Keywords: Best subset regression, HSW, KAP, Logistic regression model, Multiple linear regression, Tobit model, SWM, System dynamics, WTP

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AGFI	Adjusted goodness-of-fit index
AIC	Akaike information criterion
ANOVA	Analysis of variance
AVE	Average variance extracted
BIC	Bayesian information criterion
CF_i	Fraction of total carbon
CFI	Comparative fit index
CH_4	Methane
CO_2	Carbon dioxide
CVM	Contingent valuation method
CR	Construct reliability
CSARO	Community Sanitation and Recycling Organization
DDOCm	Decomposable degradable organic carbon
DOC	Degradable organic carbon
DoPC	Department of Pollution Control
EF	Emission factor
FCF_i	Fraction of fossil carbon
FOD	First Order Decay
GDP	Gross domestic product
GHG	Greenhouse gas
Gg	Gigagram
GFI	Goodness-of-fit index
GOF	Goodness of fit
HH_UCV	Service-registered household
HH_NCV	Non-registered household
HSW	Household solid waste
IFI	Incremental fit index
IPCC	Intergovernmental Panel on Climate Change
ISWM	Integrated solid waste management
JICA	Japan International Cooperation Agency
KAP	Knowledge, attitude and practice
Kg	Kilogram
MAE	Mean absolute error
MCF	Methane correction factor
Mg	Megagram
MoE	Ministry of Environment
MoH	Ministry of Health
MoI	Ministry of Interior
MoIH	Ministry of Industry and Handicraft
MoP	Ministry of Planning
MoPWT	Ministry of Public Works and Transport

MoT	Ministry of Tourism
MS	Mean square
MSE	Mean square error
MSW	Municipal solid waste
MWTP	Mean willingness to pay
N_2O	Nitrous oxide
NFI	Normed fit index
NGO	Non-governmental organisation
PDPC	Provincial Department of Planning Capital
PET	Polyethylene terephthalate
PPCH	Phnom Penh City Hall
RGC	Royal Government of Cambodia
RMSE	Root mean square error
RMSEA	Root mean square error of approximation
RSE	Residual standard error
SD	Standard deviation
SE	Standard error
SEM	Structural equation model
SoS	Sum of square
SWM	Solid waste management
UNEP	United Nations Environment Programme
USD	United State Dollar
WGR	Waste generation rate
WTP	Willingness to pay

Chapter One
Introduction

1.1 Background

Solid waste is a worldwide environmental problem owing to population growth, urbanisation and economic development. Annual waste collection globally amounted about 1.3 million Gg/year in 2012 and would increase to 2.2 million (UNEP, 2013) to 3 million Gg/year in 2025 (Charles et al., 2009) due to a drastically loading volume of generated waste. An average waste generation rate (WGR) in the United States was the largest at 2.08 kg/capita/day while it was about 1.51 kg/capita/day in the European Union. In the developing countries, the WGR per capita per day was about 0.77 kg on average (Troschinetz and Mihelcis, 2009). The relationship between income and waste generation is very significant so that an increase in income would result in an increasing amount of waste. Thus, solid waste generation is a function of living standard, consumption patterns and economic activity (Eawag and Sandec, 2008).

Solid waste management (SWM) is challenging, as it requires appropriate technologies and sufficient resources that are limited, especially in developing countries (Abu Qdais, 2007; Ngoc and Schnitzer, 2009; AIT/UNEP, 2010). In consequences, the management would likely fail, and open dumpsite is a costless and typical method for final disposal in operation. Adverse impacts on the environmental quality and public health usually occur caused by open dumping (ISWA, 2016). Those effects are concerning the deterioration of surface and groundwater, soil and air quality because of landfill leachate and gases including methane (CH_4) and carbon dioxide (CO_2). These landfill gases are the greenhouse gases (GHGs) that have harmful effects on the global climate (Tabata et al., 2010; Friedrich and Trois, 2011; Habib et al., 2013).

SWM requires many works including preventions, reduction, recycling, recovery, and final disposal. UNEP (2013) defined integrated solid waste management (ISWM) as "a strategic approach to sustainable management of waste, covering all sources and all aspects, including generation, segregation, transfer, sorting, treatment, recovery and disposal in an integrated manner, with an emphasis on maximising resource efficiency". It would drive the management system more sustainable (Abu Qdais, 2007; Chen et al., 2010; UNEP, 2013). In the design of an ISWM, three main conditions should be in consideration: social, economic and environmental aspects and stakeholders should be identified. This system can enhance efficiency, minimise cost, maximise benefits and opportunities, and improve social responsibilities and participation. The participation is required in various stages of the management stream. Identification and prioritisation of financial, social, technical and environmental conditions are also important that make the stakeholders concerned of. It should be discussed regarding the situation of specific stages of source segregation, collection, transport, treatment, disposal, and recycling and resource recovery (UNEP, 2009).

1.2 Problem statements

Phnom Penh, the capital of Cambodia, has put efforts in solving mismanagement of solid waste. The city has undergone rapid urbanisation that puts heavy workloads on SWM. In 2003, The WGR per capita per day was about 0.74 kg which was comparable to 0.762 kg in 2013. The household waste generation rate was about 0.487 kg in 2003 (JICA, 2005) and 0.498 kg in 2013 (Hul et al., 2015). However, final disposal amount significantly increased to 1.86 Gg/day in 2015 (Seng et al., 2018) from 1.12 Gg/day in 2010 (Seng et al., 2013). The generation rate seems not indifferent year to year yet increasing in some population surely loads more waste generated into the environment. Effective management strategies are required to cope with the increasing amount of waste and its potential problems. Initially, 3R programs that encourage the individual to reduce, reuse and recycle waste were promoted. Also, source segregation is recommended to enable the treatment possibilities. In promotion, the pre-sorting of dry waste (inorganic) and wet waste (organic) was introduced in Phnom Penh. Nevertheless, waste was still unsorted and disposed of into an open dumpsite (Seng et al., 2018) that is a general common method for final disposal in the country (Sethy et al., 2014; Hul et al., 2015).

Moreover, collection service seems limited to serve the needs of the residents, especially those living in the suburbs. According to RGC (2015), Phnom Penh municipality is responsible for SWM in the capital. Waste collection and transport, however, have been franchised to a private company, CINTRI (Cambodia) LTD., due to such management difficulties since the year 2002 (Seng et al., 2010). The company has continuously strengthened the service provision and quality (CINTRI, 2017) but still challenges with lacks of institutional capacity, performance, participation, etc. (Kum et al., 2005; Spoann et al., 2018). Of 96 communes in the city, the collection service had run only in 76 (PDPC, 2015), and was reported infrequent and irregular (Kum et al., 2005; Denny, 2016). Therefore, open burning, burying and littering occurred (Seng et al., 2010; Sethy et al., 2014). Only the central districts were served a daily-basis collection (Seng et al., 2010) with 100% collection coverage (CINTRI, 2017).

The collection service monthly charged between 3,200 to 4,000 Riel (Denney, 2016) or 5,000 to 10,000 Riel (Sang-Arun et al., 2011) based on a household's economic conditions as an additional fee to the electricity bill. Providing an efficient service was recommended as a priority action to better the SWM (Heisler, 2004; Seng et al., 2010; Sethy et al., 2014). However, it should be attentive of introducing a new strategy, mainly in the setting of the tipping fee, as Kum et al. (2005) and Sang-Arun et al. (2011) showed that the public tended to present a low willingness to pay (WTP) for the service. Failing to serve people at their affordability, therefore, would risk the management in a plan to fail. It is considerate to have the public's knowledge, attitudes, practices (KAP) and WTP estimated in advance. Public knowledge and participation is a primary driving key to attain the management's objectives (Brunner and Feller, 2007; Chen et al., 2010; Hiramatsu et al., 2009). The individuals should be knowledgeable of necessities and pathways that ISWM could be practical and efficient and engaged into the processes of policy formatting, system planning, and decision making

(Seng et al., 2018). It is crucial to understand the local perspectives toward the present situation. Also, the baseline data are needed for future prediction and planning of measures for the improved system as UNEP (2017) emphasised that data and information about solid waste in Cambodia were lacking.

1.3 Research objectives

This study generally aimed to evaluate scenario-based management of HSW in Phnom Penh city, Cambodia based on public's behaviours. The specific objectives were:

- To estimate the generation of HSW and its determinants
- To evaluate current management practices and handling methods used for HSW
- To assess the public's knowledge, attitudes, practices (KAP) and willingness to pay (WTP) for improved management service
- To project the future HSW generation and segregation-based management scenarios.

1.4 Scopes and limitations

The scopes and limitations of the study were as follows:

- The study area was in Phnom Penh city, the capital of Cambodia which comprised twelves administrative districts with a total area of 678.47 km^2 (PPCH, 2011).
- The target group of the study was household level including registered users of waste collection service and non-users of the service.
- Type of solid waste included food waste, garden waste, wood, paper, textile, plastic, leather and rubber, nappies, metal, glass, ceramic and stone, hazardous waste (batteries, medical waste and e-waste) and others that are generated from households.
- Handling methods of waste were the discharge for collection, recycling, reuse, sale and illegal dumping.
- Potential emissions of GHGs such as methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) were calculated.
- The base year of the future evaluation of HSW generation was 2016-2017, and the target year of the project was 2025.

1.5 The organisation of the dissertation

The dissertation was prepared into eight different chapters excluded abstract and appendices that were attached before and after the dissertation body.

Chapter One: an introduction part described in this chapter about the background, problem statements, objectives and scopes of the study.

Chapter Two: the existing literature on waste management in Phnom Penh was reviewed. It presented available data of waste generation, and management included legal frameworks and institutional arrangement that described how waste was managed nationwide.

Chapter Three: the design of the proposed study was explained in this chapter. It came along with the explanation of research methods applied in the study included empirical data collection, waste generation and composition study, household questionnaire survey, key informant interview, statistical analysis and valuation, etc. Theories and application of methods used in the assessments were reviewed.

Chapter Four: this chapter presented a case study on HSW generation and determinants. It presented the updated results of waste generation and compositions in the area. Moreover, determinants on waste generation were evaluated.

Chapter Five: a case on HSW management and handling methods was evaluated in this chapter. It assessed the public perceptions of SWM service and how waste was handled. Also, a flow of handled waste was drawn, and potential emissions of GHGs were calculated using the IPCC 2006 method.

Chapter Six: knowledge, attitudes, practices and willingness to pay toward household solid waste management service was the title of this chapter. It was another case study that presented the results of the household questionnaire survey and modelling using Logistic regression and Tobit regression methods.

Chapter Seven: this chapter the scenario-based evaluation of HSW management modelling using system dynamics method between 2017 and 2025. The models were proposed, the scenarios were developed based on baseline data found in chapter four, five and six. There were three models to assess the trend of HSW generation, and one of them was chosen to simulate the waste segregation-based management models on a monthly basis between t = 0 and t = 96. The public's segregation willingness was also analysed in structural equation modelling.

Chapter Eight: the main findings of the entire dissertation were concluded in this chapter. Drawbacks and policy implications were also included in a sub-heading of recommendations. They were proposed individual stakeholders including policy makers, service providers, local communities and researchers.

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Chapter Two
Literature Review

2.1 Waste generation and compositions

In Phnom Penh, waste generation rate (WGR) increased from 0.74 kg/capita/day in 2003 (JICA, 2005) to 0.91 kg/capita/day in 2009 (Sang-Arun et al., 2011). Food waste was the major component, shared about 49.18% in 2014-2015 (Seng et al., 2018). It was much larger found in the previous studies of MoE (2004), Kum et al. (2005), JICA (2005), Sang-Arun et al. (2011) and Heng et al. (2011). It is noticeable that the proportion of food waste appeared to be about 87% in 1999 (MoE, 2004). Plastic was the second largest portion, about 21.13%. It appeared to increase from only 6% in 1999 (MoE, 2004) and 13.2% in 2002 (Kum et al., 2005). Another matter of facts, nappies and hazardous waste (batteries, medical waste and electrical waste) were only found in Phnom Penh between 2014 and 2015, as shown in Table 2.1 (Seng et al., 2018).

Table 2.1 Waste compositions in Phnom Penh (%)

	1999[a]	2002[b]	2003[c]	2009[d]	2011[e]	2014[f]	2014-2015[g]
Food waste	87	65.0	63.3	70	50.5	51.9	49.18
Plastic	6	13.2	15.5	6	17.8	20.9	21.13
Textile	-	-	2.5	3	11.1	2.5	8.01
Wood/leaves	-	-	6.8	6	-	2.3	6.69
Paper	3	3.8	6.4	5	12.7	9.9	6.54
Nappies	-	-	-	-	-	-	2.91
Glass	1	4.9	1.2	2	4.0	1.5	1.42
Stone/ceramic	-	-	1.5	-	-	0.5	1.54
Metal	1	1.0	0.6	2	0.3	1.1	1.05
Rubber/leather	-	0.6	0.1	-	-	0.2	0.87
Hazardous waste	-	-	-	-	-	-	0.17
Others	2	11.5	2.1	6	3.5	9.5	0.49

Source: [a] MoE, 2004; [b] Kum et al., 2005; [c] JICA, 2005; [d] Sang-Arun et al., 2011; [e] Heng et al., 2011; [f] Hul et al., 2015; [g] Seng et al., 2018

2.2 Management service

Phnom Penh City Hall (PPCH) oversees of the SWM in the capital. However, cleansing, collection and transport service has been franchised to a private company, CINTRI (Cambodia) Ltd. since 2002 (JICA, 2005; Kum et al., 2005; Seng et al., 2010). Fig. 2.1 presents the history of SWM service in Phnom Penh. In recent years, the SWM fuctions has been transferred to authorities at district level. The district authorities, in effect, become a responsible body of planning and implementation in their jurisdiction (Spoann et al., 2018). The city had no formal treatment facilities equipped; open dumpsite was the only one option in operation. Fig. 2.2 presents the waste flow in Phnom Penh.

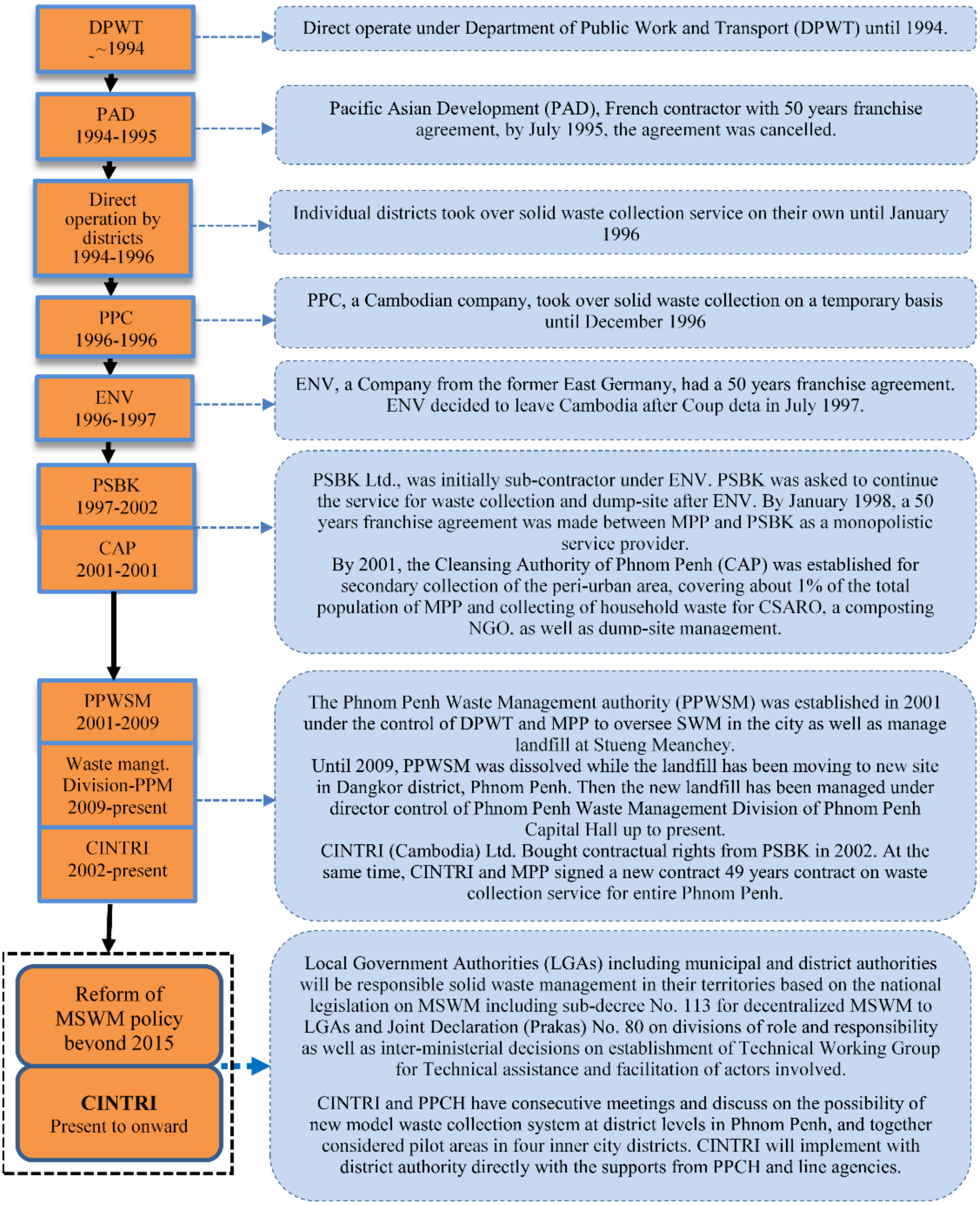

Fig. 2.1 SWM service history in Phnom Penh (Spoann et al., 2018)

In 2015, CINTRI has provided the service to 78.4% of 269,169 household in Phnom Penh. The collection service in this city could collect about 82.1% of total generated waste (Seng et al., 2013) when about 80% of residents paid the tipping fee (Sang-Arun et al., 2011). The collected waste has been disposed of into Stungmean Chey dumpsite from 1965 to 2009 and Dangkor Landfill from 2009 till present (JICA, 2005; Kum et al., 2005; Seng et al., 2010). The landfill ground was sandy, and the groundwater table seemed to be at the height of 2 to 3 meters in sandpit as high as a water spring level. The bottom line was improperly installed; it was two meters thick of clay (Heng et al., 2011) due to financial challenge and low permeability of natural soil of the landfill and surrounding area (JICA, 2005). The total depth of landfill was nine meters. Landfill leachate was frequently pumped and stored in a leachate storage pond (Heng et al., 2011; Sang-Arun et al., 2014; Uch et al., 2014).

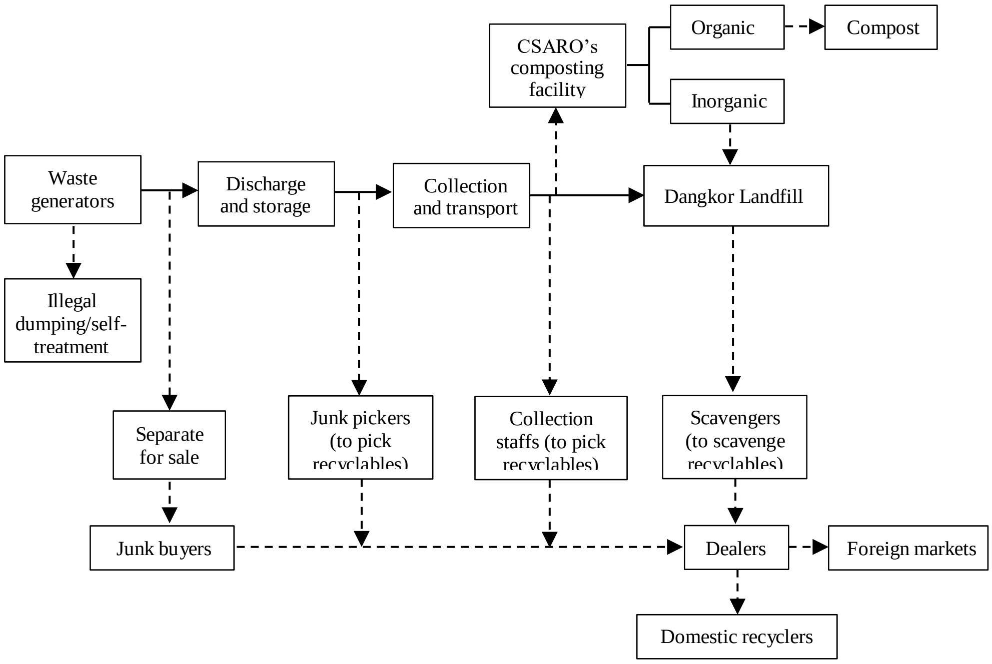

Fig. 2.2 Waste management flow in Phnom Penh (Seng et al., 2018)

2.3 Recovery and recycling

Informal sector has an important role in material recovery and recycling in the city (Sethy et al., 2014). Recyclables are paper, plastic, aluminium, ferrous scrap, other metals, glass and rechargeable batteries. There were about 2000 waste pickers (Sang-Arun et al., 2011; Uch et al., 2014) including 500 scavengers at Dangkor Landfill (Uch et al., 2014). The scavengers recovered office paper, cardboard, PET bottle, other plastics, aluminium, ferrous can, other metals and glass bottle. In 2003, about 8.6 Mg/day of recyclables was recycled. It was equal to only 9.3% of total waste including cardboard (13.2 Mg), ferrous/ferric can (7.33 Mg), plastic (5.76 Mg), office paper (5.06 Mg) and other glasses (4.5 Mg) (JICA, 2005). Food waste was recycled to be animal feed (Sang-Aru et al. 2011).

In Dangkor Landfill, the recovered material has been recorded by the management agency. The data shows that the number of materials tended to decrease despite the increasing amount of waste disposal. Total recovery was about 9.63 Gg/year in 2011 but decreased remarkably to 5.55 Gg/year in 2013. Plastics seemed the largest proportion in recovery, especially 3.13 Gg/year of plastic bags of and 1.10 Gg/year of plastic sacks in 2013 (Table 2.2). A study of Seng et al. (2018) which interviewed the landfill scavengers found that the total recyclables were about 7.28 Gg/year in between 2014-2015. Recovered things were then marketed to depots when scavengers themselves also reused the valuable materials (Heng et al., 2011). These recyclables were generally exported to foreign recycling markets in China, Malaysia, Republic of Korea, Singapore, Thailand and Vietnam (DoPC, 2014).

Table 2.2 Recovered materials from Dangkor Landfill in Phnom Penh (Gg/year)

Year	Food residues	Paper	Plastic	Metal	Glass	Textile	Rubber	Total
2011 [a]	-	0.16	8.37	1.10	-	-	-	9.63
2012 [a]	-	0.11	8.13	0.88	-	-	-	9.12
2013 [a]	-	0.13	5.02	0.40	-	-	-	5.55
2014-2015 [b]	0.60	0.30	5.62	0.45	0.29	0.01	0.02	7.28

[a] Landfill Data, 2016; [b] Seng et al., 2018

2.4 Environmental impacts

Nationally, waste sector emitted about 229.24 Gg of carbon dioxide equivalent (CO_2-eq) in 2000 to the environment. It was less than 1% of the total greenhouse gas (GHG) emissions in the country. Mainly, GHGs were emitted from final disposal sites while methane (CH_4) and nitrous oxide (N_2O) contributed about 93% and 7% of the total emissions respectively (GSSD, 2015) as shown in Table 2.3. The World Bank reported on Cambodia Environmental Monitoring (World Bank, 2003) that surface and groundwater quality had been polluted by improper management of untreated waste. The degradation of water quality and aquatic biodiversity would have become serious problems that put health risk in concerns (EUDC, 2012).

In Environmental Profile Report (EUDC, 2012), atmospheric pollution in Phnom Penh, as well as in Cambodia, was a result of opened solid waste burning. It emitted CO_2, SO_2, NOx, dioxin and furans. Also, JICA (2005) presented a high risk of a health problem of waste pickers at Stungmean Chey dumpsite. It found that the concentrations of mercury, caesium and cadmium were high. Seng (2016) calculated the GHGs emitted from Dangkor Landfill and found that the total emissions were about 169.06 Gg/year in 2009, 565.59 Gg/year in 2014 and 635.86 Gg/year in 2015 (Table 2.4). It seemed that the emissions had increased as the amount of waste disposed of increased, and food waste made the largest contribution at about 50% of the total emissions.

Table 2.3 GHG emissions from waste sector in Cambodia, 2000

Sources	CH_4 (Gg)	N_2O (Gg)	Total CO_2-eq (Gg)
Waste disposal on land	9.69	-	203.46
Wastewater handling	0.49	0.05	25.78
Total	10.18	0.05	229.24

Source: GSSD, 2015

Table 2.4 Estimated total GHG emissions

Year	CO_2-eq emissions (Gg/year)					
	Food waste	Wood/leave	Paper	Textile	Nappies	Total
2009	123.10	14.07	23.45	8.44	-	169.06
2014	293.28	44.61	98.23	93.42	36.05	565.59
2015	342.55	71.63	127.77	70.62	23.28	635.86

Source: Seng, 2016

2.5 Management opportunities

The present SWM should be transformed into an integrated system that was introduced by UNEP (2013) to evolve waste minimisation, segregation, collection and transfer, recycling, recovery and treatments. Succeeding this approach must overcome an endless number of complications as it needs appropriate technologies and sufficient resources (Abu Qdais, 2007; Ngoc and Schnitzer, 2009). By analysis of waste physical and chemical components, Seng (2016) found suitability of anaerobic digestion and composting for organic waste, refuse-derived fuel generation and gasification with melting for plastic, textile, rubber and leather, and incineration without energy recovery for mixed waste. Integrated solid waste management (ISWM) was proposed by Seng (2016) shown in Fig. 2.3.

However, according to JICA (2005) and Kum et al., (2005), Phnom Penh lacked the equipment, expertise and financial resources to make management efficient. The advanced treatment technologies may not be suitable due to the limited economic capacity. Brunner and Feller (2007) recommended costless and available handling methods to be selected for an improved system. As seen possibility of material recovery and organic composting, both ways were primarily recommended (Sang-Arun et al. 2011; Hul et al. 2015). It was because of not only the richness of organic matters and recyclables generated but also the existence of recycling activities taken by informal sector in the city as reported by JICA (2005), Sang-Arun et al. (2011) and Uch et al. (2014).

So that the material recovery and organic waste composting seemed practicable, to begin with before running such costly technologies (Seng, 2016). The RGC (2017) referred to the needs for improving SWM and 3R (reduce, reuse and recycle) and capacity building of officials to fulfil an objective of the National Environment Strategy and Action Plan 2016-2023. It seems to require baseline data and information to formulate relevant regulations, policy and guidelines and awareness raising to promote public participation regarding social responsibility.

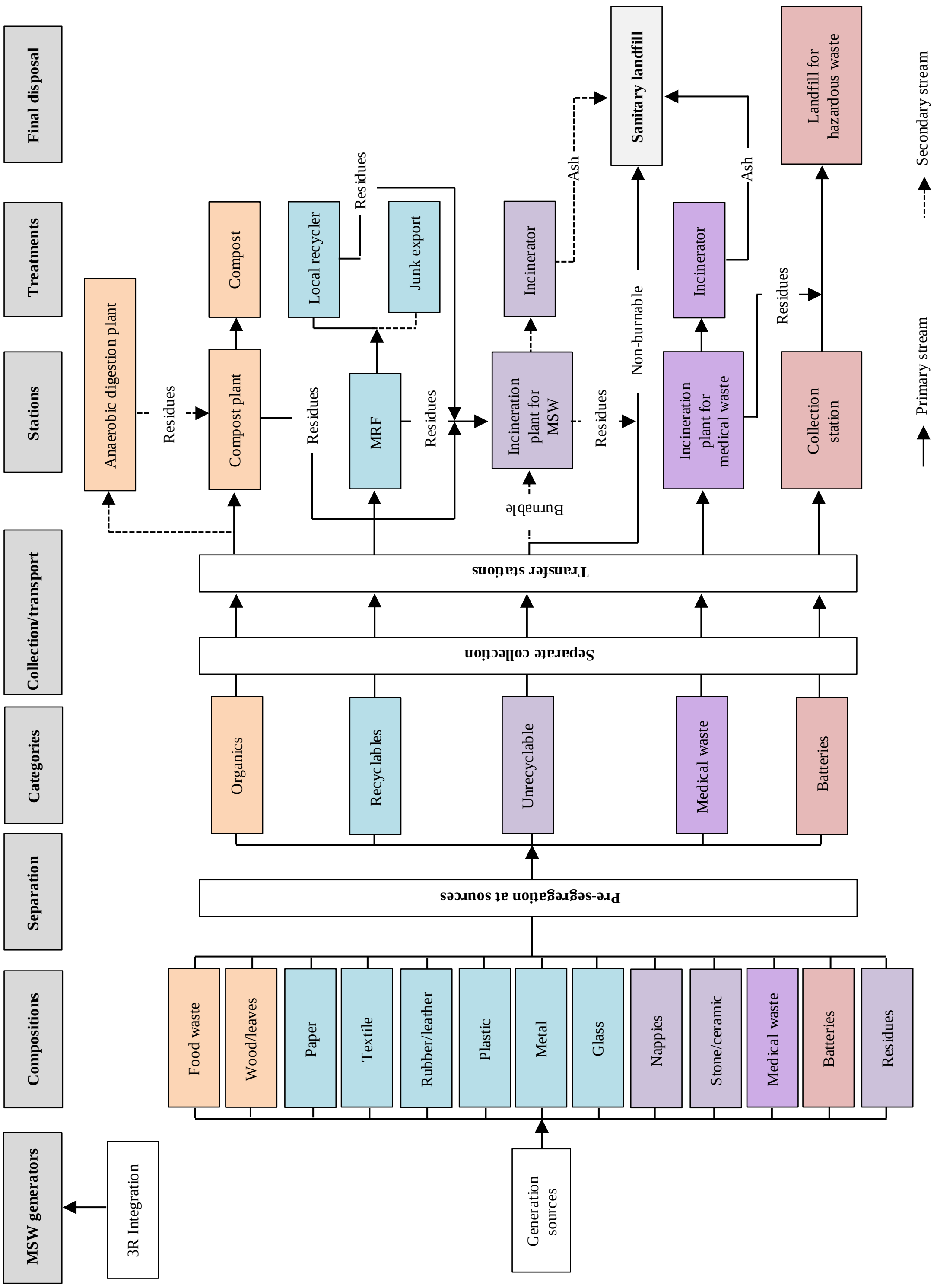

Fig. 2.3 Diagram of the proposed ISWM system (Seng, 2016)

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Chapter Three
Research Design and Methods

3.1 Introduction

The primary objective of this research was to assess the integrated management options of household solid waste (HSW) based on public's behaviours in Phnom Penh, Cambodia. The data collection started from August 6 to September 4, 2016, and August 5 to 31, 2017. The projection was made for the target year of 2025. Both primary and secondary data were collected from field observation, key informant interviews, household questionnaire survey, waste generation and composition study, and estimates of greenhouse gas (GHG) emissions. Fig. 3.1 present a diagram of the research's conceptual framework.

