THESIS OUTLINE

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Declaration of originality

Completion statement by supervisor

Abstract

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Acknowledgements

Abbreviations/Glossary

Analysis of Waste Generation and Recycling Potential for Development of 3R-based Solid Waste Management in Phnom Penh, Cambodia

カンボジア・プノンペンにおける３R をベースとした廃棄物マネジメント構築のための廃棄物発生量とリサイクルポテンシャルの分析

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ABSTRACT

Municipal solid waste management (MSWM) become challenging and more complex in many nations, especially the developing ones. Rapid urbanization, industrialization and population growth are the root causes of the tremendous increase in waste volume which pose a serious burden and challenge for planners and policy makers. Most Asian countries, including Cambodia, are experiencing enormous challenges in their management of urban waste. Cambodia is one of the least-developed countries (LDC), but the rate of development has been remarkable noticed over the last two decades. Waste volume has drastically increased year by year due to urbanization, lifestyle changes and rapid population growth. Phnom Penh, the capital of the Kingdom of Cambodia, is the most development among the towns. Waste collection efficiency was low resulting in piles of waste and scattered waste existing in the city (mostly in peri-urban areas). Illegal dumping and uncollected waste remain a major problem, leading to many social concerns such as aesthetics, environmental degradation, damage to urban infrastructure - including drainage blockages and flooded roads. Open dumping is a common disposal method used throughout the country even in Phnom Penh city. All kinds of waste, except hazardous waste, are disposed of at dump sites/landfills without any separation/pre-treatment. Waste reduction is urgent required through material recovery. Some researchers have studied solid waste management in the city, but the available information on both the quantity and quality of municipal solid waste is also limited, old and unreliable. This information needs to be updated in order to provide more information for waste planners and decision makers and to create a waste generation database.

The main objective of this dissertation was to determine the household solid waste and commercial waste generation, composition, potential for recycling and then to describe the relationship between waste generation and relevant socio-economic factors, residents' awareness on SMW, and their attitudes and willingness to participate in household solid waste management and to evaluate the appropriate waste treatment methods in Phnom Penh city, Cambodia. These presented by the following issues: i) to determine the quantity and composition of household solid waste and commercial solid waste to evaluate the potential for recycling; ii) to identify the factors influent on household solid waste generation; iii) to examine behavior, habit and attitudes towards waste discharge, waste separation, good waste management and 3R practices; and iv) to evaluate the appropriate waste treatment options to mitigate the greenhouse emission and to minimize the waste

volume to landfill which contribute to environmental and health impact.

In order to approach and achieve the proposed objectives, we conducted researches on waste characterization with the waste samples collected from two different sources: i) street waste (317.1kg) obtained from 20 collection points along the streets to check the waste composition; and ii) household solid waste was collected daily from 26 households for two consecutive weeks to determine waste generation and composition, and to evaluate the appropriate waste treatment in September 2012. The waste was separated into three categories and was quantified by weight as: i) combustible (89.70%), non-combustible (8.90%), and recyclable (1.40%) for the street waste and 91.53%, 8.08%, 0.39% for household waste, respectively. The combustible materials mainly consisted of food (58.76%), plastic (17.27%), paper (7.71%)) for the street waste and 66.20%, 9.80%, 4.50%for the household waste, respectively. The average household solid waste generation rate was 0.40kg/capita/day. The household solid waste generation rate per capita per day was positively correlated with household income, household size and house floor area. Food waste was predominant, 60-70%, C/N ratio of 20:1 and moisture content (63.10%), composting could be the good choice to treat household waste in Phnom Penh. The low heat value (LHV), at 894 kcal/kg and moisture content (63%) are not suitable for incineration. If food waste is separated out for animal feed, composting/bio-digestion, the LHV of the remaining waste becomes higher (1,429kcal/kg), making it suitable for treatment. The author also analysed the relationship between waste generation rate and some socio-economic factors. Besides waste characterization, questionnaire survey was also carried out