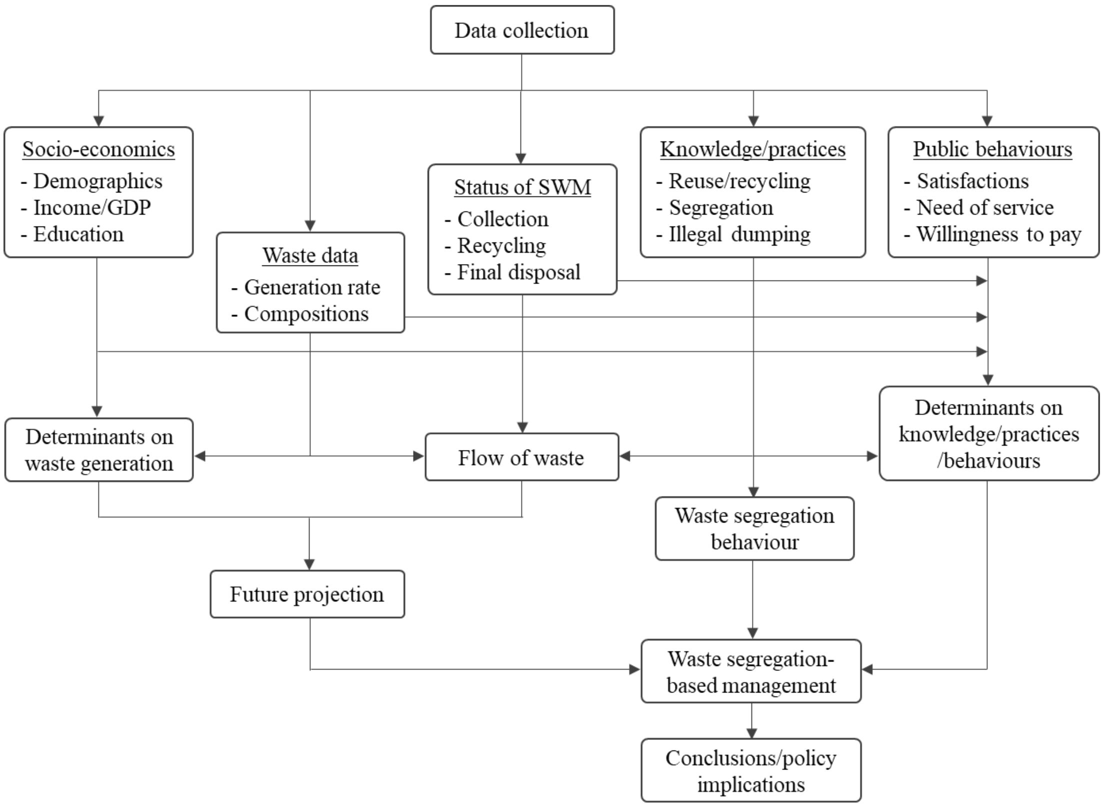

Fig. 3.1 Diagram of the research framework

3.2 Study area

The study took place in Phnom Penh, the capital of Cambodia at 11°33' North and 104°55' East (Fig. 3.2). In the year 2007, the total generated waste in the city was about 1,159 Mg/day, and the collection rate achieved only 81% (Phong, 2010 cited by Hoklis and Sharp, 2014). With a slight improvement in 2009, the management service reached about 82.1% collection of 1.31 Gg/day waste generated (Seng et al., 2013). Since 2010, the PPCH had widened the city's area of 376.17 to 678.47 km^2 (PPCH, 2011) and placed 20 new outskirt communes out of the collection coverage (Hul et al., 2015; Denney 2016). The city had 96 communes in 12 districts, and the population density was about 2,468 per km^2 (MoP, 2013). CINTRI

(Cambodia) Ltd. run municipal waste collection service over 76 communes by 2017 (CINTRI, 2017). Approximately 75.18% of 260,544 homes were service-registered users (PDPC, 2015). Five districts situate in the outskirt of the city and are considered suburbs that experience fast-growing development. It shared about 38.76% of the total population in the capital in 2015 (PDPC, 2016). However, only 45.67% of 98,816 homes in these districts registered the collection service in 2014 (PDPC, 2015). Solid waste disposed of into the dumpsite was about 1.86 Gg/day in 2015 (Seng et al. 2018).

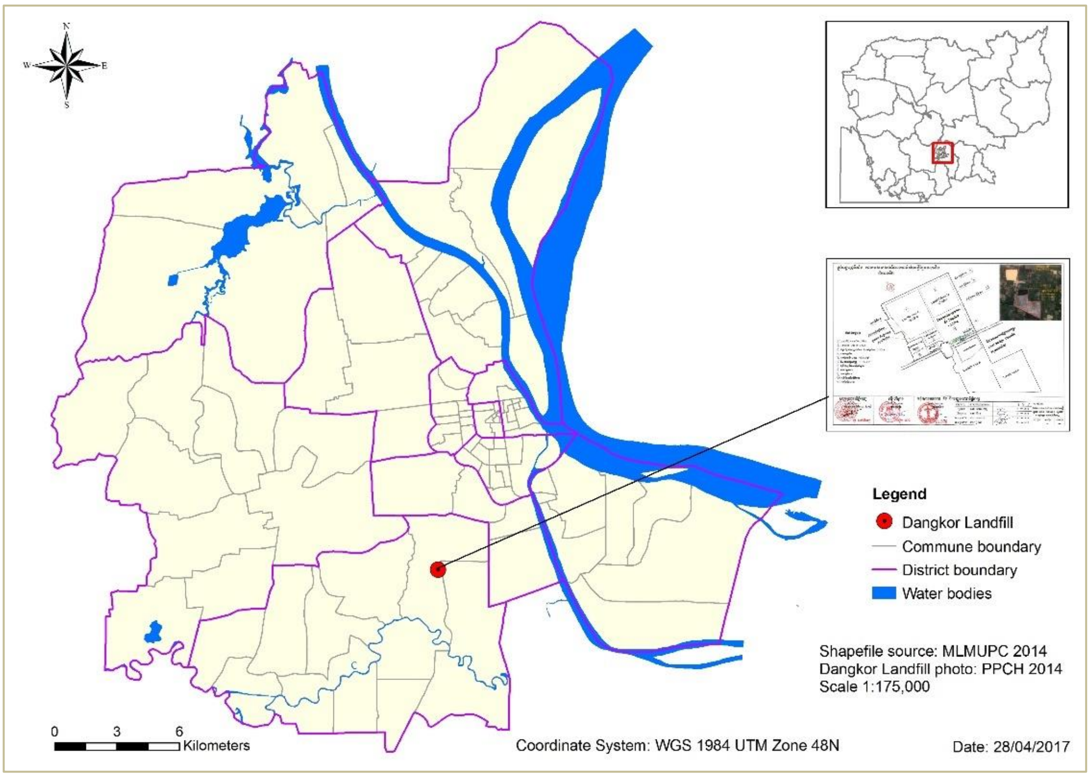

Fig. 3.2 Map of Phnom Penh city

3.3 Empirical data collection

Field observation was carried out to understand the situation of waste management and the practice of illegal dumping in the area. Authorities and residents were interviewed to collect data on SWM status, collection service, and KAP using a semi-structured questionnaire. The information was used to design a structured questionnaire for the household survey. Also, we visited a) Department of Solid Waste Management/Ministry of Environment, b) Phnom Penh Department of Environment, c) Office of Solid Waste Control/Phnom Penh City Hall, and d) CINTRI (Cambodia) LTD to collect secondary data. The data included [1] solid waste collection and disposal, [2] self-treatment activities, [3] informal waste recycling, and [4] implementation of waste pre-segregation at the source.

3.4 Questionnaire interview

A set of structured questionnaires was prepared for the door-to-door-household interview which was used throughout the research depending on the objectives of each case study (Appendix 1). The questionnaire had four sections. The first one was about general socio-economic information of the respondents and their families such as age, gender, types of house, household size, education, occupation and income. The second part focused on SWM service in the area including the public perspectives regarding access to collection service, collection frequency, tipping fee, satisfaction and WTP for improved service as well as for starting the waste collection if the service were not accessible. Then, we prepared questions about HSW generation and disposal. Individual respondent was asked to estimate their average WGR, types of waste and handling methods. A list of 27 sub-compositions of waste and eight handling methods was enlisted for the interview in this section. The term 'illegal dumping' sounded unethical, so we avoided using it. The practice of illegal dumping was counted if the respondents ever burned, buried, or littered waste. In the final part, we made enquiries of related knowledge about environmental and health problems caused by waste, pre-sorting and willingness to segregate for discharging. To disclose any misunderstanding of the questionnaire, we performed a pre-test by interviewing ten residents. The enumerators were well trained before the study started. We coded and entered the data in EpiData and rectified misentry before analysis in R Studio.

3.5 Waste generation and composition study

This study aimed to estimate WGR and compositions of HSW in the city and the determinant factors on generation. The sample size selection was following the number recommended by Nordtes method (Nordtest, 1995), and the waste sample was directly collected from houses every 24 hours for one-week sampling per specific study area. Therefore, WGR per capita and household per day could be calculated. Solid waste was manually sorted into 13 main compositions as shown in Table 3.1. Multiple linear regression models were developed to assess how socio-economic elements would affect the waste production, and the best suitable variables for the models were chosen by application of the best subset regression (Hocking and Leslie, 1967). Table 3.2 presents the assessment criterion of the models

Table 3.1 Waste compositions

Waste compositions	Explanations
1. Food waste	Food residues, snack, beverage, etc.
2. Garden waste	Leaves, trim, branches, grass, animal excreta, soil, etc.
3. Wood	Wood-made products, timber, firewood, etc.
4. Paper	Tissue, office paper, newspaper, magazine, booklet, cardboard, carton, paper containers, tickets, calendar, wrapping paper, etc.
5. Plastic	PET, a shopping bag, foam plastic, resin, film, plastic bottle, packed plastic, plastic wrapping, sack, etc.
6. Metal	Ferrous can, ferrous scraps, aluminium scraps, copper, metal and non-metal wrapping, etc.
7. Glass	Glass bottle, broken glasses, etc.
8. Textile	Cloth, fabric, wool, cotton, etc.
9. Leather and rubber	Leather products, rubber products.
10. Nappies	Napkins, disposable nappies, sanitary products, etc.
11. Stone and ceramic	Stone, ceramic, brick, concrete, inert materials, etc.
12. Hazardous waste	Rechargeable and non-rechargeable batteries, medical waste, and waste electrical and electronic equipment.
13. Others	Dust, fine particles, etc.

Table 3.2 Model's assessment criterion for determinants on waste generation

Assessment criterion	Abbreviation	Explanation	Preferred value
Akaike information criterion Bayesian information criterion	AIC BIC	Criterion for model selection	Low in value
Coefficient of determination	R^2	Predictable power of dependent variable	Closer to one
Mallow's Cp statistics	Cp statistics	Assessment norm of regression fitness	Closer to number of variables
Residual standard error Mean square error Root means square error Mean absolute error	RSE MSE RMSE MAE	Measurement of prediction's accuracy	Closer to zero

Source: Hocking and Leslie, 1967; Pardoe, 2006; James et al., 2013; Hoang et al., 2017a

3.6 Knowledge, attitudes, and practice

The study on knowledge, attitudes and practice (KAP) was carried out in only five outskirt districts of Phnom Penh where SWM service seemed insufficient. KAP refers to the ways that individuals are aware of, think of, and behave toward the SWM that would be the key to solving problems (Kiran et al., 2015). We emphasised the awareness of waste-related problems (water pollution, air pollution, etc.) and health effects caused by waste (infectious diseases, skin infections, etc.). The attitudes were about the public's satisfaction with SWM status, collection service, collection frequency and tipping fee. In the case of practice, we raised an observation concerning the illegal dumping. Households were grouped into service-registered households (HH_UCVs) and non-registered households (HH_NCVs). The determinants on KAP were analysed using maximum likelihood method of the logistic regression model. Socio-economic factors (age, income, gender and education) were the independent variables in the assessment. The logistic regression models were evaluated using the goodness of fit (GOF) tests including coefficient of determination (R^2), Chi-square, Hosmer-Lemeshow test (Hosmer and Lemeshow, 2000) and Wald statistics (Hu et al., 2006).

3.7 Willingness to pay

According to Bateman and Willis (2001), Willingness to pay (WTP) is the price that individual would contribute to the provided public goods. One of the commonly used approaches in WTP evaluation is the contingent valuation method (CVM) which measures economic concepts for nonmarket services and goods with theoretical scenario studies. It is an empirical approach and one of the monetary evaluation methods that help calculating mean, median and maximum WTP values for benefit-cost and policy analyses (Whitehead and Haab, 2013; Ferreira and Marques, 2015). Many researchers had applied this method in determining the public perceptions toward environmental management services including curbside recycling program (Blaine et al., 2005), improved waste management facility (Afroz and Masud, 2011), and waste collection system (Afroz et al., 2009; Awunyo-Vitor et al., 2013; Ferreira and Marques, 2015; Maskey and Singh, 2017).

Furthermore, WTP is associated with income, household conditions, environmental attitudes, etc. (Bateman and Willis, 2001). Afroz et al. (2009), Afroz and Masud (2011) and Maskey and Singh (2017) found that education, income, consciousness about solid waste management and satisfaction with collection service have significantly positive impacts on households' willingness. Awunyo-Victor et al. (2013), unlikely, pinpointed a negative effect of income on WTP and amount of money offered by residents. Other conditioning variables that presented significant effects on willingness included the age of respondents, health awareness (Patrick et al., 2017), and the amount of waste bag (Awunyo-Victor et al. 2013). Therefore, it is crucial to identify the relationship of WTP with the socio-economic and environmental factors.

The study selected contingent valuation method (CVM) to evaluate public's WTP for waste collection service. CVM has various elicitation methods such as open-ended, iterative bidding, payment card, and single and N-bounded dichotomous choice formats. The open-ended question, which asks the respondents to answer their own unbounded or unprompted WTP valuation (Frew et al., 2003), would draw out a true WTP (Bateman and Willis, 2001). The iterative bidding approach allows the interviewees to accept or reject the values which would continuously be lowered or raised as suggested by the interviewers. This approach would cause biases and underestimates as the starting and bidding values of WTP questions would influence the results (Halstead et al., 1991). The payment card or payment scale approach enables a selection of a prespecified WTP value from the same ordered list or cards. The dichotomous choice formats ask a randomly starting value that is predetermined by the observers, and the respondents are supposed to accept or reject the offer values (Frew et al., 2003). The dichotomous formats were recommended by Whitehead and Haab (2013) to avoid biased and underestimated results. However, the elicitation effects would still occur in any approaches (Bateman and Willis, 2001). Therefore, the open-ended form seemed to be the least biased option and was elicited for the assessment. The effects of socio-economic and KAP factors were analysed in the logistic regression model on WTP (positive and negative responses), and in Tobit models on bid values of both HH_UCVs and HH_NCVs. The GOF of the models were assessed using methods as same as in KAP's models.

3.8 Potential emissions of GHGs

The potential GHGs emitted from such practices were calculated using IPCC 2006 Model, an inventory software developed by Intergovernmental Panel on Climate Change (IPCC) to implement "2006 IPCC Guidelines for National Greenhouse Gas Inventories". This program could estimate the emissions of GHGs from the waste disposal site, biological treatment, and incineration/open burning. Emissions of methane (CH_4) from disposal site is based on First Order Decay (FOD) method (IPCC, 2006). Fig. 3.3 presents decision tree for CH_4 emissions from disposal sites with options of Tier 1, 2 and 3. The GHG emissions of IPCC 2006 Model could be estimated by two options: a multi-phase model based on waste composition data and single-phase model based on bulk waste. Material degraded in a specific year would be interpreted into CH_4 by an exponential factor of the FOD model. However, generation and emission of CH_4 would vary from disposal site to another, and it depends on methane correction factor (MCF), as shown in Table 3.3, and degradable organic carbon (DOC) in waste. In case of open burning, the emission factor is 6.5 kg/Mg of wet waste for CH_4 and 0.15 kg/Mg of dry residue for nitrous oxide (N_2O) calculation, and the oxidation of carbon input is 0.58 for carbon dioxide (CO_2) estimate (IPCC, 2006). The emission values of GHGs were converted to CO_2 equivalent ($CO_{2\text{-eq}}$) by multiplication with the 100-year global warming potential index shown in Table 3.4.

Table 3.3 Default values of MCF

Type of disposal sites	Default values of MCF
Managed – anaerobic	1.0
Managed – semi-aerobic	0.5
Unmanaged – deep (> 5m waste) and/or high-water table	0.8
Unmanaged – shallow (< 5m waste)	0.4
Uncategorised	0.6

Source: IPCC, 2006

Table 3.4 Global warming potential index

Type of GHGs	The 100-year global warming potential index (CO_2-eq)
CO_2	1
CH_4	25
N_2O	298

Source: IPCC, 2006

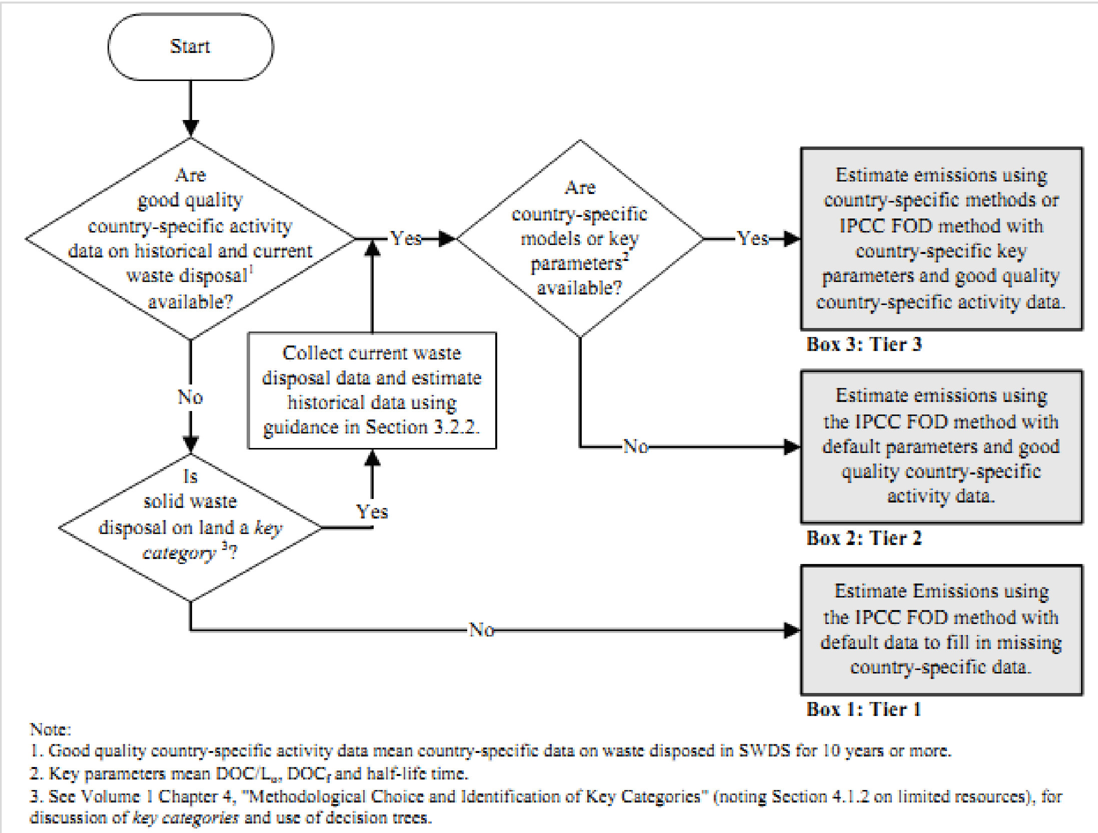

Fig. 3.3 Decision tree for CH_4 emissions from solid waste disposal sites (IPCC, 2006)

3.9 System dynamic modelling

System dynamics refer to simulation methods that provide and analyse situations and projection of behaviours changing overtimes. This technique of modelling is principally used for business and policy purposes (Duggan, 2016). It was first introduced in the 1960s by Jay Forrester at the Massachusetts Institute of Technology (Chaerul et al., 2008). The basic building block of the system dynamics includes stock and flow. A stock is the system's component giving details of mathematical state; it can be called a state variable. Flow is a rate of the component whose inflow and outflow would change a stock (Guo et al., 2016; Duggan, 2016). Therefore, a unit of a flow is a function of stock changing over a period of time. A system dynamic model also consists of converters and connectors (Guo et al., 2016; Sukholthaman and Sharp, 2016). A converter is to change rate and convert unit or is called auxiliary variable. A connector is an arrow to link the causal relationship between variables in the model. Fig. 3.4 presents a diagram of stock and flow in the system dynamics.

Four important steps need to be followed to build a model: 1) identification of stock, 2) formulation of equations for the flows, 3) determination of the time units (day, month, year) and 4) confirmation of the time interval (start and finish time) (Duggan, 2016). By this mean, it is also important to identify the modelling objectives, boundary, key variables and basic mechanisms of the system (Albin, 1997).

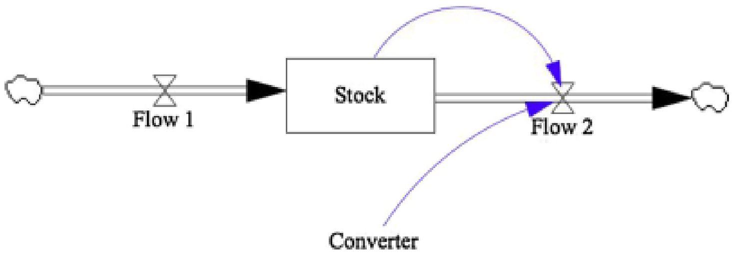

Fig. 3.4 Stock and flow diagram in system dynamics (Guo et al., 2016)

In this study, the management system of HSW in Phnom Penh was modelled using system dynamics. Fig. 3.5 shows a causal loop diagram of HSW management which is a system boundary for modelling drawn in software Vensim PLE 7.3.5. The causal loop diagram presents a closed chain of cause-and-effect connection (Sukholthaman and Sharp, 2016) that a state variable affects an auxiliary variable and in turn would alter the value of the state variable (Duggan, 2016). The connections between variables can be positive (+) and negative (-) depending on the same or opposite direction of changes caused by one variable on the other variable (Talyan et al., 2006). In brief, it is expected that population growth positively affects the amount of HSW that leads to a larger volume of illegal dumping and disposal into dumpsite as well as the environmental pollutions. Treatments and awareness raising about source-segregation and self-treatment are considered options that would change the management system.

However, the diagram of the causal loop is not for modelling (Albin, 1997) unless it is converted to stock-and-flow diagram or, in another word, a quantitative model (Talyan et al., 2006). These diagrams are useful systems to disclose possible scenarios for sustainable SWM (Prasetyanti et al., 2014). The quantitative models in this study are detailed in a case study in Chapter Seven.

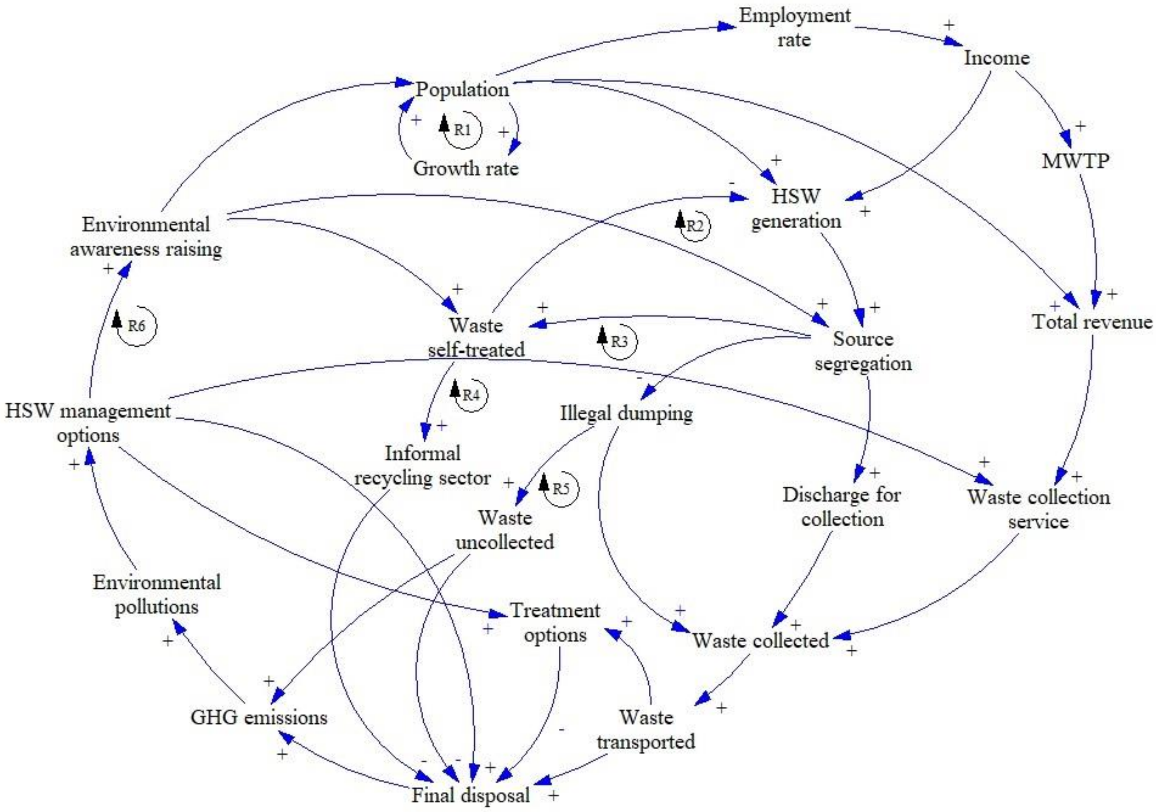

Fig. 3.5 Causal loop diagram of HSW management

3.10 Structural equation modelling

In social science, the structural equation model (SEM) is usually developed to observe public behaviour (Rosseel, 2012). Notably, many researchers applied this method to identify the factors that influence the behaviour of waste segregation (Bortoleto et al., 2012; Zhang et al., 2015; Yuan et al., 2016; Xu et al., 2017). It provides necessary information about the individual's perception that is needed for HSW management. Mostly used variables include knowledge, situation factor, experience and attitudes. In this study, we evaluated the households' willingness toward waste segregation promoted by the Phnom Penh City Hall. As realised, the residents usually sort the valuable materials to reuse and sell to the recycling market. Therefore, the effects of the experience, knowledge and situation factor were assessed using the SEM package of R software, 'lavaan'. Fig. 3.6 explains the path diagram of SEM in this study. The assessment consists of 12 observed and 4 latent variables, and the segregation willingness is the endogenous variable.

The measurement model of situation factor: consists of three observed variables 'No time to segregate waste', 'No law enforcement' and 'No public participation' that are expected to present positive effects. However, since it is negative in meaning, this measurement variable would have a negatively direct relationship on the latent variable of separation willingness.

The measurement model of knowledge about waste: includes three variables that have a path coefficient of direct relationship. The variables are ‘awareness of waste-related problems’, ‘awareness of recycling’ and ‘awareness of segregation’. They are assumed to affect the measured variable positively and significantly. Moreover, this measurement model is expected to present positive effects on segregation willingness.

The measurement model of segregation experience: contains three variables such as ‘sort for sale’, ‘reuse’ and ‘illegal dumping’ that the householders are exercising to handle their waste. They have direct impacts on the segregation experience. In assumption, the influence of the illegal dumping is expected to be negative since the residents who practice illegal dumping would not be concerned with separation. The other variables are likely to have a positive relationship. The path coefficient of this measurement model toward the segregation willingness would be either positive or negative depending on the effect of the practice of illegal dumping.

The measurement model of segregation willingness: has three variables namely ‘willingness to segregate waste’, ‘willingness to reduce waste’ and ‘willingness to reuse waste’ that present direct and positive relationship. It also involves a joint effect between knowledge, experience and situation factor.

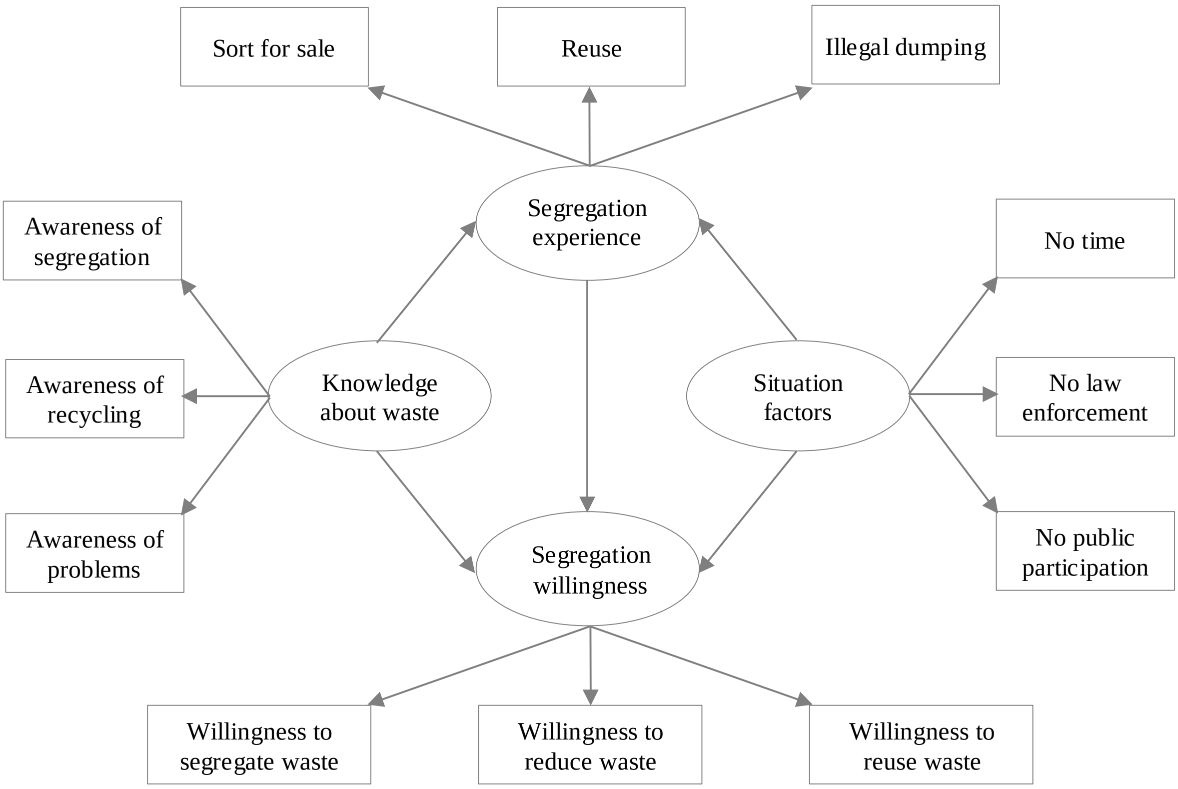

Fig. 3.6 Path diagram of a developed SEM

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Chapter Four
Household Solid Waste Generation and Determinants

4.1 Introduction

Solid waste is an urban environmental issue that the world is facing. It has placed severe pressure on sustainable development in many low- and middle-income countries (Sujauddin et al., 2008; Al-Khatib et al., 2010; Welivita et al., 2015). The poorly managed waste usually scatters in open spaces and threatens environmental quality and public health (Tadesse et al., 2008). Waste generation rate (WGR), globally, is about 1.2 kg/capita/day, and residential area which generates household solid waste (HSW) is one of the primary sources (World Bank, 2012) that should be well-managed. The intensity of waste generation would change as a function of population, economy, and time (Sankho et al., 2012; Kawai and Tasaki, 2015) when observation of WGR and characteristics will provide useful facts and figures (Qu et al., 2009; Oribe-Garcia et al., 2015). However, the management planning needs not only well-grounded data of WGR but also determinant factors that affect the variations (Sukholthaman et al., 2015). Many methods have been utilised to analyse the effects: Bayesian model average (Hoang et al., 2017a), linear regression (Thanh et al., 2010; Gu et al., 2015), logistic regression (Tadesse et al., 2008), and best subset regression (Oribe-Garcia et al., 2015). The commonly used variables are demographic data (age distribution, household size), economic indicators (income, employment rate, gross domestic product), social elements (commercial and tourist activities), geographic data (dwelling size, urbanisation level), and environmental attributes (waste separation and recycling activities).

In the case of Cambodia, the annual amount of waste countrywide was estimated at 4,960 Gg/year or 318 kg/capita/year in 2012 (Uch et al., 2014). Solid waste management faces challenges, especially in Phnom Penh capital, due to deficiencies of technical and financial resources (JICA, 2005; Kum et al., 2005). The city experiences urbanisation and economic growth when the number of the population gradually grew from 0.81 million in 1994 (MoP 2008) to 1.45 million in 2015 (PDPC, 2016). The waste amount in the city seems to increase linearly to about 677.22 Gg/year in 2015 (Seng et al., 2018) 227.91 Gg/year in 2004 (Spoann et al., 2018). An inhabitant in Phnom Penh generated only 0.762 kg/day of solid waste in the same year but would produce about 1.24 kg/day in 2030, as estimated by Hul et al. (2015). Of the total generation, HSW proportionately shared about 62.9% in 2003 (JICA, 2005) and 55.3% in 2014 (Hul et al., 2015). It seems that the share of waste generated from the residential area has decreased, yet it would still require critical considerations as it is weighty to consider the proper management rigorously. Only two studies, nevertheless, had been performed to observe HSW generation in the city so far: JICA (2005) and Hul et al. (2015). Groups of households were classified based on their income level, education and professions to discuss differences in WGR. Determinants on waste production have not been analysed regardless of their importance to management forethought.

Hence, there remain some gaps in HSW research in Cambodia regarding the determinants factors affecting the waste generation that need to be fulfilled. Otherwise, the management measures cannot be proposed. This study aims to estimate the HSW generation rate and characteristics in Phnom Penh City and analyse the influences of socio-economic factors on waste production using multiple linear regression models. It presents the updated data on the waste generation that would be necessary for further researches about waste management.

4.2 Material and methods

4.2.1 Study area

Based on collection coverage and geo-demographic facts, we geographically clustered the city into four zones for stratified random sampling (Fig. 4.1). Zone1 situates in 20 communes of Chbar Ompov, Chrouy Changva, Dangkor, Pouthisen Chey and Praek Phnov district that was newly integrated into Phnom Penh's administration (PPCH, 2011). It remains uncovered by the waste collection service (CINTRI, 2017). Zone2 shares the same districts with Zone1, and its collection rate is moderate. Zone3 locates in Mean Chey, Russey Keo and Sen Sok district where the collection covers about 87.97% of the households. Zone4 is in the central city (7Makara, Chamka Morn, Daun Penh and Toul Kork district) where achieves the collection close to 100% (PDPC, 2015).

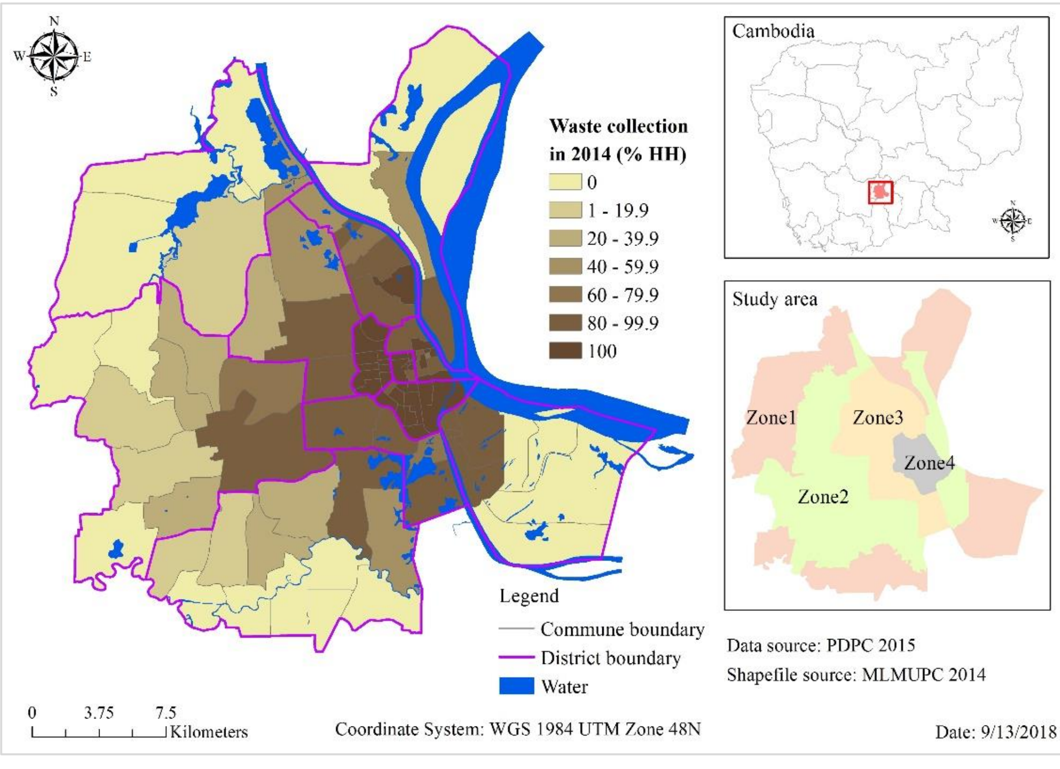

Fig. 4.1 Waste collection coverage in Phnom Penh city

4.2.2 Household survey

The door-to-door household survey was executed in two phases using a stratified random sampling method to discover the general situation of waste management practices and the socio-economics in the area. The first phase started from August 6 to September 4, 2016, in Zone1 and Zone2 and the other one was in Zone3 and Zone4 from August 5 to 31, 2017.

Respondents in each zone were selected randomly and grouped as users and non-users of the waste collection service. Table 4.1 presents the number of households engaged in the survey that were 1,280 in total. The study purposively took 400 samples in each of Zone1 and Zone2, more extensive than in Zone3 and Zone4 where the sample size was only 240 each due to difficulties of interviewing residents. The researchers ensured the understandability of the questionnaire by pre-testing and by careful training to keep the enumerators in a state of readiness. A structured questionnaire was developed after the field observation to interview householders from door to door. Individual respondents were asked regarding their socio-economic information (age, gender, household size, education level, occupation and income).

Table 4.1 Number of the sample for questionnaire and waste generation survey

<table>
<tr><th rowspan="2"></th><th rowspan="2">Total population in 2015 [a]</th><th rowspan="2">Total households in 2014 [b]</th><th rowspan="2">Service-registered households as % in 2014 [b]</th><th colspan="2">Number of households (sample)</th></tr>
<tr><th>Questionnaire survey</th><th>Waste generation survey</th></tr>
<tr><td>Zone1</td><td>161,617</td><td rowspan="2">98,816</td><td rowspan="2">45.67</td><td>400</td><td>120</td></tr>
<tr><td>Zone2</td><td>399,384</td><td>400</td><td>120</td></tr>
<tr><td>Zone3</td><td>479,006</td><td>84,719</td><td>87.97</td><td>240</td><td>120</td></tr>
<tr><td>Zone4</td><td>407,333</td><td>77,719</td><td>98.88</td><td>240</td><td>120</td></tr>
<tr><td>Total</td><td>1,447,340</td><td>260,544</td><td>75.18</td><td>1,280</td><td>480</td></tr>
</table>

[a] PDPC, 2016; [b] PDPC, 2015

4.2.3 Waste generation and composition study

Generation of HSW was observed to estimate the WGR and to analyse waste compositions. The study was executed after the household interview had been completed zone by zone. Initially, we explained the study's purposes and asked the respondents to participate in the investigation. If they agreed, the research team would provide 45L black plastic bags and instructions for storing the waste generated during each 24-hour day for a sampling period of seven days. The sample size for waste composition should be between 100-200 homes for a study in one community and 40-100 homes for the study observing socioeconomic and geographic conditions and housing situation (Nortest, 1995). We, hence, purposely selected 120 homes per zone, and the total samples included 480 homes with consideration of their income, employment rate, type of house, household size, location and access to the waste collection. The total samples included 480 homes.

Every morning, the research team went from house to house, met the residents, and confirmed the waste was generated within one day. The garbage bags were then labelled with coding tags and taken to the designated collection point. We weighed the garbage, bag by bag, using handy electronic scales and recorded the weights in a worksheet that identified each waste generators. A group of six well-trained research assistants oversaw the manual sorting into 13 main types and 27 sub-compositions. The main components included food, garden, wood, paper, plastic, metal, glass, textile, leather/rubber, nappies, stone/ceramic, hazardous and other types of waste.

4.2.4 Statistical analysis

An average of the daily WGR per household was compared between zones and divided by the number of household members to acquire WGR per capita (Hoang et al., 2017b). Analysis of variance (ANOVA) was examined to identify the statistical significance of differences in HSW generation rate and compositions between the residential locations (Edjabou et al., 2015; Suthar and Singh, 2015). The differences were significant unless the probability (p) value was smaller than 0.05 (Al-Khatib et al., 2010). We analysed standard deviation (SD), variance, skewness, kurtosis, boxplot and the density of WGR to discover the data distribution and outliers (Hoang et al., 2017b). An overall WGR in the city (WGR_{cap}) was calculated using the weighted average of means from a single zone (Eq. 4.1), as recommended for stratified random sampling by Sahimaa et al. (2015) and Hoang et al. (2017b).

$$WGR_{cap} = \left(\sum_{i=1}^{Z} \left(n_i * WGR_{cap_i} \right) \right) \Big/ N \qquad (4.1)$$

where WGR_{cap_i} is an average WGR per capita in zone i (kg/day); n_i is the number of households surveyed in zone i, N is the total number of households surveyed in the study; and Z is the number of zones.

The study measured the determinants of WGR using the multiple linear regression expressed in Eq. 4.2 (Thanh et al., 2010; Gu et al., 2015). Eleven independent variables, as shown in Table 4.2 were firstly evaluated in Pearson's correlation test to address the strength of linear bivariate association and statistical significance level based on p-value (Dowdy et al., 2004). The best subset approach was used to select highly significant and explainable predictors and build the linear regression models (Hocking and Leslie, 1967).

$$Y = \alpha + \beta_j X_j + \varepsilon \qquad (4.2)$$

where Y is the dependent variable (WGR); β_j is the slopes that indicate the average change in the dependent variable; X_j is the independent variables; α is the intercept; and ε is the average random error.

We divided the dataset into a 70% training dataset for model development and a 30% testing dataset for validation. Possible models were then developed and evaluated by Akaike information criterion (AIC), Bayesian information criterion (BIC), the coefficient of determination (R^2), residual standard error (RSE) and Mallows' Cp statistic. The model should result in a high R^2 closer to 1. The preferred RSE, a measurement of the predictions' accuracy, would be small in value when comparing the models (Pardoe, 2006). The AIC and BIC values - the criteria for model selection - were supposed to be the lowest (James et al., 2013), and the Mallows's Cp statistic - an assessment norm of regression fitness - should be close to the number of variables used in the models (Hocking and Leslie, 1967). We compared mean square error (MSE), root means square error (RMSE), and mean absolute error (MAE) between the results of the training and testing dataset for validation. The MSE, RMSE and MAE should be close to zero to prove that the model was perfectly fitted. The validity of the model would be achieved if the RMSE of the two datasets were similar. The independent variables, therefore, would be predictable (Hoang et al., 2017a). The study analysed the data using R software.

Table 4.2 Variables in multiple linear regression

Observed variables	Symbol	Type	Explanation
Income	X_{Inc}	Continuous	The total monthly income
Household size	X_{Siz}	Continuous	Total household member
Number of children	X_{Chi}	Percentage	% of children younger than 18 years old
Number of adults	X_{Adu}	Percentage	% of people aged between 18-65 years old
Number of elders	X_{Eld}	Percentage	% of people ages older than 65 years old
Employment rate	X_{Emp}	Percentage	% of income generator in each household
Engagement in home business	X_{Bus}	Dummy	1 = Yes (if a household engages in business) 0 = No
Engagement in agriculture	X_{Agr}	Dummy	1 = Yes (if a household engages in agriculture) 0 = No
Home garden	X_{Gar}	Dummy	1 = Yes (if a household has the home garden) 0 = No
Access to SWM service	X_{SWM}	Dummy	1 = Yes (if a household accesses the service) 0 = No
Urbanisation level	X_{Urb}	Cardinal	1 = Zone1 (Rural) 2 = Zone2 (Suburban) 3 = Zone3 (Urban) 4 = Zone4 (Central)

4.3 Results and discussions

4.3.1 Socio-economic status

The study omitted 118 incomplete questionnaires and analysed the responses of 1,242 households, including 388 from Zone1, 380 from Zone2, 239 from Zone3, and 235 from Zone4. The survey results that the female respondents are about three fourths in all zones or approximately 74.96% on average when the male respondents are about 25.04%. Mostly, they are between 30-49 years old at 43.08%, and the average age is at about 40 years old in all zones (Zone1: 46.20, Zone2: 44.62, Zone3: 43.23 and Zone4: 46.04) or about 45.11 years old on average of all zones. Regarding the education, the illiterate level seems to be high in Zone1 (15.98%), Zone2 (16.84%) and Zone3 (10.46%). Most of the respondents in these three zones only attend the primary school (Zone1: 38.92%, Zone2: 31.84%, and Zone3: 37.24%). Zone4 has the highest number of residents who enter the university at about 12.77%. On average, only 5.48% of them could pursue a university degree. The illiterate people are about 13.29% while about 33.74% receive only the primary school education. It seems that the people, in general, could acquire a low education level.

Household size ranged from 1 to 19 and was 4.87 on average, as same as the statistics of MoP (2013) that the family size was about 4.8 in the urban area of Cambodia. Many of the households have the number of members more than five (54.59%). Zone1 has the smallest average size at 4.64, and Zone2 has the highest average size at 4.96. In two other zones, the household size is 4.93 in Zone1 and 4.84 in Zone3. On a monthly base, the households in Zone2 earn the lowest income of 647.20 USD on average when the families in Zone4 generate the average income at 1061.45 USD, the highest rate among all zones. The monthly income of households, in Zone1, is 666.10 USD and 735.03 USD in Zone3. Based on the statistics, Zone4 seems to present the highest living standard. On a weighted number of all zones, the greatest number of households at 39.77% make income less than 500 USD/month, followed by 33.65% who get more than 500 USD/month. On average, they generate income about 748.39 USD/month. Table 4.3 describes the descriptive statistics obtained from the questionnaire survey.

Table 4.3 Descriptive statistics (%)

		Zone1	Zone2	Zone3	Zone4	Average
Gender	Female	75.77	71.58	76.57	77.45	74.96
	Male	24.23	28.42	23.43	22.55	25.04
Age	< 30	12.63	17.89	20.92	13.19	15.94
	30-49	42.01	43.42	43.52	43.83	43.08
	≥ 50	45.36	38.68	35.56	42.98	40.98
	Mean	46.20	44.62	43.23	46.04	45.11
	SD	13.62	14.90	15.14	14.73	14.51
Education level	Illiterate	15.98	16.84	10.46	5.96	13.29
	Primary school	38.92	31.84	37.24	24.68	33.74
	Secondary school	26.55	29.74	27.62	30.21	28.42
	High school	15.21	18.42	19.25	26.38	19.08
	University	3.35	3.16	5.44	12.77	5.48
Household size	1-2	5.93	9.29	6.28	10.21	7.84
	3-4	36.34	31.27	40.17	47.23	37.59
	≥ 5	57.73	59.47	53.55	42.55	54.59
	Mean	4.93	4.96	4.84	4.64	4.87
	SD	1.64	2.10	1.83	1.94	1.87
Household monthly income (USD)	< 500	42.01	43.16	39.33	31.06	39.77
	500-750	30.41	27.63	27.20	17.87	26.57
	> 750	27.58	29.21	33.47	51.06	33.65
	Mean	666.10	647.20	735.03	1061.45	748.39
	SD	500.80	471.93	829.33	1271.88	701.08

4.3.2 HSW generation rate

The missing data of 68 households were omitted, and the analysis processed the waste data of 412 households including 107 in Zone1, 102 in Zone2, 104 in Zone3, and 99 in Zone4. The generation rate varied from zone to zone, but there were no statistically significant differences among the locations. The ANOVA resulted in F-values of 0.072 ($p > 0.05$) for WGR per household and 0.275 ($p > 0.05$) for per capita. Table 4.4 presents the results of statistical analysis of HSW generation. Generation rate ranged between 0.29 to 11.74 kg/household/day or 0.19 to 1.96 kg/capita/day. Per households, the average WGR in Zone2 was the highest at 2.52 kg/day, followed by the rate of 2.43 in Zone3, 2.3 in Zone4, and 2.28 in Zone1. WGR per capita was a result of waste produced by each household in a day divided by the household size (Suthar and Singh, 2015; Hoang et al., 2017b). With the lowest mean of household size, the WGR per capita in Zone4 ranked the highest at 0.512 kg/capita/day. The rate was lower in the other zones, 0.507 kg in Zone3, 0.498 kg in Zone2, and 0.492 kg in Zone1. Fig. 4.2 presents the boxplot and density of WGR. The distribution of the WGR seems normal and positively skewed, similarly to the finding of Hoang et al. (2017b). The generation density in Zone2, Zone3, and Zone4 have likely distribution, unlike Zone1 where the peak is the lowest. Most of the inhabitants produced HSW between 0.50 to 0.749 kg/capita/day.

Table 4.4 Statistical analysis of WGR (kg/day)

	Per household WGR				Per capita WGR			
	Zone1	Zone2	Zone3	Zone4	Zone1	Zone2	Zone3	Zone4
Mean	2.28	2.52	2.43	2.30	0.492	0.498	0.507	0.512
SD	1.74	1.30	1.06	1.54	0.40	0.22	0.25	0.24
Minimum	0.58	0.29	0.71	0.63	0.19	0.20	0.23	0.29
Maximum	11.74	6.35	7.02	11.15	1.96	1.16	1.61	1.39
Variance	3.04	1.69	1.12	2.36	0.16	0.05	0.06	0.06
Skewness	2.58	0.83	1.54	2.95	2.09	1.16	2.08	1.77
Kurtosis	8.05	0.36	3.07	13.11	4.062	0.897	4.696	2.951

WGR per day in Phnom Penh was 2.382 kg/household, or 0.502 kg/capita on average, which was indifferent to 0.498 kg/capita in 2014 (Hul et al., 2015) and slightly higher than 0.487 kg in 2003 (JICA, 2005). The rate (kg/capita) was lower in some cities, 0.06 – Dehradun, India (Suthar and Singh, 2015), 0.21 – Cape Haitian, Haiti (Philippe and Culot, 2009), 0.25 – Chittagong, Bangladesh (Sujauddin et al., 2008), 0.23 – Beijing (Qu et al., 2009) and 0.28 – Suzhou, China (Gu et al., 2015), 0.223 – Hoi An (Hoang et al., 2017b) and 0.285 – Can Tho, Vietnam (Thanh et al., 2010). In contrast, the WGR in Abuja, Nigeria was 0.634 kg capita/day (Ogwueleka, 2013), higher than in Phnom Penh city. By multiplication of an average WGR per capita with 1,808,445 population data in 2017 (MoP, 2017), the total amount of HSW per day was 907.98 Mg/day or 331.41 Gg/year. It was more significant than the amount of waste generated in 2003, 213.20 Gg/year (JICA, 2005) when the total population was 1.04 million (MoP, 2008), and the average household income was about

469.58 USD/month. It proves that the waste quantity has increased due to population and economic growth (Levis et al., 2013).

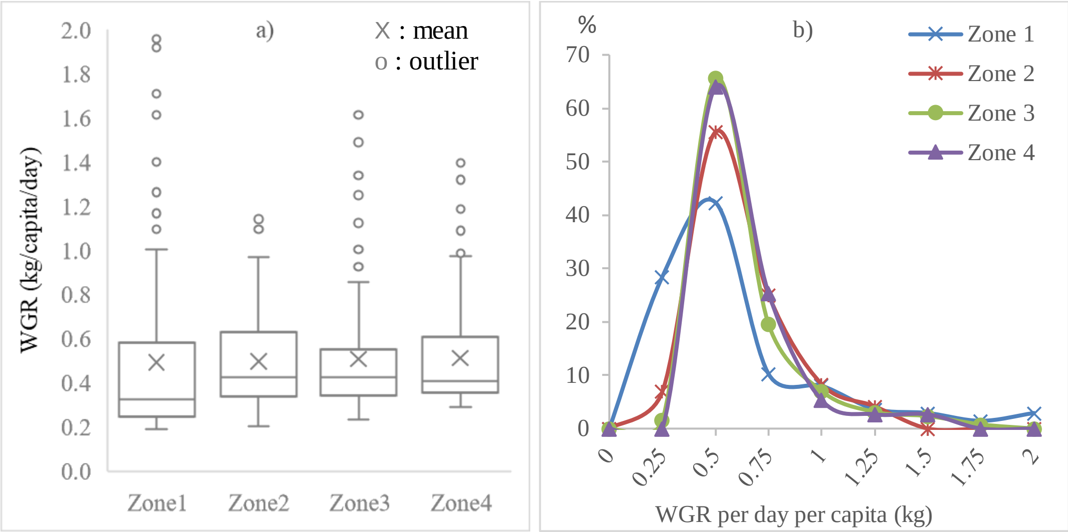

Fig. 4.2 a) Boxplot of WGR and b) density of WGR

4.3.3 HSW compositions

A total HSW of 6.842 Mg was manually sorted. On a wet basis, food waste was the largest component of HSW with a share of 52.49% on average, followed by 18.37% of plastic and 11.70% of garden waste (Table 4.5). In comparison with previous results, the proportion of food waste has notably decreased as it was about 63.6% in 2003 (JICA, 2005) and 57.4% in 2014 (Hul et al., 2015). The percentage of plastic in these studies is comparable. The share of food waste would increase as socio-economic conditions improve (Suthar and Singh, 2015). Moreover, the fraction of garden waste is about five times larger than in 2014 and two times larger than in 2003 for two reasons: 1) the city expansion that included the rural area under administration and 2) gardening and farming that most households in the suburbs engaged. Nappies, wood, and hazardous waste, found by this study, were not recorded in the previous ones. Hazardous waste included batteries, medical waste, and e-waste (RGC, 2015). Fig. 4.3 compares the sub-compositions of HSW among all four zones.

In some cities, food represents the biggest proportion of waste but is likely to be larger than in Phnom Penh. It was about 80% in Dehradun, India (Suthar and Singh, 2015); 62% in Chittagong, Bangladesh (Sujauddin et al., 2008); 69.3% in Beijing (Qu et al., 2009) and 65.7% in Suzhou, China (Gu et al., 2015); and 84.18-85.10% in Can Tho, Vietnam (Thanh et al., 2010). None of them, unexpectedly, had a proportion of plastic more massive than Phnom Penh. The generation of eight HSW types (plastic, garden waste, paper, metal, glass, ceramic/stone, hazardous waste, and others) have significant statistical differences between zones ($p < 0.05$). Food waste was constituent to HSW and comparable in all four zones while Zone2 seemed to generate a significant portion of garden waste but the lowest percentage of plastic and paper. Reasons for the differences involve dissimilarities of habits, economic structures, urbanisation levels, geographical locations, and lifestyles (Suthar and Singh, 2015; Hoang et al., 2017b). Recyclables shared about 19.58% of the total HSW.

Table 4.5 HSW characteristics in Phnom Penh (%)

	2003	2014	2016-2017 (between zones)			
	(JICA, 2005)	(Hul et al., 2015)	Mean	SoS	MS	F-value
Food waste	63.6	57.4	52.49	549	183.1	0.617
Plastic	18.0	18.1	18.37	2,800	933.4	9.355 ***
Garden waste	6.0	2.5	11.70	18,661	6,220.0	46.690 ***
Paper	4.6	5.9	5.89	629	209.2	8.834 ***
Nappies	-	-	3.23	233	77.6	1.338
Textile	2.5	2.6	1.95	8	2.6	0.192
Metal	0.7	1.1	1.62	267	89.1	6.323 ***
Glass	0.6	1.4	1.27	120	40.1	3.828 **
Leather/rubber	0.1	0.2	0.92	13.6	4.5	0.894
Wood	-	-	0.68	6.6	2.2	1.097
Ceramic/stone	1.6	0.6	0.29	9.7	3.2	3.021 **
Hazardous waste	-	-	0.21	2.5	0.9	5.076 ***
Others	2.3	10.2	1.38	438	145.8	4.245 ***

SoS: sum of square, MS: mean square, ** p-value < 0.01, *** p-value < 0.001

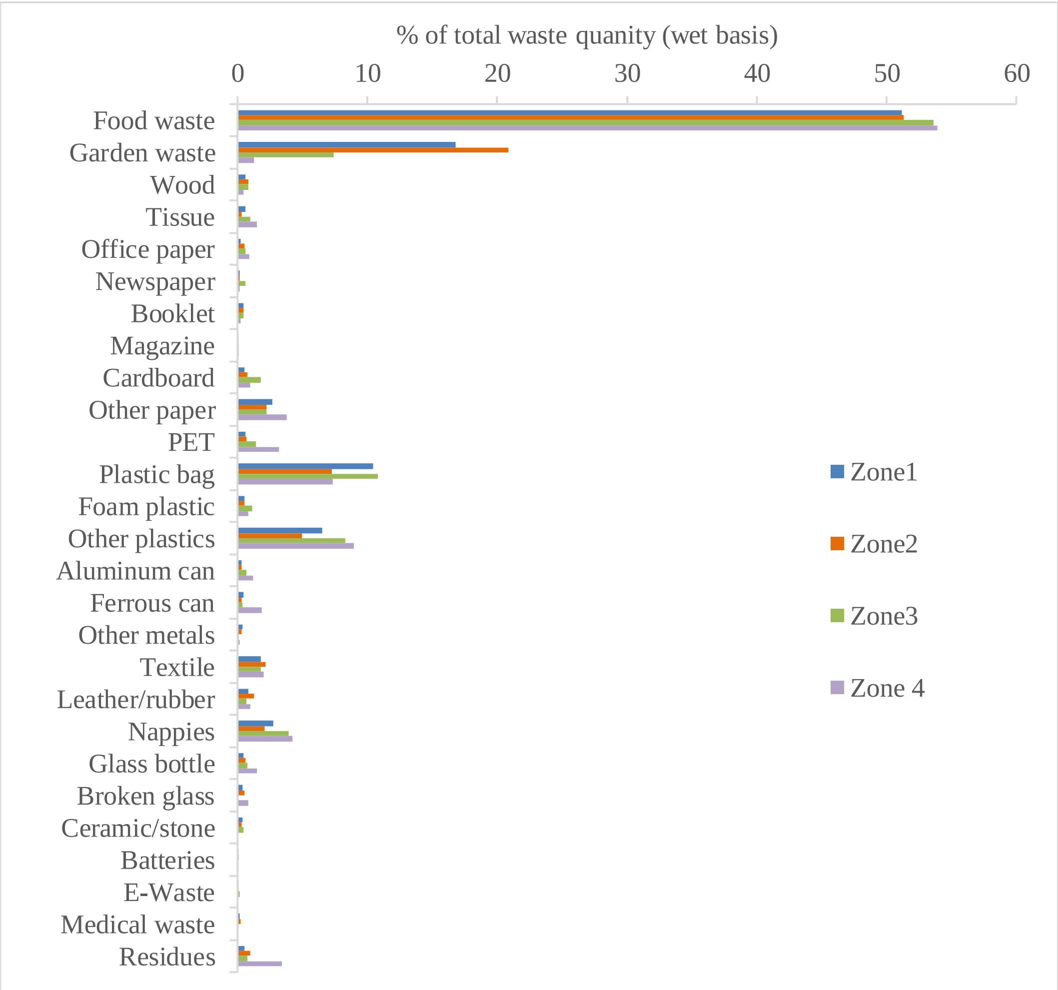

Fig. 4.3 HSW sub-compositions by zone

4.3.4 Determinants of waste generation

The correlation result between WGR per household and per capita was significant and positive ($\beta = 0.77$, $p < 0.001$). The income (X_{Inc}), household size (X_{Siz}), and engagement in home business (X_{Bus}) present a significantly positive relationship with WGR per household ($p < 0.001$). On the other hand, five variables including household size (X_{Siz}), number of children (X_{Chi}), number of adults (X_{Adu}), employment rate (X_{Emp}), and engagement in home business (X_{Bus}) have a significant correlation with WGR per capita ($p < 0.001$). Three variables of them are positive; yet X_{Siz} and X_{Chi} are negative which are also found by Hoang et al. (2017) in Hoi An, Vietnam (Table 4.6). Since the data collected as of household-based variables, we run the regression models with the dependent variable of WGR per household.

Table 4.6 Correlation results between predictor variables and waste generation

Predictor variables	WGR (household/day)	WGR (Capita/day)
WGR (household/day)	-	0.77***
X_{Inc}	0.23***	0.02
X_{Siz}	0.32***	-0.25***
X_{Chi}	-0.05	-0.15***
X_{Adu}	0.06	0.15***
X_{Eld}	-0.01	-0.02
X_{Emp}	0.07	0.20***
X_{Bus}	0.17***	0.14***
X_{Agr}	0.03	0.03
X_{Gar}	0.02	-0.04
X_{SWM}	0.08	0.06
X_{Urb}	0.01	0.03

*** $p < 0.001$

The best subset provides five possible models from five different predictors (Table 4.7). Model 1, with one variable of X_{Bus}, has the lowest R^2 (0.272) and the highest values of the other assessment criteria (RSE, AIC, BIC, and Cp statistic), so it is not suitable for prediction. The two variables of X_{Bus} and X_{Siz} in Model 2 do not qualify to be selected in comparison to the rest of the models. Model 3, 4 and 5 present likely evaluation results. Model 4, with four variables regressed, has the best Mallows's Cp statistic of 4.71, the highest adjusted R^2, and the lowest AIC of -529.862 while Model 3 has the lowest BIC value of -511.165. Both models achieve the same RSE of 0.096, and their adjusted R^2 values are not different (Model 3 = 0.333 and Model 4 = 0.336). The R^2 values seem low, but they usually do not exceed 50%, according to Lebersorger and Beigl (2011) and Hoang et al. (2017a). Hence, we chose Model 3 and Model 4 for the validation analysis as they would express better and more precise estimations.

In Model 3, the three variables of X_{Bus}, X_{Siz} and X_{Emp} have a positive and significant effect on the changing of WGR per household when the intercept was about 0.0004. With an extra predictor of X_{Inc}, Model 4 gets the intercept of 0.004, and all the variables are also significant and positive. The result indicates that the increase in income, household size, employment rate and engagement in home business would noteworthily lead to the growth of waste generation per household unit. The parameter estimates could be written for Model 3 (eq. 4.3) and Model 4 (eq. 4.4).

$$Model\ 3: Log\ (WGR_{HH}) = 0.0004 + 0.109X_{Bus} + 0.179X_{Siz} + 0.075X_{Emp} \quad (4.3)$$

$$Model\ 4: Log\ (WGR_{HH}) = 0.004 + 0.106X_{Bus} + 0.156X_{Siz} + 0.063X_{Emp} + 0.073X_{Inc} \quad (4.4)$$

Table 4.7 Results of the regression models

	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	0.106***	0.053***	0.0004	0.004	0.025
X_{Bus}	0.123***	0.109***	0.109***	0.106***	0.107***
X_{Siz}	-	0.153***	0.179***	0.156***	0.155***
X_{Emp}	-	-	0.075**	0.063*	0.043
X_{Inc}	-	-	-	0.073	0.073
X_{Chi}	-	-	-	-	-0.033
R^2	0.274	0.322	0.340	0.345	0.347
Adjusted R^2	0.272	0.318	0.333	0.336	0.335
F-value	108.50***	67.98***	48.82***	37.37***	30.01***
RSE	0.100	0.097	0.096	0.096	0.096
AIC	-506.294	-524.050	-529.497	-529.862	-528.586
BIC	-495.265	-509.384	-511.165	-507.864	-502.921
Cp statistic	29.273	10.508	5.041	4.710	6.000
Number of variables	1	2	3	4	5

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Fig. 4.4 presents diagnostic plots of linear regression from Model 3 and Model 4. The plot of residuals versus fitted values shows that the residuals of both models seem to scatter near a horizontal line equally. A linear relationship between the predictors and the dependent variable exists. The normal quantile-quantile (Q-Q) plot displays the distribution of residuals, and they seem to lie customarily. The spread of residuals in a scale-location plot proves homoscedasticity as the residuals horizontally spread. The plot of residuals versus leverage shows no influential outliers since the residuals are all inside of Cook's distance. Due to diagnostic plots, the data satisfies the linear estimation of the models. For model validation, the value of MSE, RMSE, and MAE of Model 3 and Model 4 are low and alike. Their results are also comparable between the training and testing datasets (Table 4.8). Therefore, the validation demonstrates a good fit for both models; yet Model 4 seems better for R^2.

Table 4.8 Models' validation

Model	Datasets	R^2	RSE	MSE	RMSE	MAE
Model 3	Training	0.340	0.096	0.009	0.096	0.064
	Testing	0.282	-	0.015	0.124	0.079
Model 4	Training	0.345	0.096	0.009	0.096	0.064
	Testing	0.277	-	0.015	0.124	0.079

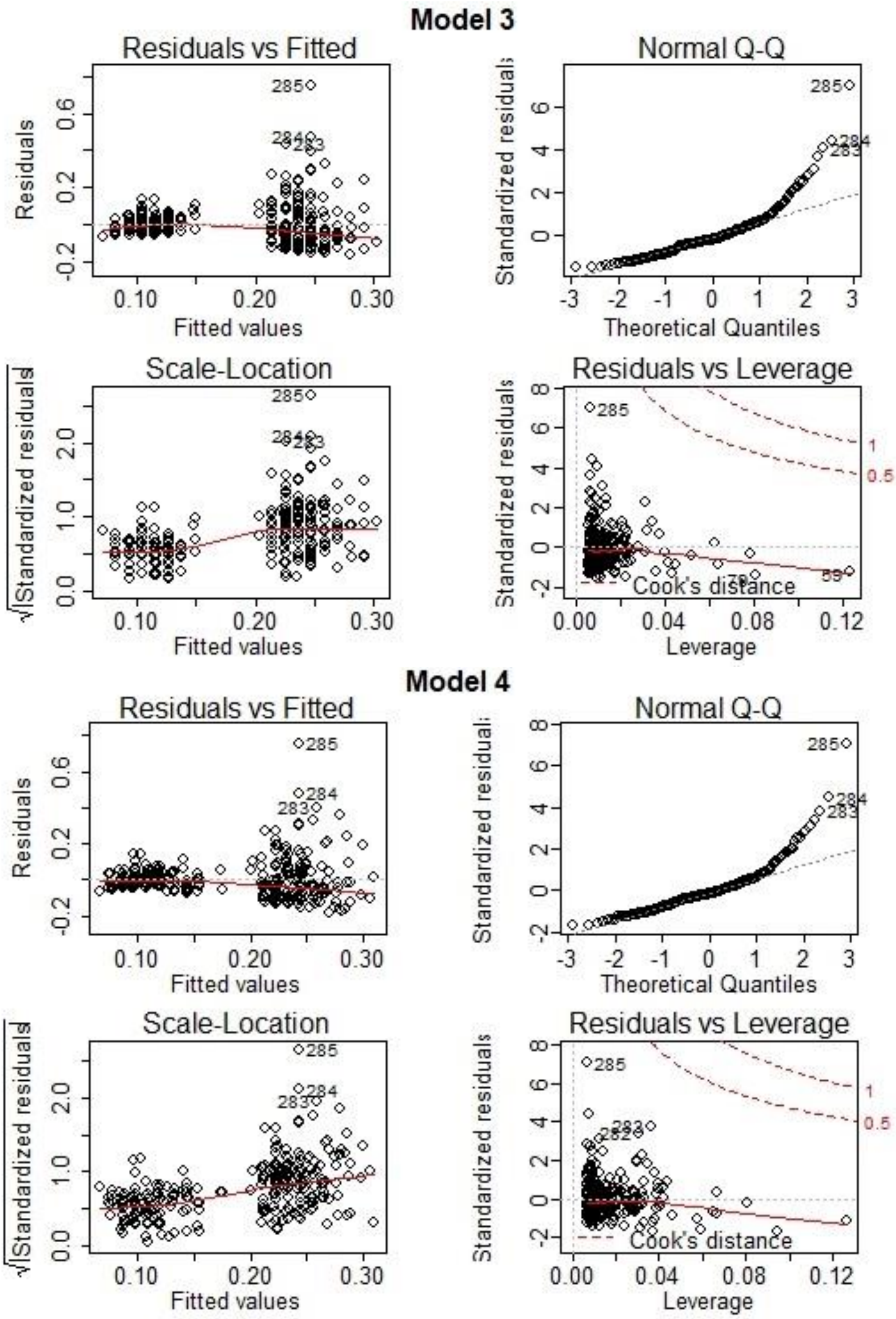

Fig. 4.4 Diagnostic plots of the linear regression models

4.4 Conclusions

The study estimated the generation rate and characteristics of the household waste in Phnom Penh City, Cambodia. The multiple linear regression models for waste production were evaluated. The study could be concluded as follows:

- The daily waste generation rate was about 0.502 kg/capita on average, and the residents living in the central area seemed to generate the highest rate per capita.
- Waste generation rate is comparable between zones even though it has a relationship with income, household size and engagement in home business. Many waste compositions would be varied from zone to zone since they are significantly affected by urbanisation level. However, generation of food waste, the largest composition, has no relationship with the urbanisation.
- About a half of household waste was made up of food residuals followed by plastic, garden waste, and paper. More importantly, food waste, plastic and garden waste are the three major components that should be highly considered in the management works, and so is hazardous waste that should not be mixed and disposed of with household solid waste.
- The linear regression models revealed significant factors affecting household waste generation. These included the positive effects of income, household size, employment rate, and engagement in the business of individual households.
- Such indicators can be useful in the prediction and planning of solid waste management. Time-series data of these related variables, nevertheless, are necessary for estimating the future amount of waste generation. As such, the studies should have been regularly performed.

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Chapter Five
Household Solid Waste Management and Handling Methods

5.1 Introduction

Solid waste management (SWM) in Phnom Penh, capital of Cambodia, is an authority of Phnom Penh City Hall (PPCH) that includes collection, transportation, recycling, and final disposal (Kum et al., 2005). Since 2002, collection and transportation have been franchised to CINTRI (Cambodia) LTD. The waste data which totalled up to 1.31 Gg/day in the city is likely not to include uncollected waste that was about 17.9% of the total generation in 2009 (Seng et al., 2013) owing to inaccessibility to waste collection, especially in the suburban areas. Up to 24.8% of the total household have no access to the collection service (PDPC, 2015). Fig. 5.1 presents the waste collection coverage in 2013. The red-marked areas have no service covered, and the blue-coloured region has about 80% to 100% of households using the service. The activities of open burning, burying and littering of waste are reported by Seng et al. (2010), Sethy et al. (2014), Kham and Daniel (2015) and Denny (2016). Moreover, waste was usually handled by various self-treatments (Seng et al., 2010) including reuse, recycling and sale to junk buyers (Uch et al., 2014). The residents indirectly participate in the recycling by sorting and selling such recyclables including paper, metal and plastic to the informal sector (Seng et al., 2010; Uch et al., 2014). It shows that the locals appear to take various conventional methods to treat their waste. The quantity of household solid waste (HSW) flow has not been updated since 2003, a study by JICA (2005).

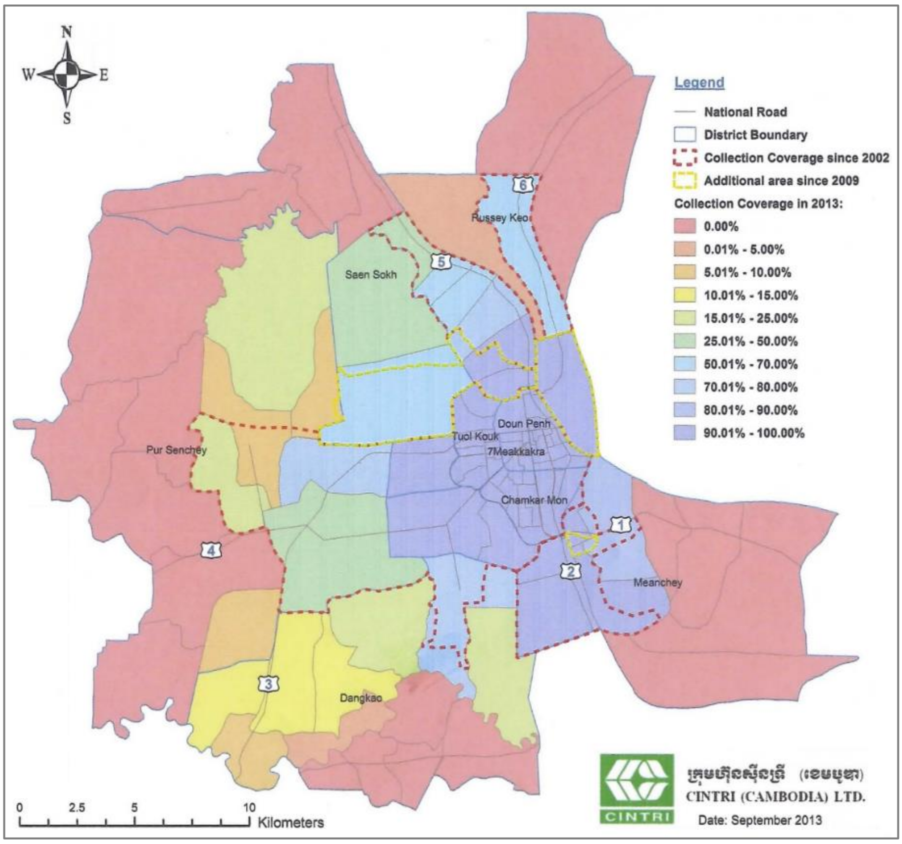

Fig. 5.1 Waste collection coverage in Phnom Penh city in 2013 (CINTRI, 2017)

Another matter of fact is related to source pre-segregation of waste into wet and dry things. It has been introduced since 2015 by a new sub-decree on solid waste management issued by RGC (2015). The wet waste refers to the organic matters which contain rich moisture, and the dry residue is inorganic including paper, plastic, metal and others that can be recycled. Source pre-segregation is a required action to recover valuable materials and to better manage the waste (Seng et al., 2018). However, the public awareness of the issue is unknown. There are no such reports regarding the implementation of waste segregation. Unsorted waste is still discharged and collected.

The collected waste is disposed of into Stung Mean Chey dumpsite from 1965 to 2009 and Dangkor Landfill from 2009 till present (JICA, 2005; Kum et al., 2005; Seng et al., 2010). It is the only formal method for final waste disposal. There are no other treatment facilities equipped beside contributions of non-governmental organisation (NGO) and informal sector (Sethy et al., 2014). To be specified, aerobic composting of organic waste has been implemented by an NGO, Community Sanitation and Recycling Organization (CSARO), with a treatment capacity of 4 Mg/day (Seng et al., 2018) which produced about 35.6 tons/years of compost in 2015. It contributed to the waste reduction of 264.4 tons/year to final disposal (CSARO, 2015). The informal sector has involved in recycling activities through buying, picking and scavenging recyclables from house to house, in the public areas and the dumping sites. An exact number of people who engage in the informal sector is unknown. There were approximately 2,000 junk pickers/buyers in the city (Sang-Arun et al., 2011), and 300 of them were doing their job in the Dangkor Landfill which recovered about 607.07 Mg/month of recyclables (Seng et al., 2018).

The literature review shows that the HSW stands out as a significant proportion of solid waste in the city, yet the management service seems insufficient leading the locals to practice such self-treatment activities. In developing countries, big cities usually encounter difficulties in the management of household waste (Kapepula et al., 2007). It requires efficient measurement to enhance the situation, particularly to restrain the public from burning and littering waste. Since updated data on waste flow are not available; it is important to have reliable data that are useful for future management and planning. This present study analysed the management and handling methods of HSW in Phnom Penh. Emissions of greenhouse gases (GHGs) were also estimated from the potential activities of waste handlings. Results of the study would be baseline data for future scenario analysis.

5.2 Material and methods

5.2.1 Study area and data collection

This study took place in four divided zones of Phnom Penh city as a continuous observation from Chapter Four. Both primary and secondary data were collected for the research. Key informants from relevant institutions were interviewed to collect unpublished information due to a shortage of available data.

Individual respondents were first asked regarding the general situation about SWM including access to the collection, collection frequency, and satisfaction with collection frequency and management status. Then, the questions were about how they handle the waste in each action of reuse, recycling, sorting for sale, discharge for collection, open burning, burying and littering to open space and water environment. A list of 27 waste types was prepared, and the householders were suggested to answer concerning each of them. The final part focused on the public's knowledge and willingness to segregate their waste at home. In the section of separation willingness, the interviewers explained to the respondents about the importance of segregation before asking about their willing to participate. If the answer was positive, we introduced the segregation options that the respondents could select included two groups (organic and inorganic waste), three groups (organic, recyclable and non-recyclable waste) and four groups (organic, recyclables, non-recyclables and hazardous waste).

5.2.2 Statistical analysis

a. Handling of HSW

The total quantity of HSW generated in zone i (Q_i) was a result of multiplying the number of populations with an average WGR per capita in that zone. Moreover, the amount of waste composition x generated in zone i (Q_{x_i}) was calculated in eq. 5.1, and eq. 5.2 estimated the percentage of waste quantity handled by method m in Zone i Q_{m_i}. The number of households handling any methods, including reuse, recycling, sale, burning, burying, litter and discharge for collection, used in the calculation was the result of the questionnaire survey. Flow of the handling HSW was graphed using STAN 2.6 known as Substance Flow Analysis software.

$$Q_{x_i} = (Q_i * x_i)/100 \qquad (5.1)$$

$$Qm_i = \left(\sum_{x=1}^{w} \left(Q_{x_i} * Pmx_i \right) \right) \Big/ Q_i * 100 \qquad (5.2)$$

Where x_i is the percentage of composition x in Zone i; Pmx_i is the fraction of the number of households using method m among the number of households using all methods to handle waste composition x in Zone i; and w is the number of waste compositions.

b. Potential GHG emissions

The potential emissions of GHGs were calculated using IPCC 2006 Model (IPCC, 2006) for HSW handled by 1) collection for disposal, 2) open burning, 3) burying, 4) littering to open space and 5) scattering to water bodies. Household waste discharged for the collection was assumed to be collected and disposed of into the open dumpsite. Dangkor Landfill is the only one dumpsite in Phnom Penh whose depth is about 9m (Interview with Key Informants). In this case, the methane (CH_4) emissions were based on First Order Decay (FOD) the default value of parameters in Eq. 5.3 and Eq. 5.4, and so are emissions from buried and littered HSW. The methane correction factor (MCF) is 0.8 for disposal site and 0.4 for the other two cases (IPCC, 2006). Table 5.1 presents the default parameters in the calculation.

$$CH_4\ generated_T = DDOCm\ decomp_T * F * 16/12 \quad (5.3)$$

$$CH_4\ emissions = \left(\sum_x CH_4\ generated_{x,T} - R_T\right) * (1 - OX_T) \quad (5.4)$$

Where, CH_4 generated$_T$ is amount of CH_4 generated from decomposable material; DDOCm decomp$_T$ is DDOCm decomposed in year T (Gg); F is a fraction of CH_4, by volume, in generated landfill gas (fraction); 16/12 is molecular weight ratio CH_4/C (ratio); x is waste category or type/material; R_T is recovered CH_4 in year T (Gg); and OX_T is oxidation factor in year T.

Table 5.1 Default parameters in IPCC 2006 model

Parameters	Range	Default value
DOC_f		0.5
Delay time (month)		6.0
Fraction of methane (F) in developed gas		0.5
Oxidation factor (OX)		0.0
Conversion factor, C to CH_4		1.33
CH_4 correction factor (MCF) for depth of disposal site ≥ 5 m		0.8
CH_4 correction factor (MCF) for others		0.4
Degradable organic carbon (DOC: % wet weight)		
Food waste	0.08-0.20	0.15
Garden	0.80-0.22	0.20
Paper	0.36-0.45	0.40
Wood and straw	0.39-0.46	0.43
Textile	0.20-0.40	0.24
Disposable diaper	0.18-0.32	0.24
Methane generation rate constant (K/year)		
Food waste	0.17-0.70	0.40
Garden	0.15-0.20	0.17
Paper	0.06-0.085	0.07
Wood and straw	0.03-0.05	0.035
Textiles	0.06-0.085	0.07
Disposable diaper	0.15-0.20	0.17

Source: IPCC, 2006

In the case of open burning, the emissions of Carbon Dioxide (CO_2), Nitrous Oxide (N_2O) and CH_4 were calculated as shown in Eq. 5.5 and Eq. 5.6. Table 5.2 presents the dry content and default values for the calculation. The oxidation factor of carbon input is 58%. The emission factor (EF) of CH_4 is 6.5 kg/Mg of wet waste when the EF of N_2O is 0.15 kg/Mg of dry waste (IPCC, 2006). All the emissions were converted into Carbon Dioxide equivalent ($CO_{2\text{-}eq}$) based on the 100-year global warming potential index values: 1 time for CO_2, 25 times for CH_4 and 298 times N_2O (IPCC, 2007).

$$CO_2\ emissions = \sum_i (SW_i * dm_i * CF_i * FCF_i * OF_i) * 44/12 \quad (5.5)$$

where SW_i is the total amount of waste type i, dm_i is the fraction of dry matter content in wet-weight waste type i, CF_i is the fraction of total carbon in the dry matter, FCF_i is the fraction of fossil carbon in the total carbon, OF_i is the oxidation factor, 44/12 is the conversion factor from C to CO_2, and i is the type of waste open-burned.

$$CH_4/N_2O\ emissions = \sum_i (SW_i * EF_i) * 10^{-6} \qquad (5.6)$$

where EF_i is the aggregate CH_4/N_2O emissions factor (kg CH_4/N_2O per Mg-waste), 10^{-6} is the conversion factor from kg to Gg.

Table 5.2 Dry content and default values of CF_i and FCF_i of solid waste

Compositions	Moisture (%)	Dry content (%)	CF_i (%) [b]	FCF_i (%) [b]
Food waste	78.77 [a]	21.23	38	-
Garden waste	57.12 [a]	42.88	49	-
Wood	57.12 [a]	42.88	50	-
Paper	63.61 [a]	47.84	46	1
Plastic	18.37 [a]	86.11	75	100
Rubber and leather	18.09 [a]	81.91	67	20
Textile	44.28 [a]	55.72	50	20
Nappies	58.29 [a]	41.71	70	10
Others	22.73 [a]	77.27	3	50
Other inert waste	10 [b]	90	3	50

Source: [a] Seng et al., 2018; [b] IPCC, 2006

5.3 Results and discussions

5.3.1 Solid waste management

At the time of the questionnaire survey, the collection service served by CINTRI was being widened to the non-service area. The results show that Zone1 has about 6.70% of households register the collection service while many of them still do not. In Zone2, about 45% of households are the registered users of the service. Most of the people in Zone3 (86.61%) and Zone4 (0.85%) has access to the solid waste collection. Only the households in the poor communities seem not able to do so. On average, about 51.29% of total respondent households in the city has been served the waste collection service. Among the registered service users, the collection frequency seems to be varied according to their residential locations and road infrastructure. About 88.41% of households in Zone4 are served the daily basis of the collection, but only about 35.27% of households in Zone3 are, and none of the users in Zone1 is. The household in Zone1 and Zone2 mostly report reception of the collection service twice a week. On average, the most frequent collection service is served daily to about 40.44% of total households, followed by a frequency of twice a week to 24.47% and every other day to 18.58%. Table 5.3 presents the results of the solid waste management status in the city.

The people respond to the collection frequency that it is the most satisfactory in Zone4 about 57.94%, the highest rate among all zones. The satisfaction rate is only 38.46% in Zone1, 34.78% in Zone3 and 30.99% in Zone2. On average, about 40.84% of the total respondents are satisfied with the collection frequency. However, it is dissatisfactory to about 25.58% when about 33.58% of them did not respond with satisfaction or dissatisfaction. On the other hand, the overall management situation seems satisfactory to only 18.76% of the respondents. About 35.59% of them appear not to be satisfied when up to 45.65% is reported neutral, neither dissatisfied or satisfied with the management situation. Dissatisfaction happens toward the carelessness of the waste collectors that makes the collection incomplete and unclean. Infrequent and irregular service also causes a lack of satisfaction.

Table 5.3 Solid waste management status (%)

		Zone1	Zone2	Zone3	Zone4
Collection service	Registered	6.70	45.00	86.61	99.15
	No	93.30	55.00	13.39	0.85
Collection frequency	Daily	-	7.02	35.27	88.41
	Every other day	26.92	16.96	33.33	6.44
	Twice a week	38.46	47.37	16.91	3.00
	Once a week	23.08	22.22	11.11	2.15
	Less than once a week	11.54	6.43	3.38	-
Satisfaction with collection frequency	Dissatisfied	26.92	34.50	38.65	3.43
	Neutral	34.62	34.50	26.57	38.63
	Satisfied	38.46	30.99	34.78	57.94
Satisfaction with management status	Dissatisfied	43.30	48.16	23.01	15.32
	Neutral	46.39	38.95	49.79	51.06
	Satisfied	10.31	12.89	27.20	33.62

5.3.2 Pre-segregation of HSW

The results of the questionnaire survey concerning the knowledge of waste pre-segregation show that only about 43.88% of the respondents, on average, are aware of. Many of them are the collection of service users residing in Zone3 (55.23%) and Zone4 (60%), as shown in Table 5.4. Only about one-third of households from Zone1 and Zone2 are knowledgeable. Nevertheless, none of the residents has involved in segregating their HSW into wet and dry waste for disposal even notwithstanding the facts that the segregation was introduced and promoted by the city hall and the sub-decree of waste management (RGC, 2015). The respondents only sort waste for reuse, recycling and sale. Five main barriers make the practice of waste pre-segregation at the household scale unsuccessful (Fig. 5.2). Mainly, it is related to the law enforcement which is seen as insufficient or ineffective by about an average of 61.27% households. Inactive participation from their neighbours also seems to be a reason for about 60.06% families. Another matter of facts is the non-existence of the waste separation system from collection to final disposal. There were several campaigns in the city centre, but the demonstrations could not be sustained since waste is still mixed while collected. Likely, pre-segregation seems not unachievable to introduce in the non-collection service area (Interview with key informants). Lack of incentives is one of the reasons leading to unsuccessful waste separation even though this practice is lawfully mandated (Fujii, 2008; Agamuthu et al., 2009).

Table 5.4 Knowledge of segregation and willingness to segregate (%)

		By service users		By zone			
		HH_UCV	HH_NCV	Zone1	Zone2	Zone3	Zone4
Knowledge of segregation	Yes	50.86	36.53	34.79	36.05	55.23	60
	No	49.14	63.47	65.21	63.95	44.77	40
Willingness to segregate	1 Group	22.76	44.79	46.91	45.53	14.23	11.49
	2 Groups	68.60	51.40	49.74	52.11	74.90	75.74
	3 Groups	7.69	3.80	3.35	2.37	9.62	11.49
	4 Groups	0.94	-	-	-	1.26	1.28

HH_UCV: service-registered households, HH_NCV: non-registered households

The research team also explained the importance of pre-segregation to all respondents. We then asked if they would segregate their waste in the future. About 33.49% of them, on average, address no interest to participate since the current problems could not be solved. Most of them are from Zone1 and Zone2 who have no access to the collection service. However, up to 66.51% are willing to segregate their waste, it is 88.51% from Zone4, 85.77% from Zone3, 54.47% from Zone2 and 53.09% from Zone1. Noticeably, it seems possible to introduce waste pre-segregation into two groups (organic and inorganic waste) as major respondents have the willingness. Only a small number would sort into three groups (organic, recyclable and non-recyclable waste) and four groups (organic, recyclable, non-recyclable and hazardous waste).

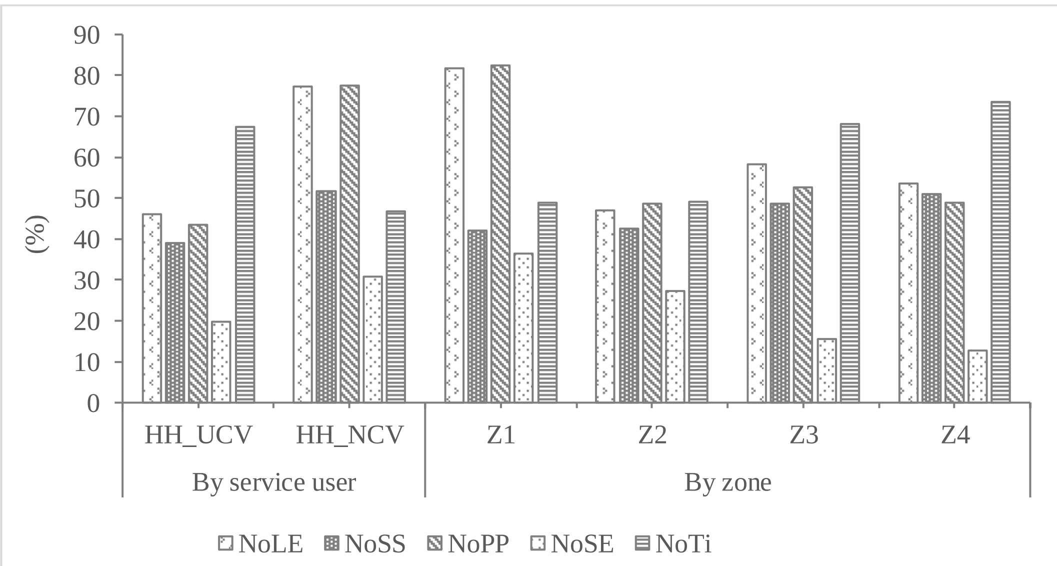

Fig. 5.2 Reasons for not segregating (NoLE: no law enforcement, NoSS: no segregation system, NoPP: no public participation, NoSE: no segregation equipment, NoTi: No time)

5.3.3 HSW handling methods

Eight different methods were locally used to handle HSW, including reuse, recycling, sale, discharge for collection, burning, burying, littering to open space, and littering to water/canal (Table 5.5). Most of the households sorted their waste for reuse, recycling and sale. They usually utilised food and garden waste to feed the animals (cattle, poultry and pets) and produced organic fertiliser. This is a reason that the number of households recycling waste seemed high in Zone1 (70.1%) and Zone2 (35%) where many people still engaged in agricultural activities. Unlikely, up to 84.68% of the households in Zone4 could reuse their useful materials including booklets, cardboard, glass and plastic bottles, clothes (textiles), and plastic bags. Most of the residents also sorted such valuable materials to trade with the informal sector (junk buyers), and the ratio was likely comparable in all zones. Selling plastic, paper, metal, glass, rechargeable batteries and e-waste to junk buyers was one of the customs which was also carried by the commercial sector (Mongtoeun et al., 2014). It also happens in many cities of the developing countries that could be beneficial for local livelihoods (Wilson et al., 2006; AIT/UNEP RRC.AP, 2010; Linzner and Salhofer, 2014). Another way was to exchange the used clothes with homemade products (such as traditional mats) produced by rural families. Rice residues were usually sun-dried and traded with animal feed producers which did not happen in Zone1 and Zone2 because they instead utilised it for their animal and gardening. The practice of reuse and recycling have statistical significance in differences between zones ($p < 0.001$).

Table 5.5 Handling methods of HSW (% of households)

	Recy-cling	Reuse	Sale	Discharge for collection	Illegal dumping				
					Burning	Burying	L_OS	L_WC	Overall
Zone1	70.10	16.24	94.33	6.19	92.53	20.88	46.39	6.19	93.81
Zone2	35.00	11.58	77.37	46.32	47.11	8.68	23.42	3.16	58.16
Zone3	9.21	27.20	88.28	87.87	18.83	4.60	12.13	7.53	30.13
Zone4	3.83	84.68	88.94	99.57	0.85	0.43	1.28	0.85	2.55
HH_UCV	7.69	45.21	87.13	99.69	6.12	0.63	2.98	2.51	10.20
HH_NCV	63.97	13.72	86.78	1.49	92.73	20.17	46.61	6.61	98.84

L_OS: littering to open space, L_WC: scattering to water/canal, HH_UCV: service-registered households, HH_NCV: non-registered households

The collection service was a formal mean that was being used by households. One family handled in more than one practice based on waste types, residential locations, access to the collection service. Open burning, burying, and littering is considered illegal dumping by RGC (2015). However, it was a conventional handling method (Seng et al., 2010; Sethy et al., 2014), particularly of those living in Zone1 (93.81%), Zone2 (58.16%) and Zone3 (30.13%). The illegal dumping was also noticed in Zone4 as of about 2.55% of households who were generally the residents in the poor communities. Some families living near waterways, canals, and open sewage systems tended to litter their waste into the water bodies or by the riverbanks that would be washed out by the rainstorms. Kham and Daniel (2015) also found similar findings of waste handling in the suburban area that included burning (66%), burying (11%), disposal into vacant and public spaces (9%), disposal into water (5%) and the others (9%).

On the other hand, about 10.20% of the collection service-registered households also seemed to dump their waste illegally when the service was irregular or infrequent. For example, at the time of the study, the service was expanded to Zone1 where was considered the non-service area, and about 6.70% of households registered as users. Nevertheless, only 6.19% could use the collection service while the rest of them still exercised the illegal dumping. Vice versa, about 1.49% of the service-unregistered families, also discharged their waste to be collected without paying. Despite the segregation for recycling, reuse and sale, the discharged HSW remained mixed waste included such materials that have possible values for recovery, as also mentioned by Matter et al. (2013). Fig. 5.3 presents the households' handling methods by waste type.

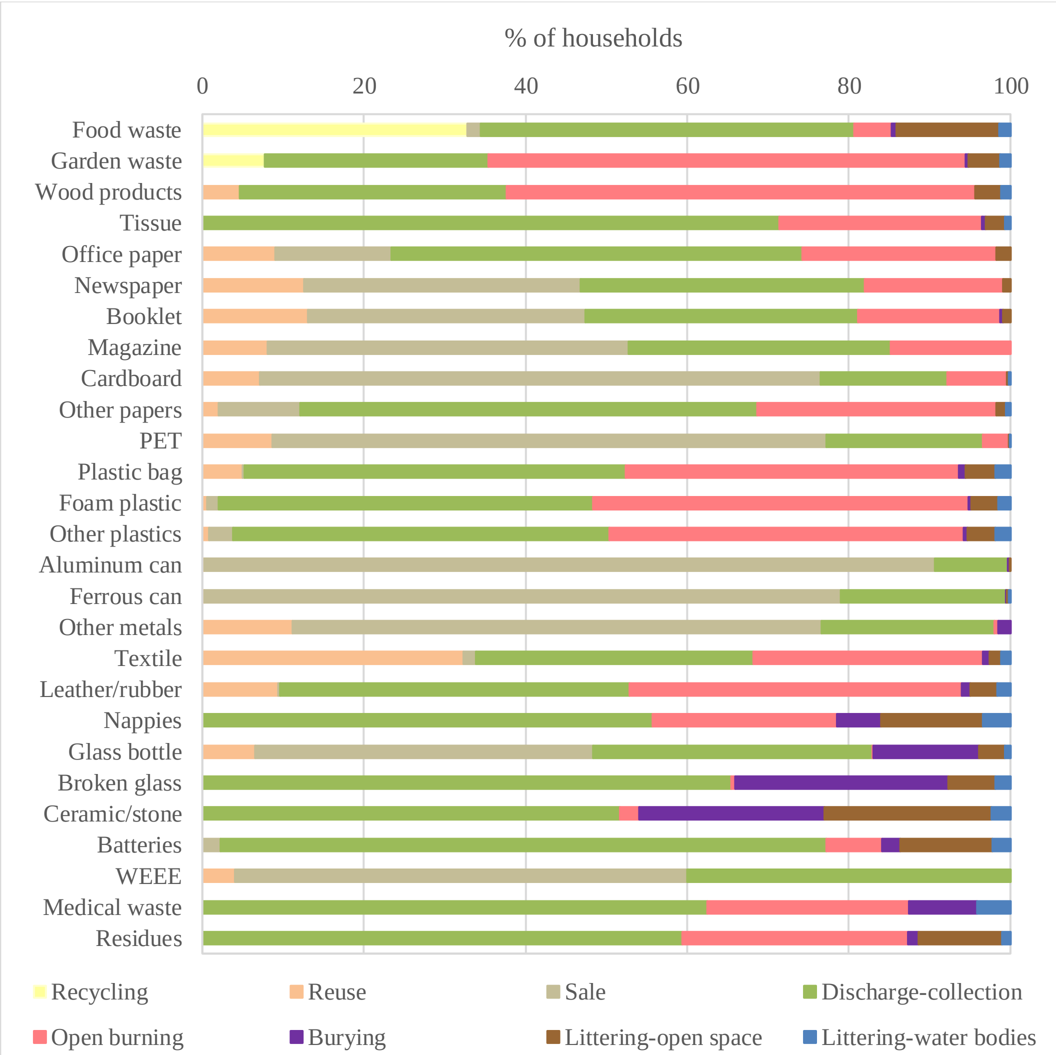

Fig. 5.3 Households' handling methods by waste type

Discharge for collection and the practice of illegal dumping have statistically significant differences between zones ($p < 0.001$). The illegal dumping also has a significant negative correlation with access to service (β = -0.89) and service frequency (β = -0.83) at $p < 0.001$. It means that the illegal dumping is strongly associated with the non-existence of service and rare collection frequency. The householders openly burnt and litter especially garden waste, wood, plastic and leather/rubber, and usually buried sharp and infectious materials, including nappies, broken glass, ceramic/stone and hazardous waste. Open burning is worrisome as it would emit harmful pollutants (Heisler, 2004; Hul et al., 2015). WGR per household has no significant relationship with any handling methods ($p > 0.05$).

5.3.4 Flow of HSW

In the previous chapter, we found that the total HSW generated in Phnom Penh was about 907.98 Mg/day when the total population was approximately 1,808,445 in 2017 (MoP, 2017). Table 5.6 presents the quantity of HSW handled by each method in each zone. The quantification of waste handled by individual methods shows that the regular service could collect up to 60.14% or about 546.05 Mg/day of the total HSW as it was objectively disposed of by the residents for collection. The calculation shows that the collected waste was majorly disposed of from Zone4 and Zone3. Of the waste amount generated in each zone, it was about 85.29% and 72.13% respectively. The collection amount of Zone2 was likely to be about 43.26% while it would be far less in Zone1, about 3%. The recycling rate could be about 11.15% (101.25 Mg/day) while sale and reuse proportionated about 5.47% (49.69 Mg/day) and 1.92% (17.46 Mg/day) respectively. Unlike, the reused and traded proportion seemed to be comparable between all zones, recycled waste was had a large amount in Zone1 (34.39%) and Zone2 (19.33%).

The illegal dumping of HSW totalled up about 193.53 Mg/day or 21.31%, which was almost triple in percentage if compared to 7.6% in 2003 (JICA, 2005). Remarkably, the open burning shared the major fraction of the illegally dumped waste about 13.59% or about 123.37 Mg/day followed by littering to open space (52.81 Mg/day), littering to water bodies (11.36 Mg/day) and burying (5.99 Mg/day). It is alarming that the quantity of waste dumped illegally is massive, especially in the suburban areas (Zone1 and Zone2) where the collection service was not widely served. Fig. 5.4 presents the flow of HSW in each zone by each handling method.

Table 5.6 The quantity of HSW handled by each method

Handling methods	% of HSW generated by zone				Overall
	Zone1	Zone2	Zon3	Zon4	
Recycling (%)	34.39	19.33	4.78	1.90	11.15
Reuse (%)	1.03	0.69	1.67	3.86	1.92
Sale (%)	2.98	3.03	6.67	7.94	5.47
Discharge for collection (%)	3.00	43.26	72.13	85.29	60.14
Open burning (%)	40.72	20.59	8.84	0.21	13.59
Burying (%)	1.77	1.07	0.54	0.01	0.66
Litter to open space (%)	14.19	10.69	3.71	0.37	5.82
Littering to water bodies (%)	1.92	1.34	1.66	0.42	1.25

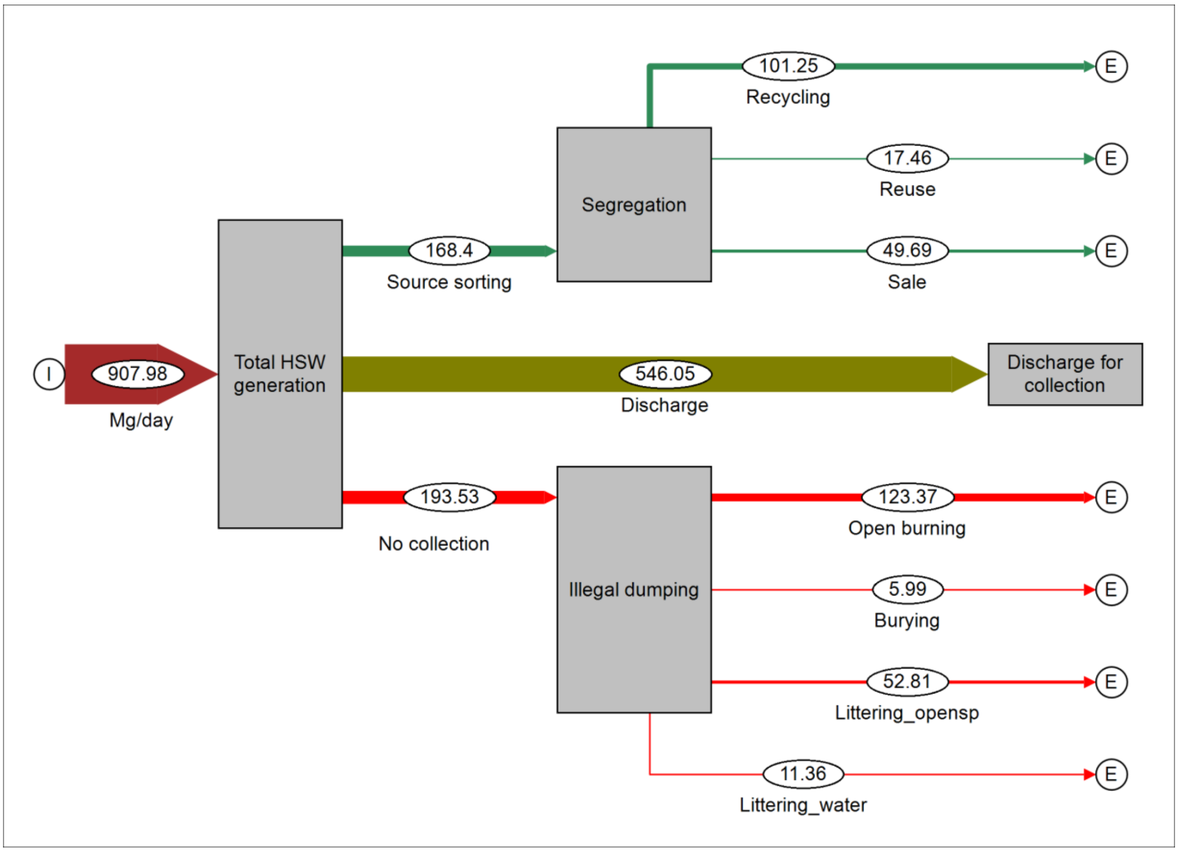

Fig. 5.4 Flow diagram of total HSW in 2017

5.3.5 Potential emissions of GHGs

The potential emissions of GHGs were calculated toward handlings of HSW including disposal, open burning, burying, littering to open space and littering to water bodies. Table 5.7 presents the GHG emission potential from HSW treated by each handling method. The calculation shows that the total emissions would be about 219.40 Gg/year. The final disposal of HSW into open dumpsite amounted the emissions of 182.23 Gg/year which was the largest $CO_{2\text{-eq}}$ emitted. However, the emissions from final disposal of HSW was less than the emitted GHGs of total collected municipal solid waste which was about 348.2 Gg/year of $CO_{2\text{-eq}}$ in 2009 (Hoklis and Sharp, 2014) and 635.86 Gg/year of $CO_{2\text{-eq}}$ in 2015 (Seng, 2016). The generated GHGs of open burning was about 26.99 Gg/year. The other three methods produced far less amount of emissions including littering to open space: 7.92 Gg/year, littering to water bodies: 1.55 Gg/year and burying: 0.70 Gg/year.

It seems that food waste tends to emit the massive GHGs from disposal site when burning of plastic generated the remarkable emissions. Seng et al. (2013) recommended organic composting which could reduce a large amount of food waste and the potential GHGs. Also, Seng et al. (2018) suggested that material recovery should be in practice to minimise dumping of plastic. The illegal dumping is worrisome, although its emitted GHGs is comparatively less than dumpsites. Especially, the open burning of waste that would emit not only the GHGs but also such harmful substances as particle matters, black carbon, dioxin, furans, etc. It concerns the environmental quality and public health (Kham and Daniel, 2015;

Kumari et al., 2017; Das et al., 2018). Kumari et al. (2017) mentioned that the residents in the area where open burning took place would be exposed by carcinogenic risk caused by the harmful pollutants.

Table 5.7 Potential emissions of GHGs from HSW

	CO_2-eq emissions (Gg/year)				
	Disposal	Open burning	Burying	Littering to open space	Littering to water bodies
Food waste	111.68	0.85	0.30	6.09	1.03
Garden waste	19.51	3.56	0.13	1.03	0.24
Wood	3.91	0.14	-	0.05	0.02
Paper	29.67	0.51	0.02	0.23	0.05
Textile	4.23	0.42	0.03	0.07	0.04
Nappies	13.23	0.28	0.23	0.46	0.17
Plastic	-	20.65	-	-	-
Leather/rubber	-	0.33	-	-	-
Hazardous waste	-	0.04	-	-	-
Others	-	0.20	-	-	-
Total	182.23	26.99	0.70	7.92	1.55

5.4 Conclusions

The study analysed the management situation and local perceptions toward household solid waste management in Phnom Penh. The waste management practices were addressed. The remarkable results can be concluded:

- Management works seem to be limited in the provision of high quality and satisfactory collection service, especially in the suburban area. The dissatisfaction appears to be related to the cleanliness and infrequency of the collection. It needs more enhancement, especially in the suburbs.
- Self-treatment methods practised by the locals present both positive and negative impacts. Reuse, recycling and sale significantly reduce approximately 18.55% of total generated household waste sent to the dumping site. However, open burning, burying and littering which are the illegal activities sum up to 21.31%. It would affect environmental quality and public health. The illegal dumping in the suburbs seems to be a consequence of lacking collection service.
- Food and garden waste were the two objects recycled by the locals, especially the families in the suburbs - for animal feeds, farming, and gardening - whereas the remaining valuable materials were reused and traded in the informal recycling markets.
- The collection service was reasonably used in urban and central districts. The illegal dumping, on the other hand, seemed to be habitual as it quantitatively constituted about one-fifth of the total waste generated, predominantly in rural and suburban areas.
- The total potential emissions from handled HSW is about 219.40 Gg/year of $CO_{2\text{-eq}}$, and about 83.06% of the total emissions are from the disposal site. Amount of waste dumped illegally should be put into the management plan.

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Chapter Six
Knowledge, Attitudes, Practices and Willingness to Pay toward Household Solid Waste Management Service

6.1 Introduction

As the population and economy rapidly grow, the Phnom Penh City Hall (PPCH), waste management authority, is likely not well prepared to resolve several complicities of SWM. Phnom Penh city has no other formal treatment facilities beside open dumping (Seng et al., 2010). One of the dissatisfactory SWM elements is the collection service, responsibility of a franchised private company, CINTRI (Cambodia) LTD. The collection service monthly charged between 3,200 to 4,000 Riel (Denney, 2016) or 5,000 to 10,000 Riel (Sang-Arun et al., 2011) based on a household's economic conditions as an additional fee to the electricity bill (1 USD = 4,000 Riel). According to the Provincial Department of Planning Capital (PDPC, 2015), about 24.8% of 260,544 homes could not access the service in 2014. The locals usually burn, bury, and litter waste (Seng et al., 2010; Sethy et al., 2014; Denney, 2016) thus causing adverse impacts on the communities (Hul et al., 2015; Heisler, 2004).

A new sub-decree on SWM ratified by the Royal Government of Cambodia (RGC 2015) has prohibited such activities as open waste burning, burying, and littering due to a definition of illegal dumping. The RGC aims to enhance the quality of SWM nationwide (Mun, 2016; Muny, 2016). Regardless of the sub-decree, there is no report concerning the further expansion of the collection coverage (CINTRI, 2017). Lack of an SWM service would lead to the practice of illegal dumping (Ichinose and Yamamoto, 2011) as the locals would keep their business as usual. Providing the collection service seems to be a solution (Heisler, 2004; Seng et al., 2010; Sethy et al., 2014). However, it should be attentive of introducing a new strategy. Failing to serve people at their affordability, therefore, would risk the management in a plan to fail. It is considerate to have the public's WTP estimated in advance. Substantial causes of the illegal dumping in Cambodia, however, have not been observed. The other factors might have influenced how communities handle the waste. Šedová (2016) presented positive impacts of high education and income level, and a high generation rate of garbage on the illegal dumping. Matsumoto and Takeuchi (2011) found significantly negative influences of low income and inexistence of public collection on dumping of electrical appliances. It seems that inaccessibility to the collection service is not the only reason.

The ways that individuals are aware of, think of, and behave toward the SWM would be the key to solving the environmental problems (Kiran et al., 2015). It is necessary to disclose the determinants of the communities' knowledge, attitudes, and practices (KAP). Their relationships with socio-economic and other factors have been assessed in many studies. For example, the influences of gender, education and income were noticed significant by Adogu et al. (2015) and Murad and Siwar (2007). In this paper, we aim to assess the determinants of knowledge of waste problems and attitudes toward SWM service, the practice of illegal dumping and willingness of householders to pay for management in the suburban city of Phnom Penh. We discuss differences in KAP/WTP relationships between households using the collection service (HH_UCVs) and households not using the service (HH_NCVs). It presents remarkable results for policymakers on what should be done to improve households' KAP and SWM.

6.2 Material and methods

6.2.1 Study area and data collection

We selected a total sample of 800 households including 200 HH_UCVs and 600 HH_NCVs in five outskirt districts (Pouthisen Chey, Chbar Ompov, Chrouy Changva, Dangkor and Praek Phnov) (Fig. 6.1). It was known that not all the households in the service area accessed the collection. HH_UCV comprised the registered service users that pay the tipping fee. HH_NCVs were the unregistered households that did not pay. In 2014, there were 98,816 households in these regions. Twenty of 41 communes in the study area had no houses that registered the collection service (PDPC, 2015).

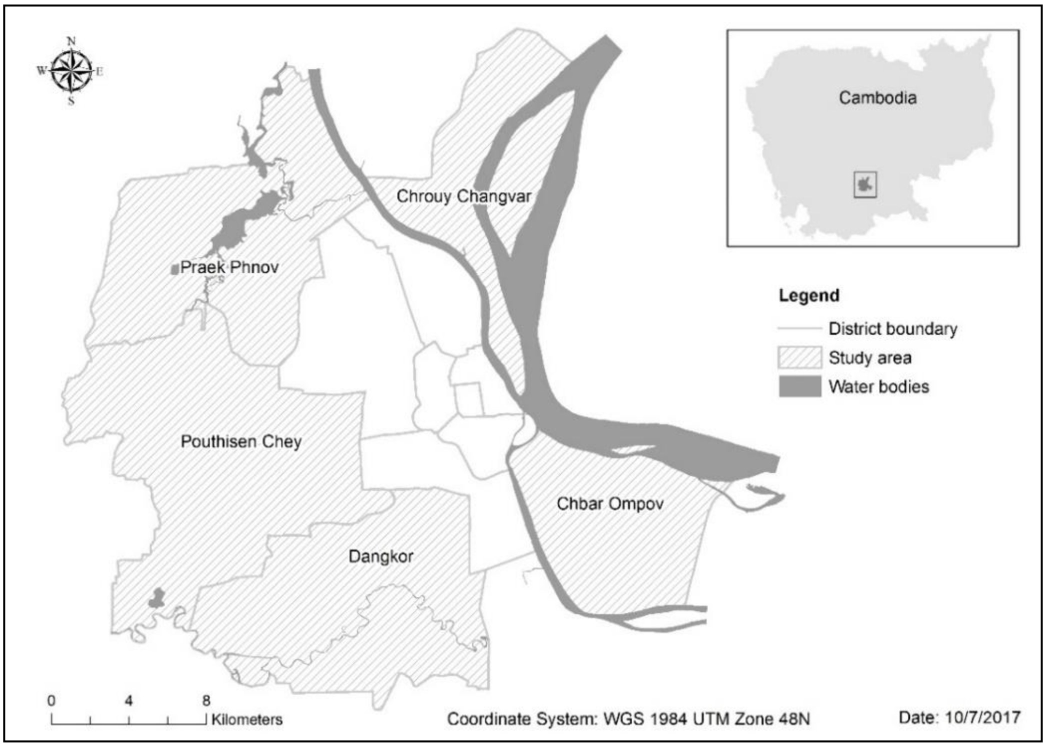

Fig. 6.1 Map of study area

Individual HH_NCV respondent was asked about the need for the collection service and preferences for the collection frequency followed by a question of WTP. For HH_UCV, the questions were about satisfaction with service quality, frequency and tipping fee and WTP for improved service. Then, we inquired the respondents about awareness of waste-related problems and health effects and to estimate their daily waste generation rate (WGR).

6.2.2 WTP mechanism

The study elicited the open-ended question format of the contingent valuation method (CVM). In prerequisite, the interviewers had to explain to the respondents about the necessities of the waste collection and the required tipping fee. If the respondents did not need the collection service, their WTP was considered negative; so their bid values were zero. If the service was needed, we asked whether they would be willing to pay. The answers of WTP were positive in case the respondents agreed to pay, or vice versa. Then, the interviewers continued with a question of how much their bid values would be. If it happened that the respondents were unsure about their WTP or refused to present their offers, their willingness would also be considered positive yet zero bid (Bateman and Willis, 2001). However, this may be a case of biases in CVM included nonresponse bias and protested zero bids when respondents bided zero or positive outlier values for their necessary service (Halstead et al., 1991; Halstead et al., 1992). As a follow-up, a question about WTP in maximum was asked in further in the assumption that the service would cost higher than expected (Whitehead and Haab, 2013). It was also the question to HH_UCVs regarding the proposed case that the existing service would need to increase in price to improve the quality. We questioned the residents to choose between paying an extra or not, and how much the bid values would be.

6.2.3 Data analysis and valuation method

The KAP study assessed the relationship between 13 variables (Table 6.1) in a maximum likelihood method of the logistic regression model (eq. 6.1). In WTP study, we developed two different models for each of HH_UCVs and HH_NCVs to assess the influences on their decisions: 1) WTP in Logistic regression models and 2) the bid values in Tobit models. The Logistic regression is usually used for discrete outcome modelling which the outcome variable is either binary or dichotomous. It analysed the relationship between a dependent variable and one or more independent variables (Hosmer and Lemeshow, 2000). In this analysis, the outcome variable of the Logistic regression models was binary (0 and 1). However, this was not a case for assessing the determinants of WTP bid values received from the open-ended question (Awunyo-Vitor et al., 2013; Maskey and Singh, 2017). Thus, the Tobit model was applied to regress a continuous dependent variable of WTP bid values. The Tobit model was used in similar studies (Halstead et al., 1991; Awunyo-Vitor et al., 2013; Maskey and Singh, 2017; Patrick et al., 2017). It seems to provide reliable, unbiased and consistent results on regression of the WTP dataset with many zero values.

The Maximum Likelihood method is used to estimate the Tobit models where the latent variables are censored to left and/or right. The influences of the explanatory variables on the non-zero WTP bidders can be examined so that the probability of changing from zero to positive bids can be estimated based on the coefficient of the explanatory variables (Halstead et al., 1991). The Tobit model was expressed in Eq. 6.2, and the outcome dependent variable in this model was continuous.

$$\text{Log } P_i/(1 - P_i) = \propto + \beta_i X_i \qquad (6.1)$$

where $P_i = 1$ for an answer of 'Yes' or $P_i = 0$ for an answer of others; $\propto$ = constant; β = coefficient of independent variables; X = independent variables and i = number of variables (1, 2, 3, …, n).

$$y_i = x_i'\beta + \varepsilon_i \quad (6.2)$$

where y_i = 0 for the zero bid values, y_i > 0 for the other non-zero bid values, x_i is a set of the explanatory variables, and ε_i is a disturbance term.

Table 6.1 Observed variables for regression models

Variables	Types	Assessment			
		K	A	P	WTP
Age (X_1)	Cardinal	√	√	√	√
Income (X_2)	Cardinal	√	√	√	√
Gender (X_3)	Dummy (1 = female, 0 = male)	√	√	√	√
Education level (X_4)	Cardinal (1-5, 5 = University)	√	√	√	√
Knowledge of health effects (X_5)	Dummy (1 = yes, 0 = no)	√			
Knowledge of waste problems (X_6)	Dummy (1 = yes, 0 = no)		√	√	√
Satisfaction with SWM status (X_7)	Cardinal (1-3, 3 = satisfied)		√		√
Satisfaction with collection frequency (X_8)	Cardinal (1-3, 3 = satisfied)		√	√	
Satisfaction with tipping fee (X_9)	Cardinal (1-3, 3 = satisfied)		√		√
Estimated WGR (X_{10})	Cardinal			√	√
Need of collection service (X_{11})	Dummy (1 = yes, 0 = no)		√		
Residence in collection coverage (X_{12})	Dummy (1 = yes, 0 = no)		√	√	
Practice of illegal dumping (X_{13})	Dummy (1 = yes, 0 = no)				√

One primary purpose of this assessment was to analyse the causes of illegal dumping. We created the dependent variables of KAP which seemed interrelated, including knowledge about waste problems, satisfaction with SWM status of HH_NCV and with service quality of HH_UCV, and the practice of illegal dumping. The independent variables, on the other hand, comprised the socio-economic status and other assumingly related factors (Murad and Siwar, 2007; Matsumoto and Takeuchi, 2011; Adogu et al., 2015; Šedová, 2016). The influences of age, income, gender, education level, relevant knowledge, the satisfaction with the SWM service, estimated WGR, and residential location on KAP was expected.

We identified the relationship between variables based on a value of estimated coefficient and their significance level based on a probability (p) of t-statistics. The Chi-square and Hosmer-Lemeshow tests were analysed to assess the significance level and goodness of fit (GOF) of the models (Hosmer and Lemeshow, 2000). We also measured the Wald test to evaluate the models as it would whether or not confirm the substantial evidence against a null hypothesis (Wasserman, 2004). Cox and Snell R^2 and Nagelkerke R^2 were applied to measure the predictive power. If the values were close to 1, the dependent variables would be predictable (Hu et al., 2006).

Mean WTP of the open-ended CVM was the average value calculated in Eq. 6.3 (Alberini and Cooper, 2000; Maskey and Singh, 2017). In the same calculation, Halstead et al. (1991) compared the mean WTP values between samples with and without the protest zero bids which should be excluded since the results would be biased (Halstead et al., 1992). Therefore, the mean values of WTP of both HH_UCVs and HH_NCVs in this study were also calculated and compared between all samples and samples without the suspected bias bids. The analysis was carried out in R Studio software with a sample of 571 HH_NCVs and 197 HH_UCVs after omitting 32 incompleted questionnaires.

$$Mean\ WTP = \left(\sum_{i=1}^{n} y_i\right)/n \qquad (6.3)$$

where y_i is the WTP bid value and n is the number of the sample size.

6.3 Results and discussions

6.3.1 KAP toward SWM

About two-thirds of the respondents are aware of the waste problems and related health effects. Residents in HH_UCVs seem more knowledgeable than HH_NCVs. The situation of SWM is not satisfactory due to the responses of 78.68% from HH_UCVs and 91.77% from HH_NCVs. Somehow, it proves that the SWM situation in the suburbs unlikely meets the satisfaction level of the respondents. About 25.74% of HH_NCVs are not in need of the collection service. They seem to prefer keeping their usual practices, given that it is costless. The majority of HH_NCVs dump their waste illegally, as also reported by Seng et al. (2010), Sethy et al. (2014), and Denney (2016). However, about 0.88% of these households dispose of theirs in a nearby waste-collection station. Illegal dumping is also a practice undertaken by 9.64% of HH_UCVs. They usually burn biodegradable waste and bury broken glass. The householders and business owners usually sort and sell recyclables such as glass, metal, cardboard, and plastic (Uch et al. 2014; Mongtoeun et al. 2014). More than two-thirds of all respondents estimate their WGR less than 0.5 kg/capita/day (Table 6.2).

Table 6.2 KAP toward SWM

		HH_UCV (%)	HH_NCV (%)
Knowledge of waste problems	Yes	71.07	63.40
Knowledge of health effects	Yes	75.63	72.15
	Dissatisfied	36.04	49.04
Satisfaction with SWM status	Neutral	42.64	42.73
	Satisfied	21.32	8.23
	Daily	6.09	-
	Every other day	18.27	-
Collection frequency	Twice a week	46.19	-
	Once a week	22.34	-
	Less than once a week	7.11	-
Estimated WGR (kg/capita/day)	< 0.5	69.54	74.96
	≥ 0.5	30.46	25.04
The practice of illegal dumping	Yes	9.64	99.12
The need of SWM service	Yes	-	74.26

Only home-based-business owners tend to rate theirs greater. About 39.09% are satisfied with the service quality, and 29.95% are dissatisfied. The other 30.96% do not answer either satisfied or not. The collection frequency is satisfactory to 34.52% of HH_UCVs, as it is mostly accessible twice a week to 46.19% households and once a week to 22.34% households. The dissatisfied respondents prefer a more frequent and regular service, as Denney (2016) reports that the collections occur irregularly. Householders' willingness to pay for the service seems to be at a low level (Kum et al., 2005; Sang-Arun et al., 2011), yet only 13.2% of HH_UCVs are dissatisfied with the tipping fee (Fig. 6.2).

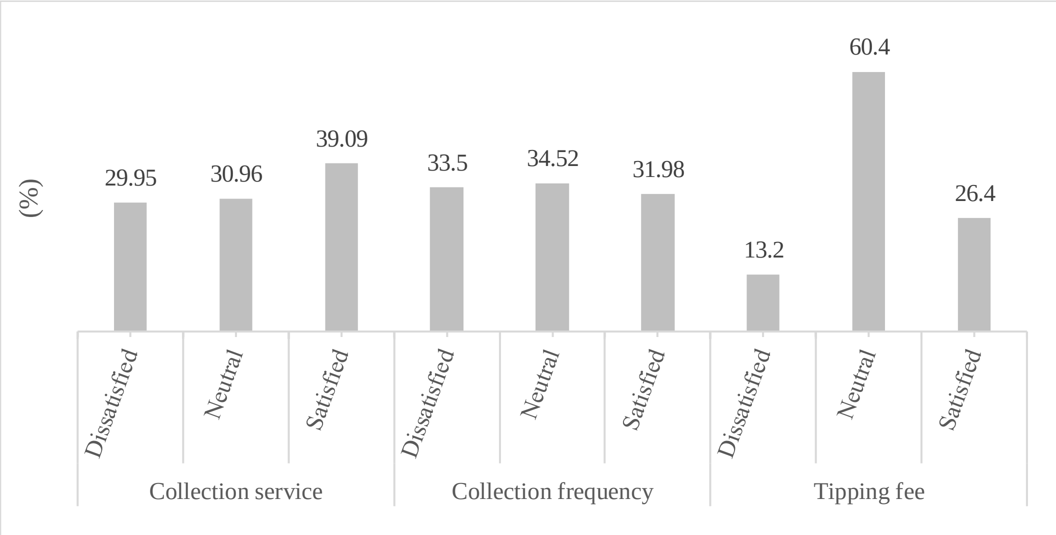

Fig. 6.2 Satisfaction level of HH_UCV toward collection service

6.3.2 Determinants of knowledge of waste problems

The regression model on HH_NCVs' knowledge shows that four observed variables are positively related, except the factor of gender (X_3). Income (X_2) is significant at $p < 0.05$ when education level (X_4) and knowledge of health effects (X_5) have a significance level at $p < 0.01$. Increasing income, education, and related knowledge would significantly improve the understanding of solid waste. Age (X_1) and gender (X_3) are estimated to show if the knowledge would differ among the respondents. The gender has zero coefficient so that the knowledge seems not to vary between male and female. The positive of age shows that the elders are more knowledgeable than the others. It is rational, as they usually respond to SWM at home. In the case of HH_UCVs, the model presents the negative influence of four observed variables and the significance of four variables. Knowledge of health effects (X_5) is positive and significant ($p < 0.01$) when education level (X_4) is insignificantly positive. The education and related awareness have positive impacts on the knowledge of HH_UCVs. The highly educated and knowledgeable respondents seem aware of the waste problems. Age (X_1) and income (X_2) are positive and significant at $p < 0.1$. The respondents would be significantly more aware as they get older and have a higher income. Only gender (X_3) has a significantly negative coefficient ($p < 0.1$). The male respondents seem more acknowledging. It is explainable that the male HH_UCVs are high-educated and able to understand more deeply about social issues.

Table 6.3 Determinants of knowledge of waste problems

	HH_NCV		HH_UCV	
	β	SE	β	SE
Constant	-0.104 **	0.048	-0.016	0.103
Age (X_1)	0.038	0.057	0.172 *	0.101
Income (X_2)	0.232 **	0.094	0.271 *	0.145
Gender (X_3)	0.000	0.026	-0.090 *	0.047
Education level (X_4)	0.434 ***	0.058	0.024	0.021
Knowledge of health effects (X_5)	0.717 ***	0.031	0.800 ***	0.048
Wald statistics		258.540 ***		62.797 ***
Chi-square		679.650 ***		191.530 ***
Cox and Snell R^2		0.149		0.120
Nagelkerke R^2		0.720		0.646
Hosmer-Lemeshow chi-square		16.337 at 0.038 significance level		3.15 at 0.79 significance level

β: estimated coefficient, SE = standard error, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$,
Pi = 1 if householders are aware, Pi = 0 for others

Table 6.3 presents the regression results of HH_NCV and HH_UCV. The Cox and Snell R^2 are low, but the Nagelkerke R^2 is high at 0.72 for HH_NCV's model and 0.646 for HH_UCV's. The dependent variable of both models would be predictable based on the observed variables. The Wald and Chi-square present high significance level of the model ($p < 0.01$). The Hosmer-Lemeshow test obtains 16.337 Chi-square at a 0.038 significance level in HH_NCV's model and 3.15 Chi-square at a 0.79 significance level in HH_UCV's. The models fit.

There are remarkable similarities between the determinants in both groups. The education and related awareness, as expected, play a significant role in building up the acknowledgement of waste problems in the local communities. Also, the health-related perception presents a positive influence on knowledge in Malaysia (Murad and Siwar 2007) when Adogu et al. (2015) also shows the significance of education. Enhancing understanding of the related issues is vital. According to Murad and Siwar (2007), improving local livelihoods is another needed factor to increase the knowledge of all householders due to the significant and decisive element of income. Only the value of gender in HH_UCV is opposite from the others. It demonstrates the different ways that the female and male members would know about the problems of waste. However, as their participation would better the SWM status (Parizeau et al., 2006), every individual needs to be knowledgeable.

6.3.3 Determinants of attitudes

Table 6.4 presents the factors affecting the HH_NCVs' satisfaction with their SWM status. Four variables have significant effects. The need of collection service (X_{11}) and residence in collection coverage (X_{12}) are significant at $p < 0.01$. Knowledge of waste problems (X_6) has a significance level of $p < 0.05$ while the education level (X_4) and gender (X_3) are significant at $p < 0.1$. The influence of three variables is positive (X_2, X_3, and X_{12}) while the other four are negative (X_1, X_4, X_6, and X_{11}). It shows that the SWM status seems unsatisfactory to those who need the collection service, unlike the householders living in the collection coverage. The same dissatisfied attitude arises in the highly-educated, knowledgeable, and young respondents. Likewise, the education level also has a negative relationship with the level of satisfaction concerning SWM in Malaysia (Murad and Siwar, 2007). The female and high-income HH_NCVs, by contrast, would be satisfied with the SWM status.

Table 6.4 Determinants of satisfaction concerning SWM status

	β	SE
Constant	1.951 ***	0.098
Age (X_1)	-0.087	0.112
Income (X_2)	0.236	0.191
Gender (X_3)	0.088 *	0.052
Education level (X_4)	-0.115 *	0.063
Knowledge of waste problems (X_6)	-0.138 **	0.053
Need of collection service (X_{11})	-0.516 ***	0.054
Residence in collection coverage (X_{12})	0.529 ***	0.069
Wald statistics		34.078 ***
Chi-square		201.720 ***
Cox and Snell R^2		0.114
Nagelkerke R^2		0.341
Hosmer-Lemeshow chi-square		0.511 at 0.999 of significance level

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, Pi = 1 if the householders are satisfied, Pi = 0 for others

Table 6.5 presents the factors affecting the HH_UCVs' satisfaction regarding the quality of the collection service. Three variables have a significance level ($p < 0.01$) including the satisfaction with SWM status (X_7), the satisfaction with collection frequency (X_8), and the satisfaction with tipping fee (X_9). Moreover, their coefficients are positive. The three variables strongly affect the positive way that the respondents think of the service. If HH_UCVs are satisfied with these variables (X_7, X_8, X_9), they would also be happy with the service. The other factors are insignificant. Age (X_1), education level (X_4), and knowledge of waste problems (X_6) have negative influences, and income (X_2) and gender (X_3) have positive influences. It shows that the lack of education and knowledge about waste would negatively have an impact on attitudes. The young respondents also seem dissatisfied, but the females do not. It is unlikely that the high-income HH_UCVs would think differently about the service.

The results of Cox and Snell R^2 are low, yet the Nagelkerke R^2 results are high in both models. Most of the observed variables make the dependent variable predictable. The Wald and Chi-square tests indicate a high significance level of the models ($p < 0.01$). The Hosmer-Lemeshow test obtains 0.511 Chi-square at a 0.999 significance level in HH_NCV's model and 5.728 Chi-square at a 0.678 significance level in HH_UCV's. The models fit.

In comparing the attitudes of HH_NCV and HH_UCV, the models present the same relationships among age, income, gender, education, and waste-related knowledge. It confirms that, despite accessibility to the collection service, their attitudes are likely determinant. The SWM status and service, to be noticed, seem not to satisfy the high-educated and knowledgeable householders. The SWM condition needs functional improvements to raise public attitudes. It will, for instance, work with serving the collection and assuring its quality, frequent service, and affordable tipping fee. Additionally, the attitude of both HH_NCV and HH_UCV will improve by increasing their income. Murad and Siwar (2007) also discovered the positive effects of the income and service quality on the householders' satisfaction.

Table 6.5 Determinants of satisfaction concerning the quality of collection service

	β	SE
Constant	0.133	0.272
Age (X_1)	-0.011	0.208
Income (X_2)	0.236	0.299
Gender (X_3)	0.017	0.097
Education level (X_4)	-0.031	0.035
Knowledge of waste problems (X_6)	-0.025	0.064
Satisfaction with SWM status (X_7)	0.293 ***	0.064
Satisfaction with collection frequency (X_8)	0.474 ***	0.061
Satisfaction with tipping fee (X_9)	0.259 ***	0.073
Wald statistics		27.718 ***
Chi-square		153.480 ***
Cox and Snell R^2		0.309
Nagelkerke R^2		0.624
Hosmer-Lemeshow chi-square		5.728 at 0.678 of significance level

*** $p < 0.01$, Pi = 1 if the householders are satisfied, Pi = 0 for others

6.3.4 Determinants of the practice of illegal dumping

The regression on HH_NCV's illegal dumping presents the negative influence of all seven observed variables and the significance of three variables. The education level (X_4) has a significance level at $p < 0.05$, while the residence in collection coverage (X_{12}) and estimated WGR (X_{10}) are significant at $p < 0.01$. A negative estimated WGR is unexpected because the low waste-generating respondents tend to dump their waste improperly. That is explainable since the collection service is unavailable, the large waste-generating households would have reused and sold the recyclables to the informal recycling sector. As assumed, the result proves that a cause of illegal dumping is the nonexistence of the waste collection. HH_NCVs living in the service area are likely to dump their waste to be collected although they are unregistered service users. A lack of education and relevant knowledge seems to be another reason. The respondents will properly manage their waste if their education and awareness are sufficient. Adogu et al. (2015) found a similar consequence of low education. The coefficients of age (X_1), income (X_2), and gender (X_3) are insignificant, but their relationship with illegal dumping is negative. It means that the elderly and female respondents seem to dispose of their waste correctly. The low-income households also practice dumping, as Matsumoto and Takeuchi (2011) found.

Table 6.6 Determinants of the practice of illegal dumping

	HH_NCV		HH_UCV	
	β	SE	β	SE
Constant	1.054 ***	0.014	0.341 ***	0.114
Age (X_1)	-0.022	0.018	-0.036	0.101
Income (X_2)	-0.035	0.032	0.017	0.152
Gender (X_3)	-0.008	0.008	-0.034	0.046
Education level (X_4)	-0.023 **	0.010	-0.014	0.017
Knowledge of waste problems (X_6)	-0.004	0.009	-0.228 ***	0.046
Satisfaction with collection frequency (X_8)			-0.028	0.026
Estimated WGR (X_{10})	-0.185 ***	0.028	0.344 ***	0.013
Residence in collection coverage (X_{12})	-0.038 ***	0.011		
Wald statistics	10.499 ***		4.787 ***	
Chi-square	70.056 ***		32.156 ***	
Cox and Snell R^2	0.001		0.013	
Nagelkerke R^2	0.116		0.156	
Hosmer-Lemeshow chi-square	0.753 at 0.999 significance level		5.498 at 0.703 significance level	

** $p < 0.05$, *** $p < 0.01$, Pi = 1 if the householders practice the illegal dumping, Pi = 0 for others

The regression on HH_UCVs' practice of illegal dumping presents a negative influence of five observed variables and the significance of two variables. Knowledge of waste problems (X_6) is negatively significant ($p < 0.01$) when the estimated WGR (X_{10}) is positively significant ($p < 0.01$). The positive estimated WGR is expected as the large waste-generating households seem to practice the illegal dumping. It is as same as in Slovakia, where Šedová (2016) indicated a positive relationship between the two variables. The satisfaction with collection frequency (X_8) is insignificantly negative, so the illegal dumping would happen if the collection frequency is dissatisfactory. In other words, if the collection frequency is insufficient or too irregular to meet the service users' demands, people would illegally dispose of their waste. The education level (X_4) has a negative yet insignificant influence. The negative coefficients of both education level and knowledge of waste problems prove that the occurrence of improper practice is related to lack of education and relevant knowledge. The influence of income (X_2) is insignificantly positive. The high-income generation of HH_UCV would result in illegal dumping, similarly to a study of Šedová (2016). Age (X_1) and gender (X_3) are negatively insignificant so that the young and male respondents seem to perform the dumping. The dependent variables of both models seem unpredictable based on the observed variables due to low Cox and Snell R^2 and Nagelkerke R^2 results. However, the models achieve a high significance level ($p < 0.01$) in Chi-square and the Wald tests. The Hosmer-Lemeshow obtains 0.753 Chi-square at a 0.999 significance level in HH_NCV's model and 5.498 Chi-square at a 0.703 significance level in HH_UCV's. The models are fit.

Table 6.6 presents the regression results on the practice of HH_NCV and HH_UCV. Two of the observed variables demonstrate the opposite sign of the coefficient in a comparison between these two groups. The impacts of income and estimated WGR are negative on HH_NCV yet positive on HH_UCV. Increasing the income of HH_NCV seems to ease the illegal dumping. As their revenue increased, the more extensive volume of waste the householders generate (Hul et al., 2015). If so, it would be another concern in the case of HH_UCV. It is, thus, crucial to consider the factors of education and knowledge. Raising awareness about the problems would positively impact the improvement of community practices. The presence of collection service is also essential in response to the HH_NCV's situation. Moreover, the service needs to meet the demands of users; otherwise, the practice of illegal dumping would still exist.

6.3.5 HH_UCVs' willingness for improving the existing service

The questionnaire survey showed that the tipping fee varied among the households. It ranged from 3,200 to 20,000 Riel/month (Table 6.7). In general, about 73.10% of households usually paid 3,200 to 4,000 Riel/month when the monthly service charged 10,000 Riel or more to 11.16% of HH_UCVs. The lower bound of the fee was as same as reported by Denney (2016), but the higher bound was not. The range of the price matched to the List of Basic Monthly Tipping Fee for Solid Waste Collection Service determined by PPCH (2003). It defined the monthly charge of 3,200 to 4,000 Riel for general households, 8,000 to 40,000 Riel for families with a home business and 12,000 to 40,000 for detached and semi-detached houses. The tenants who own a home business would be charged higher than usual as their amount of generated waste is assumed to be as higher. A specific price depends on the size of the business (Interview with CINTRI officer). This means that quantity-based charge seems to be applied in Phnom Penh city when many countries in the region manage to utilise flat-rate charging method including Indonesia, Malaysia, Philippines, Thailand and Vietnam (Welivita et al., 2015). The differences in tipping, therefore, seem to make some users confused and dissatisfied because they are unaware of the fee determination method and must pay costlier than expected.

Table 6.7 Tipping fee and WTP of HH_UCVs

		HH_UCVs (%)
Tipping fee (Riel/month)	3200-4000	73.10
	8000	15.74
	≥ 10000	11.16
WTP for improving service	No	55.33
	Not sure	6.60
	Yes	38.07

About 55.28% of HH_UCVs was unwilling to pay extra to their current tipping fee to elevate the service since the present management and tipping are generally dissatisfactory to them.

One main reason was that if the price would increase, it might not be affordable. About 38.07% was willing to pay for the improved service in these suburban districts with one main expectation that their living environment would be cleaner. Moreover, about 6.60% seemed not sure about their WTP or bid values which could be counted as nonresponse bias. These findings are comparable to a result of Denney (2016) that about 42% of households in the central area of the city presented their positive WTP. In contrast, a study in Gorkha Municipality, Nepal found that up to 60.85% of the respondents were willing to pay for the service enhancement (Maskey and Singh, 2017). Fig. 6.3 presents the WTP bid values of HH_UCVs. The highest bid was 4,000 Riel/month as for 3.04% of households. About 15.74% answered their WTP of 1,000 Riel/month, and about 12.69% was willing to pay the extra of 2,000 Riel/month. The mean WTP for the bettering the existing service is about 731 Riel/month. If the biased responses were dropped out, the mean WTP value increases to about 783 Riel/month.

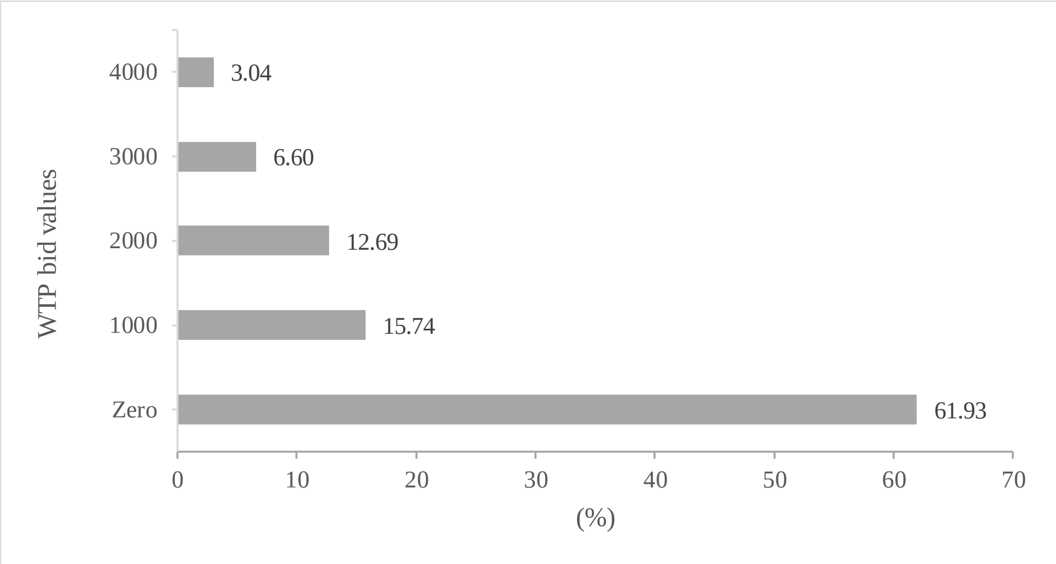

Fig. 6.3 WTP bid values of HH_UCVs

6.3.6 Determinants of HH_UCVs' willingness

The logistic regression model on WTP of HH_UCVs shows that five observed variables have significant influences. Income (X_2), Knowledge of waste problems (X_6) and Satisfaction with tipping fee (X_9) are positively significant at p-value < 0.01 while Age (X_1) and Gender (X_3) are negatively significant at p-value < 0.05 and p-value < 0.01. The other variables have insignificance level yet remarkable effects except for Education level (X_4) whose estimated coefficient is closed to zero. The Satisfaction with SWM status (X_7) and Estimated WGR (X_{10}) have a positive coefficient, and the Practice of illegal dumping (X_{13}) has a negative. On the other hand, the Tobit model on WTP bid values presents six significant conditioning variables. Five of them are as same as in the logistic model with an additional factor of Estimate WGR (X_{10}), yet the significance levels are slightly different. Among the insignificant variables, only the coefficient of Education level (X_4) is changed to a negative (Table 6.8).

The results show that a positive change of income, knowledge and the satisfaction with tipping fee would significantly affect the way HH_UCVs respond. They would be willing to pay extra and even higher to the collection service when they are high-income generated, knowledgeable of the related waste problems and satisfied with the present charge. It is reasonable that low-income households would be unable to pay if the price increases, and so are the unaware householders to understand the importance of management enhancement. The other studies of Afroz et al. (2009), Awunyo-Vitor et al. (2013), Maskey and Singh (2017), and Patrick et al. (2017) similarly found the positive and significant results of income and awareness. Nevertheless, the status of a variable namely Education (X_4) which is negative in the Tobit model of this study was found significant and positive in the previous studies. Therefore, awareness raising on related topics plays essential roles to transfer knowledge to the locals especially in case the matters of solid waste are not integrated into the educational system. The tipping fee should be low and reasonable (Welivita et al., 2015).

Table 6.8 Factors affecting WTP (Logistic model) and bid values (Tobit model) of HH_UCVs

	Logistic model		Tobit model	
	β (SE)	t-value	β (SE)	z-value
Constant	-0.044 (0.202)	-0.216	-2.218 (1.147)	-1.934 *
Age (X_1)	-0.378 (0.151)	-2.505 **	-3.470 (0.872)	-3.979 ***
Income (X_2)	1.081 (0.231)	4.686 ***	2.806 (1.113)	2.521 **
Gender (X_3)	-0.188 (0.070)	-2.683 ***	-0.923 (0.360)	-2.565 **
Education level (X_4)	0.001 (0.025)	0.018	-0.102 (0.142)	-0.717
Knowledge of waste problems (X_6)	0.282 (0.073)	3.876 ***	1.652 (0.478)	3.452 ***
Satisfaction with SWM status (X_7)	0.022 (0.043)	0.519	0.242 (0.230)	1.052
Satisfaction with tipping fee (X_9)	0.159 (0.051)	3.094 ***	0.711 (0.308)	2.309 **
Estimated WGR (X_{10})	0.253 (0.192)	1.316	3.478 (0.981)	3.546 ***
Practice of illegal dumping (X_{13})	-0.086 (0.110)	-0.788	-0.677 (0.727)	-0.931
Log(scale)			0.604 (0.092)	6.534 ***
Wald statistics		10.481 ***		60.250 ***
Chi-square		80.459 ***		77.325 ***
-2 Log Likelihood		141.850		244.370
Hosmer-Lemeshow chi-square	2.147 at 0.976 significance level			
Cox and Snell R^2		0.080		
Nagelkerke R^2		0.363		
R^2				0.287
Left-censored				122
Uncensored				75
Right-censored				0

β: estimated coefficient, SE: standard error, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The negative of Age (X_1) and Gender (X_3) show that the WTP of young and male residents would be positive and higher than the elders and female. One main reason is that the male householders are generally the family heads who are the decision makers. Also, the youngsters seem eager to live in an environmentally friendly city (Patrick et al., 2017) more than elders who are not likely to change their way of living (Afroz and Masud, 2011). Moreover, the increasing amount of generated waste seems to condition the willingness positively and more significantly toward the bid values. The residents might realise that they need a better-quality service to handle their more substantial volume of waste (Awunyo-Vitor et al. (2013). The negative coefficient of Practice of illegal dumping (X_{13}) is as same as expected. It means that HH_UCVs who burn, bury, or litter waste tend not to state a positive WTP. Even if they do, their bid value is likely low. This issue would also happen if the management situation is dissatisfactory as Satisfaction with waste management (X_7) is unexpectedly positive. The public would require an advanced improvement as it builds the public's belief in the collection service; otherwise, they would not pay or are willing to offer a small contribution. The same satisfaction also occurs in Dhaka, Bangladesh (Afroz et al., 2009) and Kuala Lumpur, Malaysia (Afroz and Masud, 2011). Therefore, the illegal dumping which appears as an uncontrollable practice should be in control to elevate the management works to the desired level.

Both models have Chi-square and Wald statistics significant at p-value < 0.01. The Logistic model achieves a low Cox and Snell R^2 at 0.08 yet a high Nagelkerke R^2 at 0.363. The Chi-square of the Hosmer-Lemeshow test is 2.147 at a significance level of 0.976. The R^2 of the Tobit model is 0.287.

6.3.7 HH_NCVs' willingness for collection service

The HH_NCVs seemed aware of the importance of the waste collection. About 5.08% of households needed their waste to be collected even on a weekly basis. The collection frequency was desired more often on a daily basis by about 26.80%, every other day at 29.42% and twice a week by 12.96% of HH_NCVs. However, provision of a frequent collection would be illogical in the area where the population density is low. It depends on the actual amount of waste generated. Furthermore, the location is likely to be far away from the centre of the city so that it requires a high-cost operation (Interview with CINTRI officer). Seemingly, the service is mostly provided twice a week to the suburban households. As the service was needed, about 71.11% of the households were willing to pay, unlike the others who were either unwilling or unsure about their WTP (Table 6.9). The unwilling respondents appeared to prefer their business as usual including open burning, burying and littering since these activities are costless rather than spending on the collection service. This similar case was also discovered by Maskey and Singh (2017). This group of respondents seemed to lack the understandings of waste problems and side effects of their practices.

Nevertheless, many householders were knowledgeable about the necessities of waste collection and the general tipping fee. Their bid values were between 3,000 to 8,000 Riel/month which were in the range of the basic monthly tipping fee of PPCH (2003). A small number of them responded with the WTP of 7,000 (2.63%) and 8,000 (2.28%) Riel/month. Many HH_NCVs would be willing to pay a monthly charge of 4,000 Riel (32.57%), followed by 5,000 Riel (16.99%) and 6,000 Riel (14.01%) (Fig. 6.4). The mean

WTP value would be about 3,438 Riel/month for the collection service or about 3,550 Riel/month if the protest bias responses of 3.15% were excluded. The biases were of respondents who stated negative or unsure WTP despite their actual need of the collection service. This value seems to satisfy the price that most of the HH_UCVs are being charged for their present service (32,00-4000 Riel/month); so that it would be suitable. However, it is necessary to engage not only the families who need the service but also those who do not as well. Otherwise, unlawful handlings of solid waste would still take place.

Table 6.9 Need and WTP for collection service of HH_NCVs

		HH_NCVs (%)
Need of collection frequency	None	25.74
	Daily	26.80
	Every other day	29.42
	Twice a week	12.96
	Once a week	5.08
WTP	No	27.84
	Not sure	1.05
	Yes	71.11

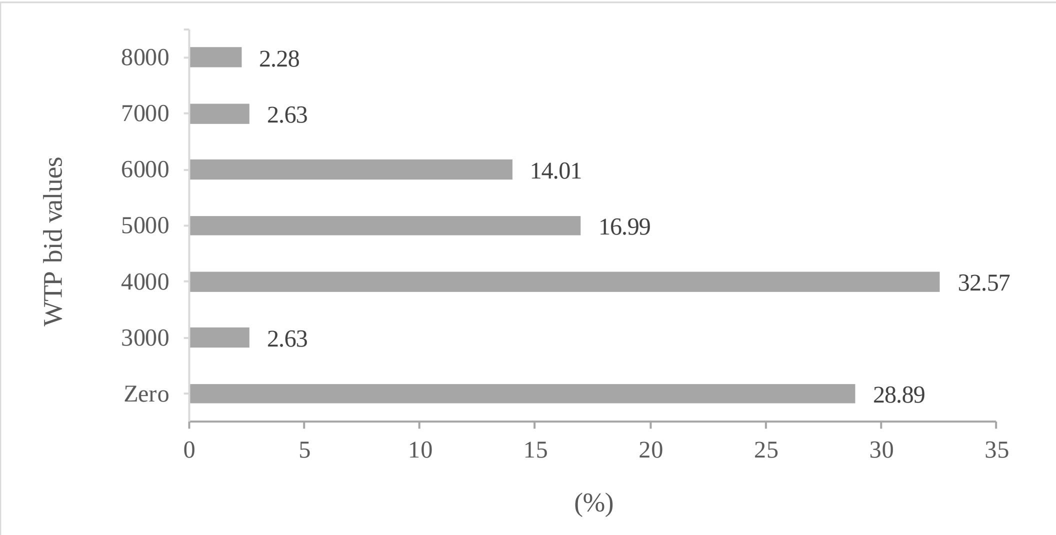

Fig. 6.4 WTP bid values of HH_NCVs

6.3.8 Determinants of HH_NCVs' willingness

The Logistic regression on WTP of HH_NCVs for the collection service shows that, of eight variables, six have significant effects. Two of them including Age (X_1) and Satisfaction with waste management (X_7) are negative at p-value < 0.01. The other significant four are positive such as Income (X_2) and Estimated WGR (X_{10}) at p-value < 0.01 and Knowledge of waste problems (X_6) and Practice of illegal dumping (X_{13}) at p-value < 0.05. The remaining two variables namely Gender (X_3) and Education level (X_4) are insignificant yet positive. On the other hand, the Tobit model on WTP bid values also presents the same six significant and two insignificant variables, yet the significance levels are somewhat different (Table 6.10).

The results show that a positive change of income and related knowledge would significantly increase the public willingness and contribution, as likely found in the models of HH_UCVs'. Income is a main economic factor determining the responses so that the WTP of HH_NCVs is positive and high when they are well-to-do. Also, such adverse effects of solid waste must be aware of to acquire supportive offers from the respondents especially at the time that collection service is inaccessible. A positive sign of Education (X_4) confirms the necessities of the awareness raising toward decision making even though this factor presents no significance level. It is an opportunity for people to become well-informed and considerate toward solid waste management (Awunyo-Vitor et al., 2013; Patrick et al., 2017). The negative coefficient of Age (X_1) means that the young respondents seem to provide a positive and high value of WTP even though Awunyo-Vitor et al. (2013) mentioned that the elders have a better understanding of the environmental problems. The positive sign of Gender (X_3) which is different from HH_UCVs' shows that the female members of HH_NCVs tend to pay higher bid than the male do. It can be explained that the females are usually in charge of the household waste management and recognise the need of collection service more clearly.

Table 6.10 Factors affecting WTP (Logistic model) and bid values (Tobit model) of HH_NCVs

	Logistic model		Tobit model	
	β (SE)	t-value	β (SE)	z-value
Constant	0.575 (0.226)	2.548 **	1.388 (1.708)	0.813
Age (X_1)	-0.370 (0.086)	-4.294 ***	-2.736 (0.634)	-4.316 ***
Income (X_2)	0.449 (0.145)	3.095 ***	3.306 (1.045)	3.165 ***
Gender (X_3)	0.031 (0.039)	0.782	0.143 (0.287)	0.499
Education level (X_4)	0.015 (0.015)	1.010	0.103 (0.110)	0.940
Knowledge of waste problems (X_6)	0.079 (0.036)	2.230 **	0.460 (0.262)	1.759 *
Satisfaction with SWM status (X_7)	-0.231 (0.027)	-8.703 ***	-1.634 (0.198)	-8.249 ***
Estimated WGR (X_{10})	0.405 (0.135)	2.996 ***	4.405 (0.978)	4.504 ***
Practice of illegal dumping (X_{13})	0.426 (0.189)	2.251 **	3.452 (1.454)	2.374 **
Log(scale)			1.036 (0.038)	27.101 ***
Wald statistics		19.051 ***		148.500 ***
Chi-square		137.010 ***		142.730 ***
-2 Log Likelihood		352.030		1224.300
Hosmer-Lemeshow chi-square	2.807 at 0.946 significance level			
Cox and Snell R^2		0.042		
Nagelkerke R^2		0.231		
R^2				0.222
Left-censored				165
Uncensored				406
Right-censored				0

β: estimated coefficient, SE: standard error, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The practice of illegal dumping (X_{13}) is unexpectedly positive and proves that HH_NCVs agree to pay the service, although they illegally dump their waste, unlikely HH_UCVs.

Nevertheless, it is reasonable since the illegal dumping is a usual waste handling method of HH_NCVs due to inaccessibility to the collection. Furthermore, the increase of generated waste amount would positively change the WTP answers and significantly raise the bid values. Large-volume-waste generators might need a proper mean to manage their waste. Dissimilarly, low-volume-waste generators would present zero or low WTP if they consider themselves the least or none pollutant. The positive coefficient of variable namely Satisfaction with waste management (X_7) was expected; therefore, the willingness is positively high if the management situation were dissatisfactory. In another word, it is not, in case the HH_NCVs are satisfied, even if the collection were not served.

The results of Chi-square and Wald statistics of both models are significant at $p\text{-value} < 0.01$. In the Logistic model, Chi-square of Hosmer-Lemeshow test results in 2.807 at a significance level of 0.946. The Nagelkerke R^2 is 0.231 while the Cox and Snell R^2 is low at 0.042. The R^2 of the Tobit model is 0.222.

6.4 Conclusions

This study discovers the knowledge, attitudes, and practices of the residents concerning SWM in the suburbs of Phnom Penh city. The logistic regression models present remarkable results. About one-third of the respondents seem to have acquired insufficient knowledge of waste problems. The residents' educational level, awareness of related topics and income level are the key determinants of their knowledge. The inadequacy of this experience, otherwise, would cause the illegal dumping, which is a common waste handling of households not using the collection service. Even if the related knowledge is adequate, the improper practice would still take place when the collection service is inaccessible or insufficient to meet the households' satisfaction level. The service users who generate a large volume of waste tend to practice illegal dumping.

The study disclosed households' willingness and influencing factors to pay for waste collection and improved collection service in the suburban districts of Phnom Penh city. Households using the service were asked regarding the improved service, and about one-third of them were willing to pay. Their decisions seemed to be significantly influenced by not only income but also knowledge of waste problems, the satisfaction with the current tipping fee and estimated waste generation rate. Improving the local livelihood and understandings of the issues are necessary. More importantly, increasing the price should be done critically because the cost needs to be satisfactory and affordable. The households currently not using the service were evaluated about their willingness to pay for the collection. About three-fourths of them seemed to be willing to pay since they needed the service. Their bid values for willingness resulted in a reasonable mean since it was as similar as the determined basic tipping fee of the city hall. However, it is worrisome because some residents do not agree to pay the cost. As a consequence, they would keep dumping their garbage improperly. The collection frequency is another matter of consideration. The users should have access to the regular collection. Even if the service is provided with an acceptable price, local practice of the illegal dumping would still exist if the collection frequency does not meet the users' needs, especially households whose waste volume is large. The provision of satisfying collection service to all the families seems to be unreachable. Other countermeasures must be considered to manage the uncollected garbage.

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Chapter Seven
Modelling of Household Waste Segregation-based Management

7.1 Introduction

As Phnom Penh is the capital of Cambodia, economic activities have attracted an endless flux of migrants to live, work and study. The city keeps urbanising, and development projects keep increasing year by year. So, does the amount of solid waste generated. It is owing to the population growth, as reported by MoP (2017) that is estimated at approximately 1.2% annually. Thus, Phnom Penh needs to improve the quality of public services and goods, especially solid waste management (SWM) that seems have been dissatisfying. Effective countermeasures are required to cope with the arising problems. However, cleaning and collection are not the only insufficient elements of the management system, but also recycling, treatment and pollution controls. The practice of source segregation remains voluntary because the tenants only sort to recover and reuse such valuable materials. The city has to consider putting the integrated solid waste management (ISWM) into practice by starting with planning a master plan. UNEP (2017) mentioned that the Royal Government of Cambodia would introduce an ISWM into the present system, yet such details were described. Seng et al. (2018) analysed physical and chemical components of waste in Phnom Penh and found the treatment suitability of anaerobic digestion and composting for organic waste, refuse-derived fuel generation and gasification with melting for plastic, textile, rubber and leather, and incineration without energy recovery for mixed waste. Material recovery was also remarked as economically and practically viable.

However, the viability of the proposed management scenarios must be evaluated based on not only waste characteristics, but also economic affordability and social acceptability. So that it is necessary to study the policy-based assessment of SWM system with possible scenarios modellings. To do so, many researchers developed system dynamic approaches to help them made an evaluation. System dynamics refer to simulation methods that provide and analyse situations and projection of behaviours changing overtimes. This technique of modelling is principally used for business and policy purposes (Duggan, 2016) that was first introduced in the 1960s by Jay Forrester at the Massachusetts Institute of Technology (Chaerul et al., 2008). The basic building block of the system dynamics includes stock and flow. A stock is the system's component giving details of mathematical state; it can be called a state variable. Flow is a rate of the component whose inflow and outflow would change a stock (Guo et al., 2016; Duggan, 2016). Therefore, a unit of a flow is a function of stock changing over a period of time. A system dynamic model also consists of converters and connectors (Guo et al., 2016; Sukholthaman and Sharp, 2016). A converter is to change rate and convert unit or is called auxiliary variable. A connector is an arrow to link the causal relationship between variables in the model. It is also important to identify the modelling objectives, boundary, key variables and basic mechanisms of the system (Albin, 1997).

In system dynamics, there are two types of the diagram: causal loop and stock-and-flow diagram. A closed chain of cause-and-effect connection between variables are shown in the causal loop diagram (Sukholthaman and Sharp, 2016), but it is not for modelling (Albin, 1997). A stock-and-flow diagram has to be converted from the loop diagram to quantify the models (Talyan et al., 2006). These diagrams are useful systems to disclose possible scenarios for sustainable SWM (Prasetyanti et al., 2014). The connections between variables can be positive (+) and negative (-) depending on the same or opposite direction of changes caused by one variable on the other variable (Talyan et al., 2006). This case study aims to apply the system dynamics to project the future trend of waste generation and handlings up to the year 2025 and to model the management system of HSW in Phnom Penh.

7.2 Material and methods

7.2.1 Modelling of HSW generation

Diagrams of the system dynamic modes were connected in Vensim PLE.3.5; the data were analysed using ‘delSolve’ of the R Studio software. Three models were developed to project the future trend of HSW generation between 2017 and 2025 with a growth rate of the population at 1.02%. One of them was selected to calculate the waste flow. In Model 1, the WGR per capita was supposed to be as same as in the base year, and Model 2 was based on historical growth rate of HSW generation at 1% per year according to the previous study of Hul et al. (2014). The waste amount was projected with economic data of income: 1727 USD/year with GDP growth rate per capita of 5.2% (World Bank, 2018) in Model 3. Ahmad (2012) and Dyson and Chang (2005) also predicted the waste generation based on the historical amount and economic activity data. Fig. 7.1 presents the modelling diagrams of HSW generation. The values of stocks and auxiliary variables were shown in Table 7.1.

Table 7.1 Variables used for modelling HSW generation

Variables	Name	Unit	Initial values/Constant
Stock	Population	Person	1808445
	Annual income	USD/capita	1727
	HSW per capita	kg/day	0.502
	HSW per income	kg/USD/capita	0.0003
Auxiliary	Population growth rate	Fraction	0.01
	Income growth rate per capita	Fraction	0.05
	HSW growth rate	Fraction	0.01

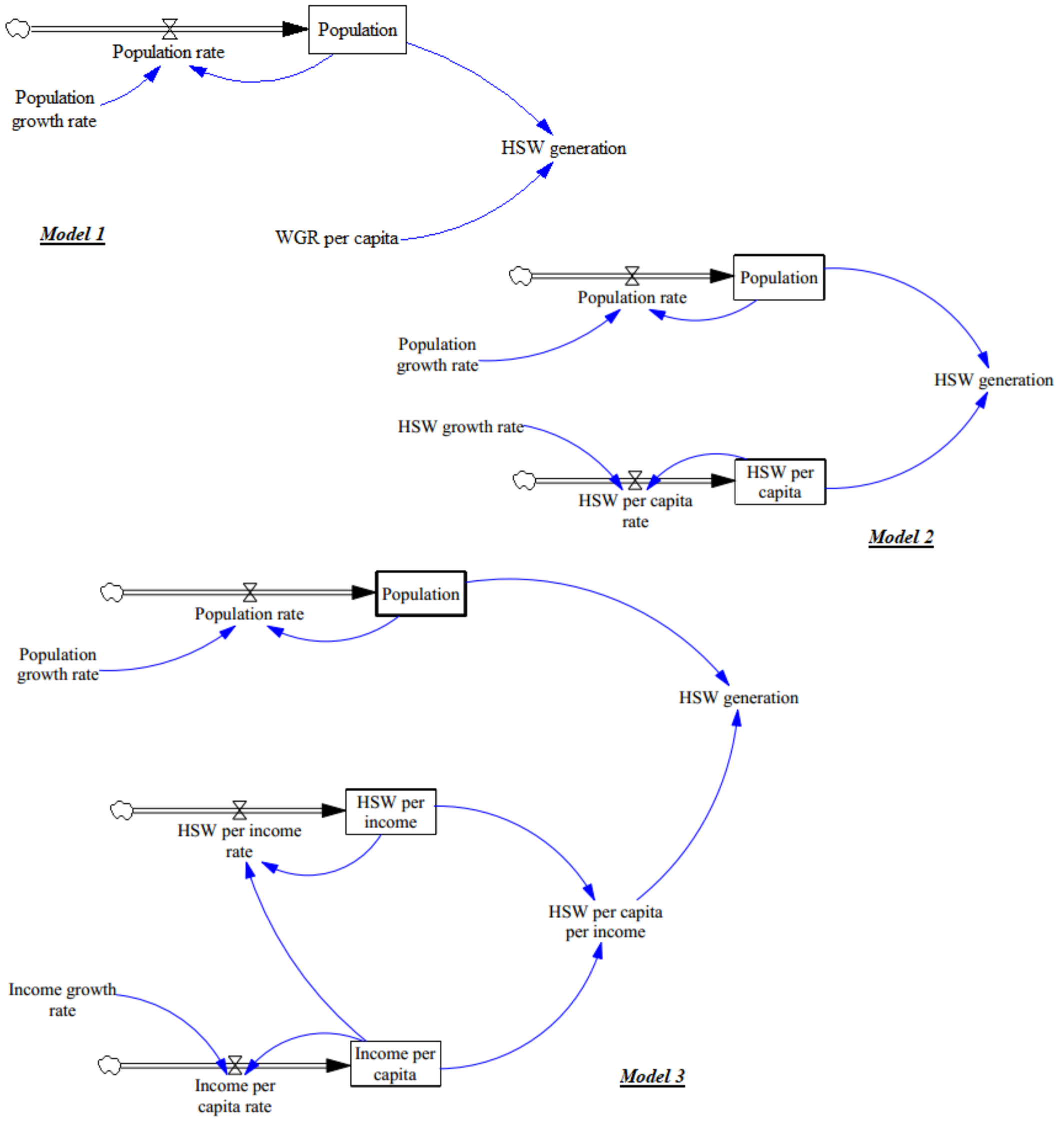

Fig. 7.1 Model 1 and 2 of HSW generation

7.2.2 Modelling of the management system

After projection of waste generation, a management system was evaluated based on the quantity of HSW and segregation scenarios. The stocks of the population and HSW per capita remained the same as in the previous models. The values of recycling, reuse and sale were merged into Self-treated HSW. A stock of Dumped HSW was a summing value of the illegal dumping and Discharged HSW was the quantity of waste discharged for collection. This aimed to assess the quantity of waste managed if the separation scenarios were proposed. Therefore, a stock of recyclables was created to estimate the volume of sorted recyclables by a specific scenario. To be noticed, it was a different case to the practice of sorting valuables for sale. Segregation, in this study, referred to segregating action of disposing of recyclables and others to be collected by collection service after such valuables were pre-sorted and sold to junk buyers. In a case of business as usual, according to a result of the previous study, we assumed the population segregating (Pop-Segregate) was zero, and so was the segregated rate. Unsegregated waste was discharged for collection and dumped illegally. The collection rate was expected to be about 83.3% (Singh et al., 2018). The collected HSW could be about 454.86 Mg/day or 13.65 Gg/month. Fig. 7.2 presents the stock-and-diagram of HSW management model.

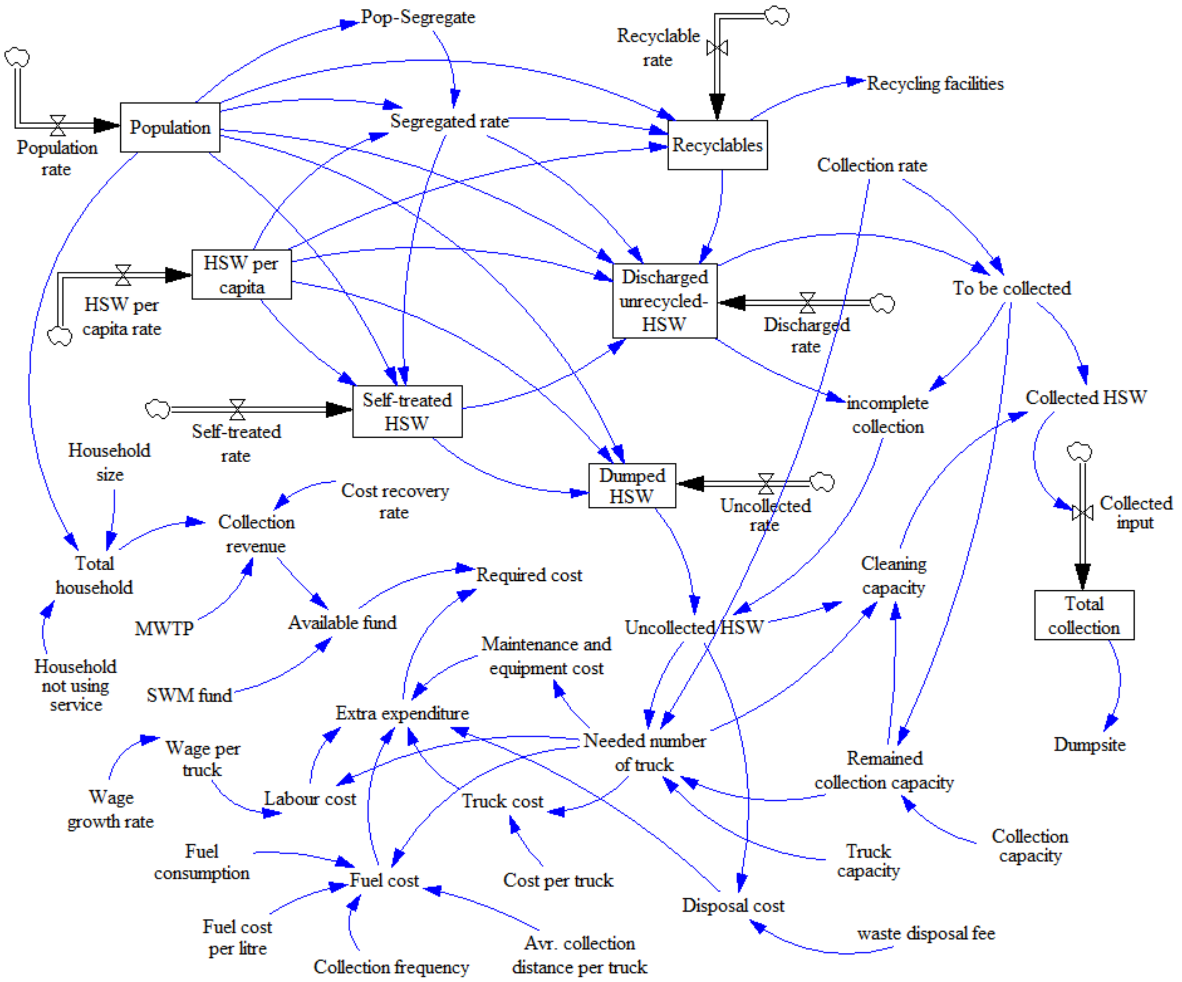

Fig. 7.2 Stock-and-flow diagram of HSW management model

Collection of the uncollected waste was necessary so that the model also calculated the number of trucks needed for this purpose. In 2013, the collection company, CINTRI (Cambodia) LTD., had collection trucks of 161 with a capacity between 2.5 to 11 Mg/truck (PPCH, 2013; Uch et al., 2014). With these statistics, the municipal solid waste collection capacity could be up to 1,125 Mg/day. In response, to the increasing amount of waste, this number also was expected to be raised. According to the annual report of CINTRI (2016), the collection trucks were in total 317. The capacity was not reported, yet we supposed that it increased in double to be 2,250 Mg/day or 67,500 Mg/month for municipal solid waste, and half of them was for HSW collection. Due to the road condition and collection points, we selected new trucks with a medium capacity of 4 Mg that would cost about 13,400 USD/truck (Japanese Car Trade, 2019). One truck would consist of one driver and two collectors. Based on a news article released on June 24, 2016 (The Phnom Penh Post, 2019), the monthly wage was 140 USD/driver and 90 USD/collector, so that the total wage per collection truck would be 320 USD with a monthly growth rate of 1%. The monthly maintenance and equipment (M&E) cost was determined to be about 2.5% of the truck price, so it was about 670 USD/truck. The collected waste in Phnom Penh was disposed of into Dangkor Landfill (Seng et al., 2018) that located about 16 km from the city centre (Uch et al., 2014). Thus, the average collection distance was presumed to be about 48 km/truck/time. The extra expenditure required for cleaning could be estimated, and so was collection revenue based on mean willingness to pay (MWTP) of the public in the Chapter Seven which was about 0.8 USD/month per household with an average member of 4.9 persons. By 2015, there were about 21.6% of the total household not using the collection service (PDPC, 2016). However, we found that only 71.11% of total non-service users would pay. Thus it became a value of the expected cost recovery rate. According to MoE (2016), annual solid waste management (SWM) fund of 8,000 million Riel (about 2 million USD) for all 26 municipalities in Cambodia. Thus, we supposed that Phnom Penh authority would have received at 80,000 USD/year or about 6,667 USD/month. Table 7.2 presents the values of variables in HSW management modelling. The time step of simulation was in months between t = 0 (2017) to t = 96 (2025).

Table 7.2 Variables used for HSW management modelling

Variables	Name	Unit	Initial values/Constant
Stock	Recyclables	Mg/month	0
	Total collection	Mg/month	13,646
Auxiliary	Self-treated rate	Percentage	18.55
	Dumped rate	Percentage	21.31
	Discharged rate	Percentage	60.14
	Pop-Segregate	Person	0
	Household not using service	Percentage	21.6
	Household size	Person	4.9
	SWM Fund	USD/month	6,667
	MWTP	USD/month	0.85
	Cost recovery rate	Percentage	71.11
	Number of labour	Person/truck	3
	Wage per truck	USD/month	320
	Wage growth rate	Percentage	1
	Truck price	USD/truck	13,400
	M & E cost	USD/month/truck	335
	Fuel price	USD/litre	0.8
	Waste disposal fee	USD/Mg	0.75
	Collection frequency	Time/month	10
	Collection distance	km/truck	48
	Fuel consumption	km/litre	1.3
	Truck capacity	Mg/truck	4
	Collection capacity	Mg/month	33,750
	Collection rate	Percentage	83.3

We developed seven scenarios of waste separation for management modelling. Based on the survey results in Chapter Five, the number of populations willing to segregate their HSW was about 66.51%, and most of them presented only willingness to make it into just two groups: recyclables and non-recyclables. If the segregation system were implemented, we expected that the maximum number would probably not be reached at the beginning. Therefore, we set the maximum by 60% of the total population, and segregation of HSW into three groups was also observed. The scenarios were proposed as follows in Table 7.3.

Table 7.3 Scenarios of HSW separation

Scenario	Pop-Segregate (%)	Groups of HSW	Explanation
S1	0	0	Mixed waste
S2	20	2	Recyclables and non-recyclables
S3	40	2	Recyclables and non-recyclables
S4	60	2	Recyclables and non-recyclables
S5	20	3	Recyclables, organics and non-recyclables
S6	40	3	Recyclables, organics and non-recyclables
S7	60	3	Recyclables, organics and non-recyclables

7.2.3 Modelling of waste segregation behaviour

Since the management system model was based on waste segregation scenarios, the public's behaviour was also modelled to explain how the individual would or would not engage in the waste segregation. A structural equation model (SEM) was developed for the assessment. It consists of three measurement models between four latent variables and their measured variables and one structural model between the latent variables. We developed an inner plot (structural model) by connecting all four latent variables of the SEM in the aspect of regression and then selected the observed variables for each measurement model in a reflective mode. In total, there are 16 variables including 12 observed, three exogenous and one endogenous latent variables. Table 7.4 explains the observed variables. The expected effects refer to the effects that the observed variables would have on the latent variables.

Table 7.4 Observed variables for SEM assessment

Measurements	Measured variables	Abbreviation	Values	Expected effect
Situation factors (SiF)	I have no time to separate waste	NoTi	1 = yes, 0 = no	+
	There is no law enforcement	NoLE	1 = yes, 0 = no	+
	There is no public participation	NoPP	1 = yes, 0 = no	+
Knowledge about waste (KaW)	I am aware of waste pollutions	AwPo	1 = yes, 0 = no	+
	I am aware of recycling	AwRe	1 = yes, 0 = no	+
	I am aware of segregation	AwSe	1 = yes, 0 = no	+
Segregation experience (SeE)	I usually sort waste for sale	SoSa	1 = yes, 0 = no	+
	I usually reuse waste	ReuW	1 = yes, 0 = no	+
	I usually practice illegal dumping	PrID	1 = yes, 0 = no	-
Segregation willingness (SeW)	I am willing to segregate waste	WtSe	1 = yes, 0 = no	+
	I am willing to reduce waste	WtRd	1 = yes, 0 = no	+
	I am willing to reuse waste	WtRu	1 = yes, 0 = no	+

The developed SEM was assessed using an R package named ‘lavann’ based on the values of the estimated coefficient and statistical significance of t-values. Households were groups into household using the collection service (HH_UCVs) and not using the service (HH_NCVs). The measurement model was evaluated based on the values of construct reliability (CR) and average variance extracted (AVE). The good model should achieve the CR higher than 0.7 and AVE higher than 0.5 (Zhang et al., 2015). The fitness of the general model was assessed by analyses of the goodness-of-fit index (GFI), comparative fit index (CFI), root-mean-square error of approximation (RMSEA), adjusted goodness-of-fit index (AGFI), incremental fit index (IFI) and normed fit index (NFI). The required values of GFI, CFI, IFI and NFI for a good fit model should be higher than 0.90. The AGFI should have been higher than 0.8, and the RMSE was expected to be lower than 0.8 (Bortoleto et al., 2012; Zhang et al., 2015)

7.3 Results and discussions

7.3.1 The future trend of waste generation

The prediction of HSW generation between 2017-2025 by zone are shown in Fig. 7.3. The results of all three models in four study zones of Phnom Penh, as divided in Chapter Four, were compared. Model 3 tends to generate a high value of upper bound, especially in Zone2 and Zone3. It could be a case of over-estimation of waste generated since the growth rate of income is as high as 5.2% (World Bank, 2018). Moreover, Model 1 seems to produce more lower bound than other models as it was assumed that the WGR would not change as a function of time. This case could be under-estimated. On the other hand, the analyses showed that Model 2 seemed to present the most reliable data among all zones according to a historical growth rate of waste generation. Therefore, the results of the waste amount projected in Model 2 was selected for further analysis. Table 7.5 presents the future trend of HSW amount in Phnom Penh. It resulted in the total amount between 917.24 to 965.5 Mg/year in 2018, 926 to 1026.63 Mg/year in 2019 and 936.05 to 1091.60 Mg/year in 2020. In Model 2, It is estimated that per capita WGR would increase to 0.507 kg/day in 2018, 0.512 kg/day in 2019, 0.517 kg/day in 2020 and up to 0.54 kg/day in 2025. Also, the annual income might be about 2011.26 USD/capita in 2020, and the number of the population would increase to 1,864,350. Similarly, MoP (2017) projected the population of 1,886,575 by the same year.

Table 7.5 Projected trend of HSW generation

Year	Total population	Annual Income (USD/capita)	Waste amount (Mg/year)		
			Model 1	Model 2	Model 3
2018	1,826,891	1817.34	917.24	926.44	965.50
2019	1,845,525	1911.84	926.60	945.27	1026.63
2020	1,864,350	2011.26	936.05	964.49	1091.60
2021	1,883,366	2115.84	945.60	984.10	1160.65
2022	1,902,576	2225.86	955.24	1004.10	1234.04
2023	1,921,983	2341.61	964.98	1024.51	1312.04
2024	1,941,587	2463.37	974.83	1045.34	1394.94
2025	1,961,391	2591.47	984.77	1066.59	1483.05

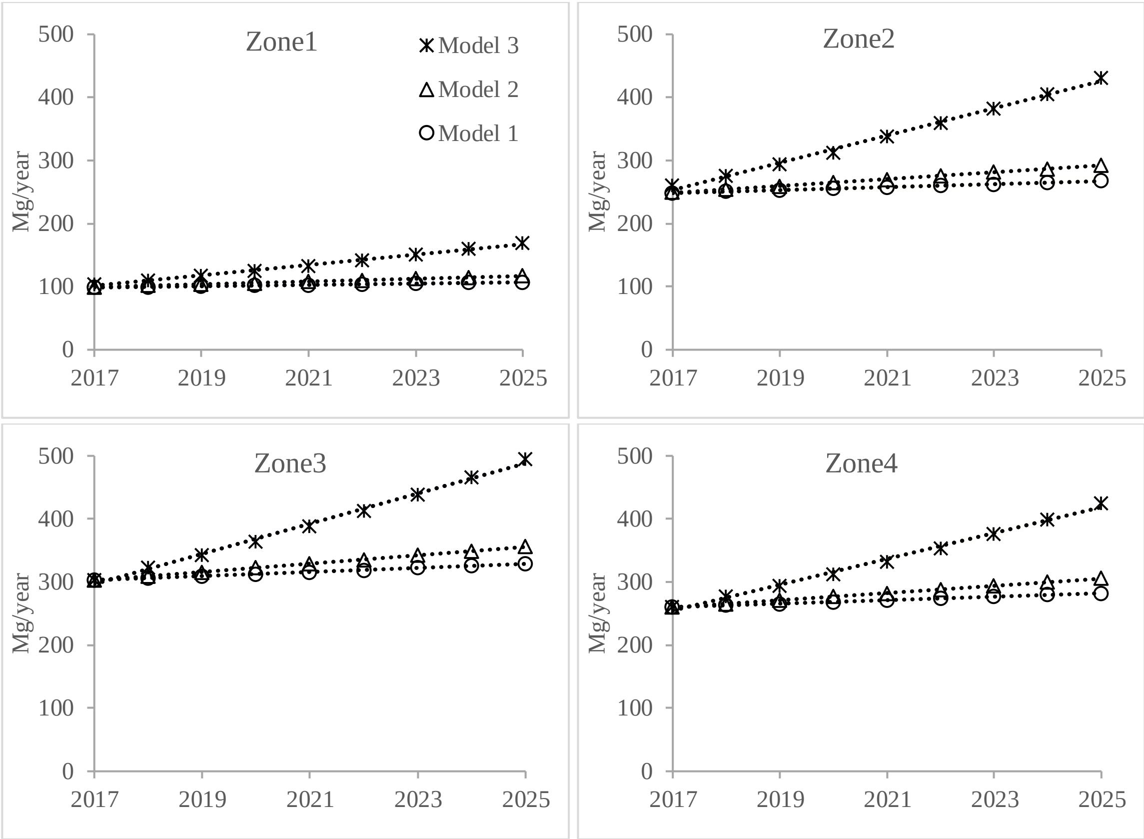

Fig. 7.3 Future trend of total HSW generation by zone

7.3.2 Segregation scenarios-based assessment

As business as usual based on data of Model 2, the annual amount of waste discharged for collection would be about 559.77 Mg in 2018, 574.07 Mg in 2019 and 588.70 Mg in 2020. The data show that the discharged amount would stand out as the most significant fraction, and the illegal dumping remains the biggest concerns toward SWM with total volume of 195.99 Mg/year in 2018, 198.47 Mg/year in 2019 and 201 Mg/year in 2020. There are no much differences in waste quantity among the other handling methods. The future impacts would be uncontrollable if no countermeasures were acted. The amount of self-treated waste could be about 5 Gg/month in all scenarios, and no further recyclables were sorted for separate disposal. In the case of BAU when the waste source-segregation was not in practice, among 16.409 Gg of monthly discharged HSW, up to 13.669 Gg could be collected. The uncollected HSW would increase to 284.72 Mg/day or 8.555 Gg/month in one month (t = 1) and about 8.627 Gg/month after 96 months (t = 96). It shows that the quantity of waste discharged, dumped and uncollected keep growing if waste were segregated. In scenario 2, if 20% of population sort the recyclables including paper, plastic, metal, textile, leather and rubber, glass and e-waste were supposed to be source segregated after self-treatments. In the first month, about 0.733 Gg could be recovered, and it would be about 0.740 Gg in the 96th months. Table 7.6 presents the segregation scenarios-based results.

In scenario 3, if the public participation rate in the segregation practice achieves 40%, about 1.467 Gg/month of recyclables would be reduced from disposal and dumping in the first month. Moreover, it would become about 2.2 Gg/month if 60% of the residents sort their recyclables, in case of scenario 4. If we assumed that organic waste could be further pre-sorted, the discharged and dumped HSW appears to be lower than the amount found in scenario 1, and so does the uncollected HSW. With 20% of population segregating organics and recyclables, in the first month in case of scenario 5, the discharged and dumped HSW could be approximately 13.788 and 4.886 Gg/month respectively. In the case of scenario 6, we supposed that the segregation practice carried out by 40% of people, the uncollected HSW could be minimised to approximately 5.8 Gg/month.

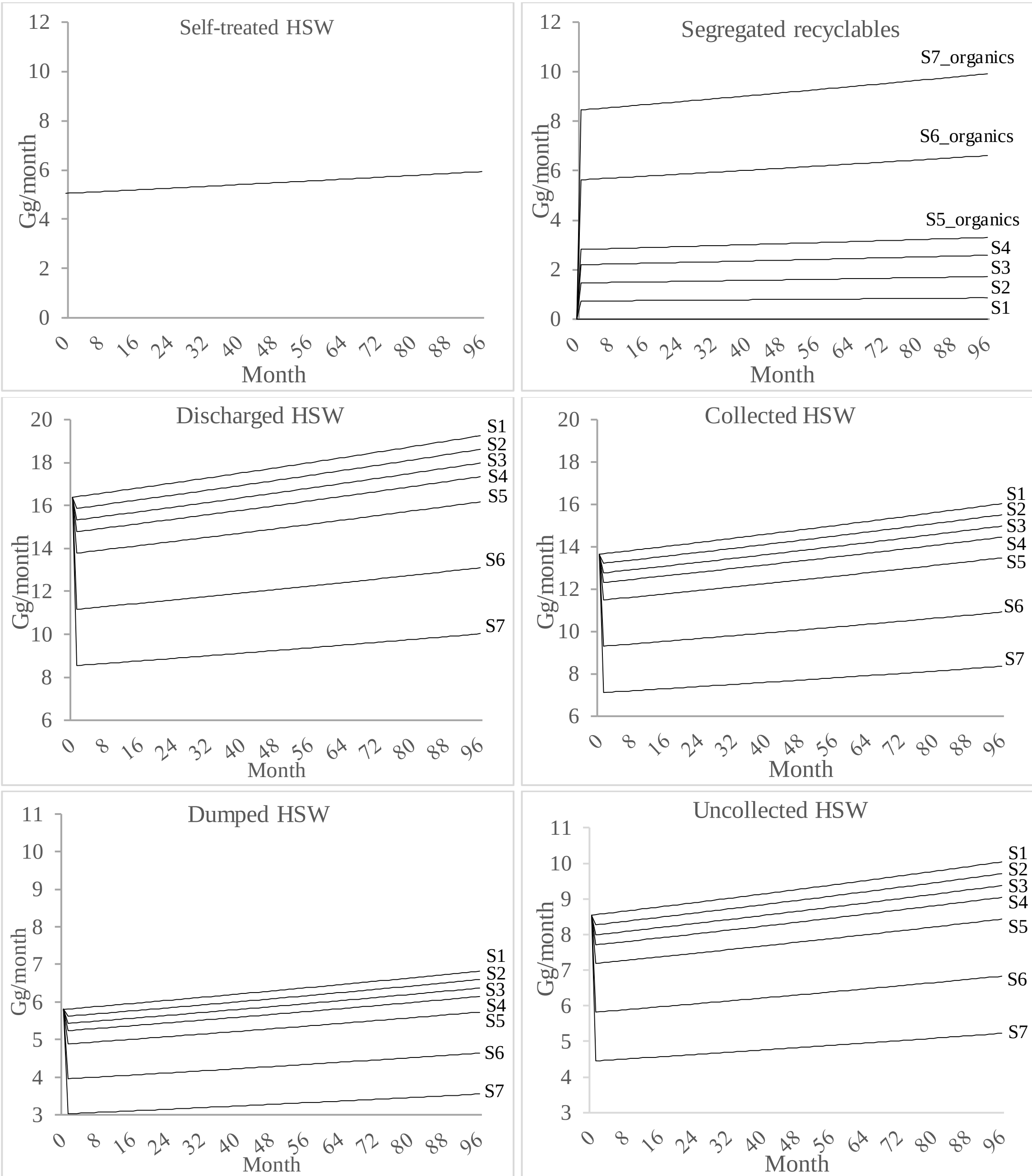

Fig. 7.4 Projected amount of HSW

Fig. 7.4 presents the projected quantity of household waste self-treated, segregated, discharged, dumped, collected and unconnected. It shows that the larger the number of populations participates into the pre-segregation practice, the less amount of HSW would be discharged and dumped. The monthly collected waste could be about 13.2 Gg in scenario 2, 12.7 Gg in scenario 3, 12.3 Gg in scenario 4, 11.5 Gg in scenario 5, 9.3 Gg in scenario 6 and 7.1 Gg in scenario 7. Fig. 7.5 presents the projected amount of HSW uncollected by zone.

Table 7.6 Scenarios-based projection results of HSW

		Amount of HSW (Gg/month)						
		Self-treated	Recyclables	Organics	Discharged	Dumped	Collected	Uncollected
S1	t = 1	5.061	-	-	16.409	5.814	13.669	8.555
	t = 96	5.104	-	-	16.548	5.864	13.784	8.627
S2	t = 1	5.061	0.733	-	15.868	5.623	13.218	8.273
	t = 96	5.104	0.740	-	16.002	5.670	13.330	8.342
S3	t = 1	5.061	1.467	-	15.326	5.431	12.767	7.990
	t = 96	5.104	1.479	-	15.456	5.477	12.875	8.058
S4	t = 1	5.061	2.200	-	14.785	5.239	12.316	7.708
	t = 96	5.104	2.219	-	14.910	5.283	12.420	7.773
S5	t = 1	5.061	0.733	2.816	13.788	4.886	11.486	7.188
	t = 96	5.104	0.740	2.840	13.905	4.927	11.583	7.249
S6	t = 1	5.061	1.467	5.633	11.167	3.957	9.302	5.822
	t = 96	5.104	1.479	5.680	11.262	3.990	9.381	5.871
S7	t = 1	5.061	2.200	8.449	8.546	3.028	7.119	4.456
	t = 96	5.104	2.219	8.520	8.619	3.054	7.179	4.493

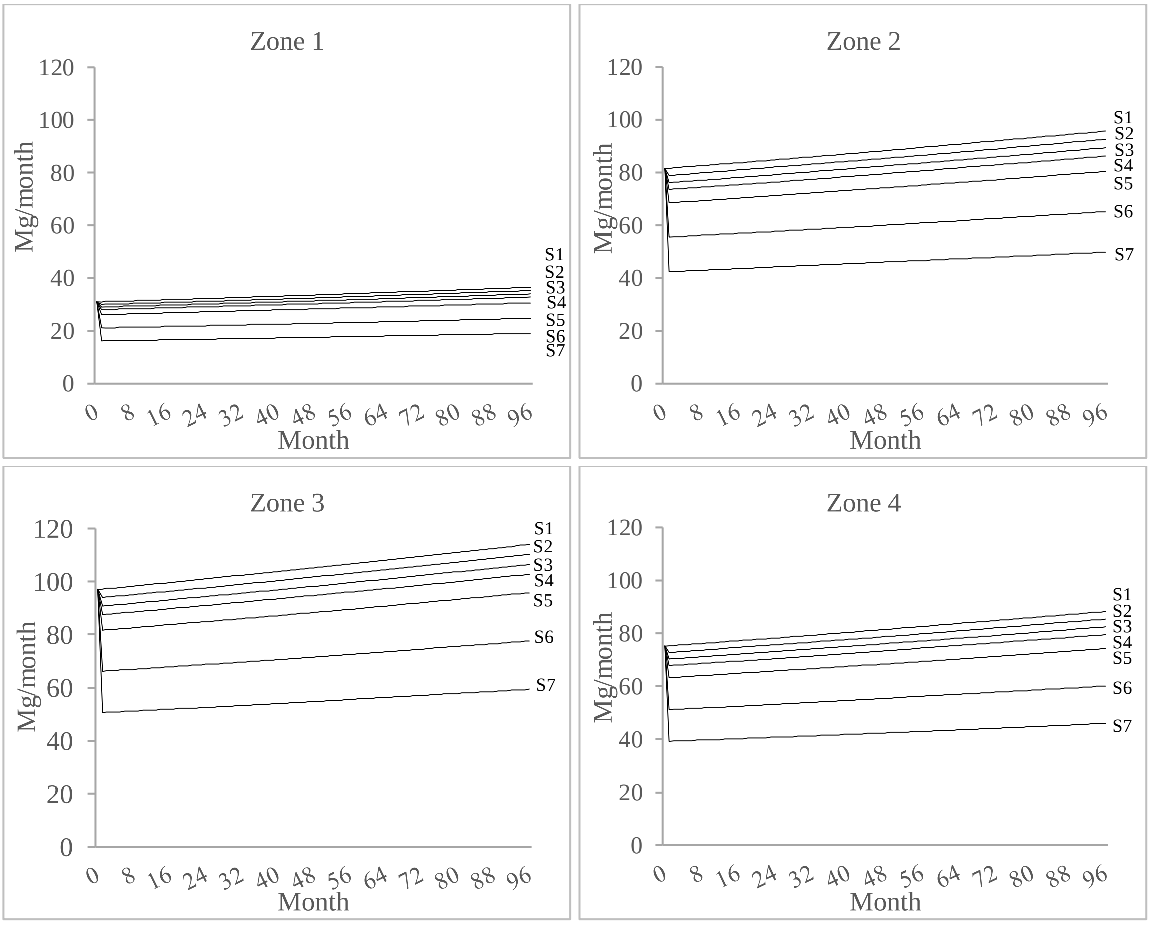

Fig. 7.5 Projected amount of HSW uncollected by zone

7.3.3 Estimates of service operation cost

The simulation model shows that CINTRI (Cambodia) LTD., the waste collection service provider, has enough capacity to collect the uncollected waste until the year 2025. However, with the collection rate of 83.3%, the company must run a more significant number of trucks to manage HSW left by incomplete collection and illegal dumping. In the case of scenario 1, it was estimated to be 43 to 50 between t =1 and 96. The required truck would be lesser if waste could be segregated and recovered. At the first month of segregation practice, the extra trucks needed for collection would be 41 in scenario 2, 40 in scenario 3, 39 in scenario 4, 36 in scenario 5, 29 in scenario 6 and 22 in scenario 7. As more trucks required, more operation cost is also in need. The total cost, as a sum of expenses on wage, maintenance, equipment, fuel and disposal fee, could be raised from 47,221 to 70,664 USD/month between first and the last month of modelling. The cost increases 1.5 times after eight years of operation due to a large volume of HSW increased. The labour cost shares a large fraction in total budget, and so does the fuel cost due to far distance between collection location and dumpsite. To be noticed, the price was not included the expenditure on collection truck since it was already available for operation.

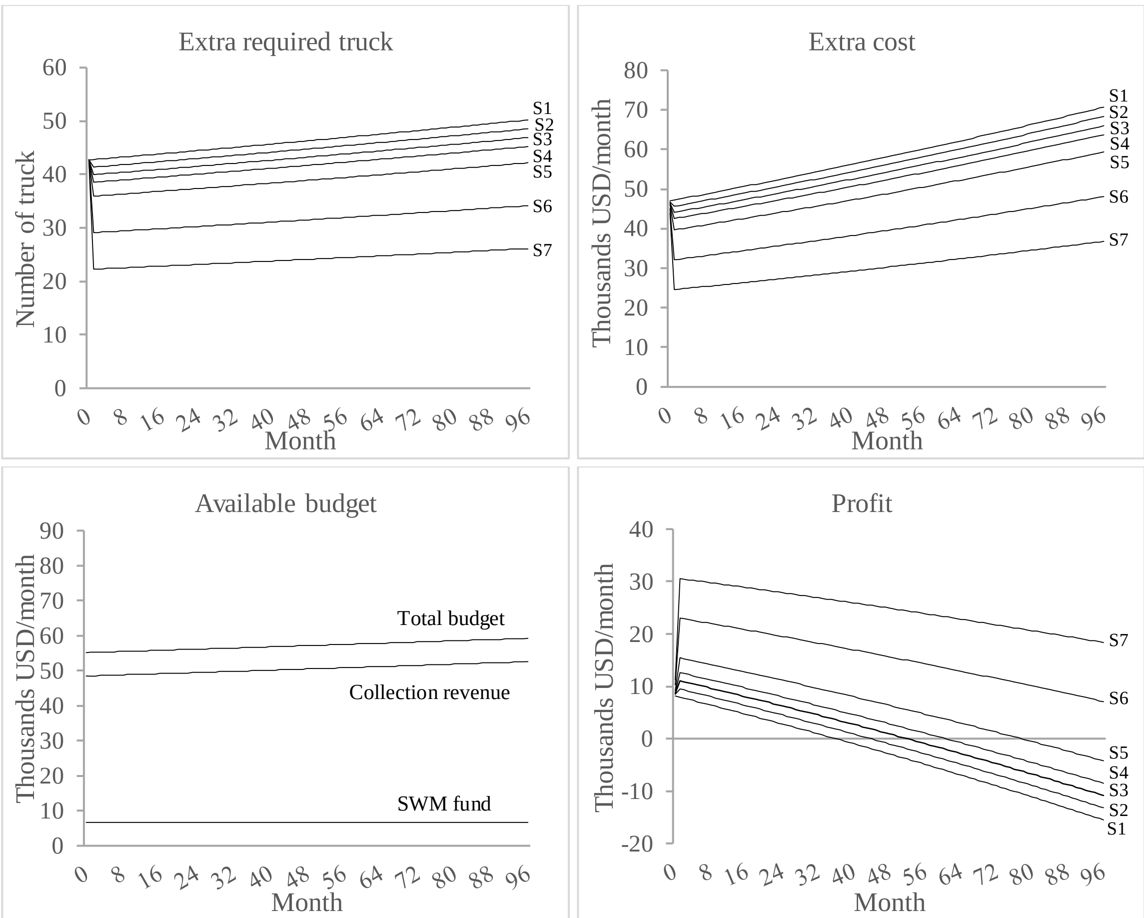

Fig. 7.6 Estimates of required truck, available budget and profit to collect the uncollected HSW

With cost recovery rate at 71.11%, the revenue collected from householders could be only 48,523 USD/month at t = 1 and 52,586 USD/month at t = 96. With the SWM fund of 6,667 USD/month, the total available budget would be between 55,190 and 59,253 USD/month.

After payment for the operation cost, the total profit would be low at 7,928 USD in the first month and even much lowered to -15,515 USD at the end of simulation month. Importantly, the profit would become negative in value after 35 months of operation. That means the extra SWM fund is necessary to cover the outlay. Otherwise, the extra service to collect the uncollected waste appears not to be sustainable financially. If alternative scenario 2, 3, 4 and 5 could be implemented besides BAU, the service could generate more and more, but still not remain positive until 2025. The available budget would be lower than the cost between 44th and 61st month of the simulation period. Unlikely, implementation of scenario 6 and 7 can be highly profitable from the beginning to the end of the simulation. Monthly profit is 23,012 to 7,058 USD earned by scenario 6 and 30,555 to 18,345 USD in case of scenario 7 between t = 1 and 96 respectively (Table 7.7). Fig. 7.6 presents the variation values of the required truck, cost, budget and profit for the collection of uncollected HSW.

Table 7.7 Projection results of the collection service operation cost

		Extra require truck	Extra cost (USD/month)	Available budget (USD/month)	Profit (USD/month)
S1	t = 1	43	47,221	55,190	7,928
	t = 96	50	70,664	59,253	-15,515
S2	t = 1	41	45,663	55,190	9,486
	t = 96	49	68,332	59,253	-13,183
S3	t = 1	40	44,105	55,190	11,044
	t = 96	47	66,000	59,253	-10,851
S4	t = 1	39	42546	55,190	12,602
	t = 96	45	63,668	59,253	-8,519
S5	t = 1	36	39,377	55,190	15,470
	t = 96	42	59,377	59,253	-4,228
S6	t = 1	29	32,137	55,190	23,012
	t = 96	34	48,091	59,253	7,058
S7	t = 1	22	24,594	55,190	30,555
	t = 96	26	36,804	59,253	18,345

7.3.4 Waste segregation behaviour

The bivariate correlation between the observed variables was analysed, as shown in Table 7.8. It shows that the variables of situation factor have a significantly positive relationship with one another. And so are the variables of the knowledge about waste-related problems and segregation experience. To be noticed, sorting for sale is positively related to awareness of pollutions and recycling at $p < 0.1$ and awareness of sorting at $p < 0.05$. However, the awareness of sorting seems to have no influences on the practice of reuse, illegal dumping or segregation willingness. The practice of sorting for sale has a significant relationship with the willingness to segregate waste, yet it is negative. This means that the householders who usually sort their recyclables for trading with junk buyer seem not willing to segregate waste for disposal. It can be explained that sorting for sale is economical while the other is not. Therefore, the incentive should be considered to run the segregation system, as recommended by Sukholthaman and Sharp (2016). Otherwise, the residents would excuse with their business as the correlation results between variables namely ‘No time’, and the willingness is significantly negative. Ineffective law enforcement and public participation would also have negative consequences on segregation willingness due to their negative relationship. More seriously, ‘No public participation’ has significance level at $p < 0.05$.

Table 7.8 Results of correlation analysis

	NoTi	NoLE	NoPP	AwPo	AwRe	AwSo	SoSa	ReuW	HaID	WtSo	WtRd
NoTi	-										
NoLE	0.84**	-									
NoPP	0.90**	0.85**	-								
AwPo	0.12**	0.08**	0.11**	-							
AwRe	0.00	0.02	0.00	0.56**	-						
AwSe	0.00	-0.01	0.00	0.62**	0.81**	-					
SoSa	0.15**	0.19**	0.18**	0.12**	0.05**	0.06*	-				
ReuW	0.14**	0.18**	0.17**	0.06	0.02	0.00	0.50**	-			
HaID	-0.12**	-0.18**	-0.18**	-0.04	0.04	0.04	-0.33**	-0.57**	-		
WtSe	-0.07**	-0.06	-0.09**	0.03	0.03	0.00	-0.06*	-0.09**	0.12**	-	
WtRd	-0.10**	0.03	-0.08**	0.03	0.09**	0.05	-0.06*	0.03	-0.02	0.77**	-
WtRu	-0.14**	-0.07**	-0.15**	0.03	0.02	0.02	-0.09*	-0.07*	0.02	0.79**	0.82**

* $p < 0.1$, ** $p < 0.05$

Fig. 7.7 presents the results of the SEM analysis. It shows that all the observed variables have significant effects on their latent variables at $p < 0.001$. Their impacts are also positive except a negative value of the practice of illegal dumping on segregation experience. Regarding the joint effects among the measurement models, knowledge about waste-related problems has a positive yet insignificant relationship neither with segregation experience or willingness. It means that the public’s experience and willingness seemed not significantly influenced by the factor of knowledge. Madhushan and Fujiwara (2010) also found out a similar effect of knowledge on the willingness of collection service users in Sri Lanka.

Unlikely, the situation factor presents a significant impact on both measured variables at $p < 0.05$. It is positive on experience but negative on the willingness. These results are reasonable since the meaning of the observed variables of the situation factor is negative. With reasons of being busy and insufficient enforcement and participation of the neighbours, the residents would negatively respond toward segregation willingness. However, it becomes positive toward the experience that sorting for sale and reuse are beneficial. On the other hand, segregation experience has a negative impact on the willingness. It could be affected by the practice of illegal dumping that mixed waste is usually dumped and burnt. One more reason would be a negative correlation between sorting for sale and willingness to segregate. It is noticeable that the sorting for sale is preferable rather than segregation for disposal because of its economic advantage. The likely findings were also mentioned in a study of Madhushan and Fujiwara (2010). Therefore, it is necessary to enforce the law and public participation, to provide such incentives, and to proscribe the practice of illegal dumping. Fig. 7.8 presents the analysis results of SEM in case of HH_UCVs and HH_NCVs. The influence of situation factor is negative on segregation willingness of both groups, yet the experience is positive on the willingness of only HH_UCVs. Sorting for sale, reuse and illegal dumping seems to be customary for HH_NCVs who are not served by the collection service. The offer of the quality service would halt their dumping; but introducing a segregation system would be challenging with the local customs, especially recycling that is directly worthy.

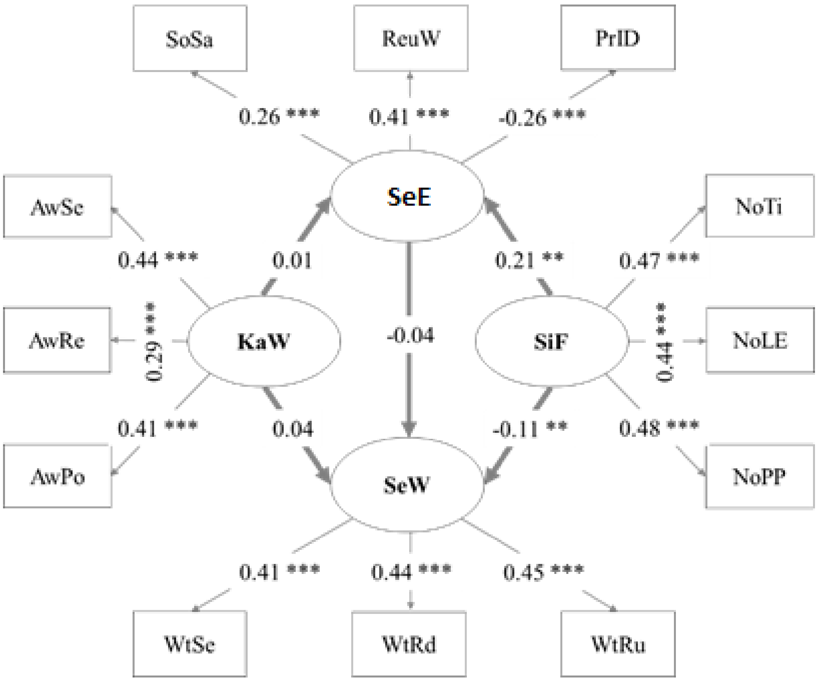

Fig. 7.7 Results of SEM analysis (** $p < 0.05$, *** $p < 0.01$)

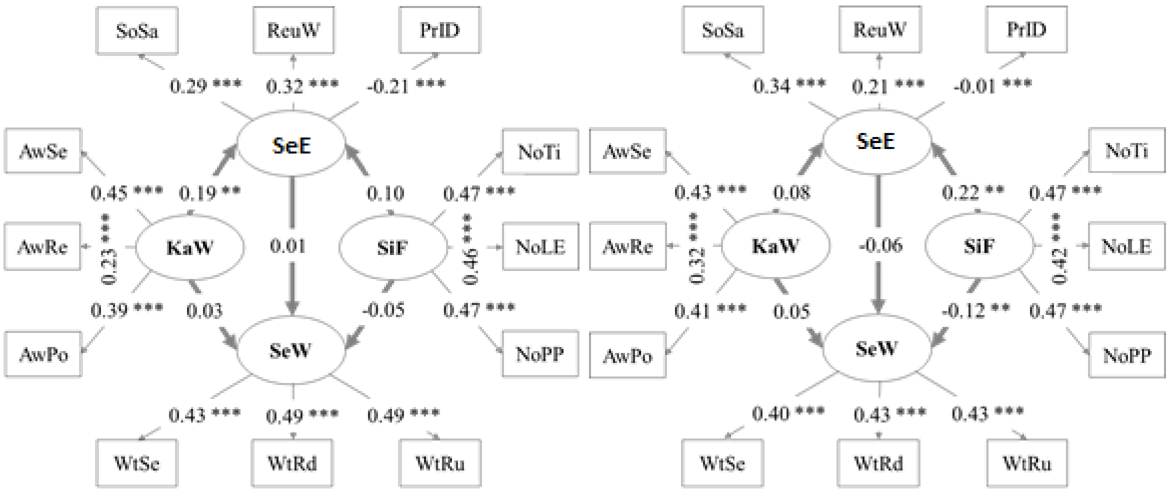

Fig. 7.8 Results of SEM analysis for HH_UCVs (left) and HH_NCVs (right)

Table 7.9 presents the assessment results of the measurement models. The assessment criteria included construct reliability (CR) and average variance extracted (AVE) that were expected to be higher than 0.7 and 0.5 respectively (Zhang et al., 2015). The analysis shows that the obtained values of both CR and AVE appear to be higher than the requirements in all constructs. It indicates the internal consistency and reliability of the model (Zhang et al., 2015; Xu et al., 2017). The results of the model fit assessment are shown in Table 7.10. The model seems to be fit as the values of all six evaluation criteria meet the suggested values.

Table 7.9 Results of measurement model assessment

Constructs	construct reliability	average variance extracted
Situation factor	0.871	0.867
Knowledge about waste	0.866	0.690
Separation experience	0.739	0.510
Separation willingness	0.934	0.795

Table 7.10 Results of model fit assessment

Model fit criteria	Obtained values	Suggested values *	Remark
GFI	0.983	> 0.90	Good model fit
CFI	0.959	> 0.90	Good model fit
RMSE	0.074	< 0.08	Good model fit
AGFI	0.967	> 0.80	Good model fit
IFI	0.969	> 0.90	Good model fit
NFI	0.951	> 0.90	Good model fit

* Zhang et al., 2015

7.4 Conclusions

The study projected the volume of HSW generated and managed between 2017 and 2025 using system dynamic modelling. The quantity of the collected and uncollected waste was estimated depending discharged, dumping and collection rate. The segregation scenarios were proposed and evaluated based on willingness to segregate waste of the householders. According to the values of willingness to pay for the service, the operation cost and profit of the collection service was also quantified to analyse the future financial needs to manage the waste. Population growth positively affects the amount of HSW generated that leads to an increasing volume of illegal dumping and discharged. It also requires the larger capacity to collect the waste and dispose of into dumpsite. If waste cannot appropriately be controlled, it would seriously affect the environmental quality and community livelihood. Provision of collection service, recycling facilities and public awareness raising about source-segregation and self-treatment should be considered options that would better the management system.

The service provider needs to enhance the quality of the service so that the collection rate could be higher. It would positively affect the financial expenses, and more profit could be generated. Transfer stations for collected waste should be considered to minimise the operation cost. Since the city has only one dump site, the collection trucks must have transported a large amount of waste to dispose of at a remote location. On another hand, the city hall should cooperate with other neighbour provincial governments to manage the discharged and dumped waste. It is even more important to recover the cost at the maximum. The expected number of households paying for the service could not even three fourth of the total. It may lead to insufficient service and make the service not sustained financially. Therefore, the subsidy should be provided to the collection company in case their cost recovery and profit is lower than expenses.

More importantly, waste segregation at source must be implemented. The structural equation model presented remarkable findings of public's behaviour regarding the segregation. The present situation factors need to be improved with effective law enforcement and incentive. Knowledge appeared not to have a significant impact, yet it is still important to provide a clear instruction of segregation system for the public. The residents would rather sort recyclables for sale instead of for disposal. Therefore, the informal recycling sector should be organised into formal management work. Another possible option is to integrate the sector into the segregation system. The authority and the private service providers should consider collecting the segregated recyclables with the assistance of the informal sector.

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Chapter Eight
Conclusions and Recommendations

8.1 Conclusions

Solid waste management has put pressures on the Phnom Penh authorities since it seemed to be a new matter that lacks information. As the capital city of Cambodia, if there were any mismanagements, the public would put on serious attention and complaints. Undoubtedly, the shortage of related knowledge and baseline data limited the quality of master planning and demonstration. The management system appeared to be dissatisfying as it could not have even sufficient cleaning and collection service, and waste had to be disposed of into an open dumpsite without any formal pre-treatments. The only informal sector could recycle a small fraction of waste. Incomplete collection resulted in illegal waste dumping that caused adverse impacts on environmental quality and public health. The present management system was not sound sustainable while the demands of the clean city were rising. This situation could be improved by turning solid waste into resources, for example by material recovery, composting and the like. It would provide opportunities to evolve the system into an integrated management approach. However, public participation was likely stressed to perform the exercises. As one of the keys to success, participation should be assured. Therefore, solid waste generation and public knowledge, behaviours and practices were assessed. Findings of four research cases in Phnom Penh could be concluded.

The analyses of the case studies in Phnom Penh showed that increases in the volume of solid waste per household had a relationship with the number of household member, employment rate and occupation in home business. It could be mentioned that household size and economic factors significantly determine the waste generation rate. With an instant growth of annual income, the generation rate of household waste would be about 0.517 kg/capita/day in 2020. Even though the statistical data of waste generation showed none significance value between residential zones, the householders residing in the central of the city seemed likely to generate the highest rate since their level of income and lifestyle was much better than others. Similarly, the total quantity of household waste had a strong relationship with the population and income growth rate. It was estimated that the total volume of waste generated from the residential areas would be approximately 964.489 Mg/year in 2020.

Food waste and garden waste had the largest and third largest fraction in the composition of the household waste and were usually recycled into animal feed and organic fertilisers. Due to the volume generated, food waste made a significant share of the total emitted greenhouse gases while the total emissions would be about 232.79 Gg of carbon dioxide equivalent in 2020. Mixed composting and anaerobic digestion of these two types of organic waste should be considered. However, it should be noted that introducing of these two options would not be viable at the household level since the city appeared to experience rapid urbanisation. On the other hand, plastic waste also had a remarkable volume that tended to increase annually. Proportionately, it was the second largest in the household waste and generally was an object to be reused, marketed and burnt openly. The burning of plastic had severe impacts on the environment, especially air quality and also produced harmful gases. Evidentally, open burning emitted the second largest potential greenhouse gases after open dumpsite's. If waste could be well pre-segregated, plastic, paper and other materials, would be recoverable for the recycling markets.

The city needs to be clean and livable so that the waste collection service was expected to be high in both quality and efficiency. It was served on a daily basis in the central area yet less frequent in the other districts, especially the poor communities. Per week, it could be thrice, twice or once in the suburbs due to the residential location. As the population density became lower in the rural area, and the collection frequency became lesser. Assumingly, it could be related to the total volume of waste generated and cost recovery. More seriously, the collection service was not even running in the rural areas of the city. Most of the householders appeared to be dissatisfied with the collection service in specific or with the management performance in general. A high tipping fee of the service was another matter of dissatisfaction. The quantity-based charge was a method used for tipping fee determination. It caused confusions among the service users because they were not explicitly aware of the determination method. Some households presumed their charge to be as same as their neighbours, yet it was higher than expected due to their activities and the size of their home business. Therefore, dissatisfaction happened toward unexpected tipping fee. Consequently, it resulted in negative willingness to pay for the improved service if extra payment was necessary. They would positively be if they were satisfied with service and could earn a high-income level. The collection service needs to be frequent and affordable to all households. When the service is provided, the satisfaction of the users toward waste management situation should be ensured by maintaining the collection quality, regularity and frequency.

The collection service requires the individual household to pay. Therefore, the willingness to pay for the service was evaluated with the houses not registered to waste collection. It found that about one-third of the households did not present the need of the collection service. They preferred to keep their way of usual practices. Most of the families in need presented positive willingness. Income was an economic factor to influence the public willingness to pay. Solid waste-related awareness positively determines public decisions and practices. However, the householders would have to spend on this service so that their net income might be affected. The residents would be highly willing to pay for the service if they can generate more revenue and assure their livelihood comfortably. Otherwise, self-treatments and illegal waste dumping, as business as usual, would remain in practices. Self-treatments included reuse, recycling, segregation for sale positively reduced the amount of waste disposed of, yet the illegal dumping such as open burning, burying and littering were negatively impactful. Collection of uncollected waste seems not to be a challenge in term of equipment and collection capacity. The service provider has enough truck to transport waste from generators. However, cost recovery might cause uncertainty. Therefore, all stakeholders need to discuss with one another in a partner and a group. The company requires appropriate profit to sustain and strengthen the service. The service users are obligated to pay the tipping fee, and if possible, the subsidy should be given by the government.

It found that using different waste handling methods is not related to waste generation rate. Recycling, reuse and sale importantly contribute to the minimisation of waste disposal. A large amount of waste is illegally dumped where the collection is not served. The causes and effects of the illegal dumping were analysed. The public behaviours of willingness to pay for improved collection service and to segregate waste were assessed. Even though the households did segregation of valuable and non-valuable waste for different purposes, the pre-segregation for disposal was not practised. It was not only because of lacking awareness, but also unexistence of the separation system. Discharged waste remained mixed. Once the separation system is well equipped, it would be practicable to encourage and enforce the tenants to segregate their waste in two groups of recyclables and non-recyclables. However, some amount of recyclables would be traded with the informal sector if it is uncontrollable. Another option is to propose segregation of waste into three groups of organics, recyclables and non-recyclables. The recyclables can be recovered, and the organics can be composted.

8.2 Recommendations for future studies

This study provided the necessary data for household waste management including waste data and public behaviours and preferences that can be used for management planning in the future. The following recommendations are proposed to improve the situations:

- Awareness raising on the topics of waste problems and fee determination methods should be adequately provided to the locals. It would significantly affect the way that the residents make decisions concerning what to do with their garbage. It can be done in both formal and informal systems, for example, by academic institutes and community-based learning. Also, the people must be well informed if there were any changes or updates on the basic charging fee to avoid any misunderstandings and dissatisfactions.
- Short-term and long-term training programs should be continuously provided to raise the understandings among the locals about proper waste management practices, public health and sanitation, and related legal frameworks.
- Public participation to segregate waste should be encouraged in all activities by not only education, awareness raising or law enforcement, but also economic incentives. All residents should be encouraged to reduce the amount of generated waste. Reuse and recycling activities should also be introduced in the area, and waste segregation of recyclable and non-recyclables materials has to be in action.
- Public awareness should be raised concerning household waste reduction, storing, reuse, pre-segregation, and recycling. Related regulations and laws should be efficiently introduced and enforced regarding especially the implementation of source segregation, and prohibition of the illegal dumping (open burning, burying and littering).
- Waste segregation system should be integrated into the management. The pre-segregation of household solid waste should be introduced with only two groups of

waste (organic and inorganic waste). The demonstrations should be guided and managed by the local authorities.

- The government and service providers should provide satisfying waste management at the desired tipping fee. If the collection service would be increased in price, it should be reasonable and affordable. The service providers and policymakers should pay more attention to the needs of all households. The collection service should be widely provided with high efficiency and sufficiency. The frequent and regular collection has to be served. Provision of the waste collection service should be improved and widened throughout the city.
- The quality and frequency of the collection service should improve to be satisfactory. Alternatives to the inexistence of regular collection service should be made. Community-based solid waste collection and management, for example, can be an alternative option. Where the problems of collection service are solved, the related laws on solid waste management should be enforced to ensure public participation. Related laws on solid waste management should be effectively implemented to prohibit illegal dumping.
- The government and the service providers can provide such supporting programs, for example, incentives and subsidies, to make the collection fee low and affordable especially to the low-income families. The service providers, responsible institutions, local government and the residents should have more discussions about general administration works before starting the collection service.
- This study only focused on household solid waste. Therefore, future study should evaluate the municipal solid waste generation and management. Also, it is important to research on cost-effectiveness for running the waste collection in the non-service area and design of the collection routes and methods to suit with the local situations. A geographical information system (GIS) based evaluation of the collection service should also be one of the evaluation topics.

Appendices

Appendix 1: Questionnaire for household survey

Questionnaire Code No.: ....

Interviewer: ...., F/M, Date of interview: ..../........./........ (DD/MM/YYYY)

Place of interview: Street: ...., Village: ...., Commune: ...., District: ....

Self-introduction

My name is ………, a student from …………. We are currently collecting data for thesis writing on Assessment of Solid Waste Management Practices in Phnom Penh City. The objective of this study is to design a sustainable system for solving and improving solid waste management in the city. Therefore, your cooperation is necessary for our research. I want to ask you some questions for about 30 minutes if you would not mind.

Section 1. General Information

Q.1.1 Name of respondent:			Q.1.2 Age:	
Q.1.3 Gender:	1. Female	2. Male	Q.1.4 Household member(s):	
Q.1.5 Type of house:	1. Thatched roof 4. Flat/apartment	2. Wooden with zinc/fibro roof 5. Villa	6. Rental house	3. Cement wall 7. Others: ....
Q.1.6 Role in family:	1. Household's head	2. Spouse	3. Son/daughter	4. Relatives

Q.1.7 Education level of respondent and household members *(Please √)*

Education level	Respondent	M1..............	M2..............	M3.............	M4..............	M5.............	M6..............
1. Illiterate							
2. Primary school							
3. Secondary school							
4. High school							
5. University							

Q.1.8 Total income in Riel/month: .... *(Please sum up income of all members' occupations)*

	Respondent	M1..............	M2..............	M3.............	M4..............	M5.............	M6..............
1. Governmental staff							
2. Employer							
3. Employee							
4. Family business							
5. Worker							
6. Farmer/fisher							
7. Taxi/tuk-tuk/motor							
8. Others:							

Section 2. Solid waste management service

Q.2.1 How is solid waste managed in the village?	1. Dissatisfied 2. Neutral 3. Satisfied
Q.2.2 Is there waste collection service in the village?	1. Yes 2. No *(Skip to **Section 2.2**)*
Q.2.3 Can your household access to the service?	1. Yes *(Skip to Q.2.5)* 2. No
Q.2.4 If No, please specify your reasons: *(After asking this Q, Skip to **Section 2.2**)*	1. Unaffordable fee 2. Unreachable point 3. Service cut-off 4. Others: ....
Q.2.5 If YES, how is the collection service? *(If 3, 4 or 5, Skip to Q.2.7)*	1. Dissatisfied 2. Neutral 3. Satisfied
Q.2.6 Why are you dissatisfied with the service? *(Multi-answer)*	1. Poor quality service 2. Irregular schedule 3. Expensive fee 4. Uncleanliness 5. Others: ....
Q.2.7 How often is the waste collected a week?	1. Everyday 2. Every other day 3. Twice a week 4. Once a week 5. Others: ....

Q.2.8 How is the collection frequency? *(If 3, 4 or 5, Skip to Q.2.11)*	1. Dissatisfied 2. Neutral 3. Satisfied
Q.2.9 If Dissatisfied, how often do you need it?	1. Everyday 2. Every other day 3. Twice a week 4. Once a week 5. Others: ....
Q.2.10 Please specify your reasons:	1. To reduce illegal waste dumping 2. To improve environmental quality 3. To improve living comfortability 4. To reduce infectious insects 5. Others: ....
Q.2.11 How much is the collection fee a month?	....Riel/month
Q.2.12 How are you satisfied with collection fee? *(If 3, 4 or 5, Skip to **Section 2.1**)*	1. Dissatisfied 2. Neutral 3. Satisfied
Q.2.13 If Dissatisfied, how much should it be? *(After asking this Q, Skip to **Section 2.2**)*	....Riel/month

Section 2.1. Willingness to pay for improved service for current service users

Q.2.14 If Satisfied, are you willing to pay higher fee for improved service?	1. Yes 2. No *(Skip to **Section 2.3**)*
Q.2.15 If Yes, how much are you willing to pay more?	....Riel/month
Q.2.16 If it requires even much higher, would you agree?	1. Yes 2. No *(Skip to **Section 2.3**)*
Q.2.17 If Yes, how much can you afford?	....Riel/month

Section 2.2. Willingness to pay for collection service for non-service users

Q.2.18 Do you need waste collection service?	1. Yes *(Skip to Q.2.20)* 2. No
Q.2.19 If No, please specify your reasons: *(After asking this Q, Skip to **Section 2.3**)*	1. Unaffordable to pay the fee 2. Satisfied with current circumstances 3. Unreliability of service 4. Others: ....
Q.2.20 If Yes, please specify your reasons:	1. To improve environment quality 2. To reduce infectious insects 3. To improve living comfortability 4. Too much waste generated 5. Others: ....
Q.2.21 How often do you want waste collected a week?	1. Everyday 2. Every other day 3. Twice a week 4. Once a week 5. Others: ....
Q.2.22 Collection fee is a must once service is provided. Are you willing to pay?	1. Yes 2. No *(Skip to **Section 2.3**)*
Q.2.23 If NO, your house will not get the service, what would you do instead?	1. To keep waste disposal in a usual way 2. To dispose waste while collecting 3. To involve in community cleaning 4. Others: ....
Q.2.24 If Yes, how much are you willing to pay a month?	....Riel/month
Q.2.25 If it requires even much higher, would you agree?	1. Yes 2. No *(Skip to **Section 2.3**)*
Q.2.26 If Yes, how much can you afford a month?	....Riel/month

Section 3. Household waste generation and disposal

Q.3.1 How much waste do your household generate a day?	....Kg/day

Q.3.2 Types of waste and handling methods *(Please √)*

How does your family handle each type of waste? ➡ / What type of waste are usually generated? ⬇	Recycle/ animal feed	Reuse	Sort for sale	Discharge for collection	Illegal dumping			
					Open burn	Bury	Litter to open space	Litter to water bodies
1. Food waste								
2. Garden waste								
3. Wood								
4. Tissue								
5. Office paper								
6. Newspaper								
7. Magazine								
8. Booklet								
9. Cardboard								
10. Other papers								
11. Glass bottle								
12. Broken glasses								
13. Aluminium can								
14. Ferrous can								
15. Other metals								
16. Textile								
17. Leather/rubber								
18. Plastic bag								
19. Foam plastic								
20. PET								
21. Other plastics								
22. Nappies								
23. Batteries								
24. Medical waste								
25. WEEE								
26. Ceramic/stone								
27. Others								

Remind: ask Q.3.2 if there is √on "Illegal Dumping" in Q.2.28; otherwise, skip to ***Section 4****)*

Q.3.3 why do you dump waste that way? *(Multi-answer)*	1. No access to collection 2. Irregular collection schedule 3. Incomplete collection 4. Collection point is way too far from home 5. Convenient way of dumping 6. Costless way of dumping 7. Others: ....

Section 4. Knowledge about waste-related issues

Q.4.1 Are you aware of environmental problems caused by solid waste?	1. Yes 2. No *(Skip to Q.4.3)*
Q.4.2 If Yes, what are the problems?	1. Water pollution 2. Air pollution 3. Soil pollution 4. Stormwater flood 5. Others: ....
Q.4.3 Are you aware of health problems caused by waste?	1. Yes 2. No *(Skip to Q.4.5)*
Q.4.4 If Yes, what are the problems?	1. Infectious diseases 2. Respiratory problem 3. Skin infections 4. Others:
Q.4.5 Do you know about 'Dry and Wet Waste pre-soring program' promoted by the Phnom Penh City Hall?	1. Yes 2. No *(Skip to Q.4.9)*
Q.4.6 If Yes, do you separate "Dry and Wet Waste" before discharge?	1. Yes 2. No *(Skip to Q.4.8)*
Q.4.7 If Yes, how often do you separate it? *(After asking this Q, Skip to Q.4.9)*	1. Everyday 2. Every other day 3. Twice a week 4. Once a week 5. Irregularly 6. Others: ....
Q.4.8 If NO, please specify your reasons: *(Multi-answer)*	1. No law enforcement 2. No encouragement from stakeholders 3. No sorting system in the area 4. No one sorting waste in the area 5. No soring equipment 6. No time 7. Others: ....
Q.4.9 If the above issues were solved, are you willing to sort waste into specific groups before discharge?	1. Sure *(Skip to Q.4.11)* 2. Not sure
Q.4.10 If NOT Sure, what concerns you? *(Multi-answer)* *(After asking this Q, Skip to Q.4.13)*	1. Encouragement from stakeholders/authorities 2. Public participation 3. Knowledge of waste sorting 4. A separate collection system for sorted waste 5. Availability of sorting bins available in the area 6. Others: ....
Q.4.11 If you agree to involve in Household Waste Sorting Program, how many waste categories do you think your household would be able to sort out? *(Please refer to Household Waste Separation Options Sheet and show the respondent to choose the possible option they can do)*	1. Two (organic and inorganic waste) 2. Three (organic, recyclable and unrecyclable) 3. Four (organic, recyclable, unrecyclable and hazardous wastes) 4. Five (organic, recyclable, burnable, non-burnable and hazardous wastes) 5. Six (organic, recyclable, burnable, non-burnable, batteries and other hazardous wastes)
Q.4.12 Please specify your reasons:	1. Easily doable 2. Time-saving 3. Costless on materials 4. Efficient management 5. Easily treatable 6. Others: ....
Q.4.13 In sum, to encourage every Household to get involved in waste management practice including Sorting reuse and recycling, what do you think the local authorities need to do? *(Multi-answer)*	1. Encouragement from stakeholders/authorities 2. Clear waste sorting system and program 3. Public participation in waste sorting 4. Improved collection system 5. Training on how to sort and store waste 6. Incentives for waste sorting 7. Others: ....

Appendix 2: Waste composition record

Waste composition record in Zone ……….   Data: ………………………..

Household Info				Waste Generation (gram)																												
Q. ID	Name	M /F	A g e	Gar bage ID	Waste Weight	Fo od	Gar den	Wo od	Paper							Glass		Plastic				Metal			Tex tile	Lea ther	Nap pies	Stone	Hazardous			Others
									Tis sue	Office paper	News paper	Maga zine	Book let	Card board	Others	Bottle	Others	Bag	Foam	PET	Others	Al. can	Fe. can	Others					Batte ries	Medi cal	WE EE	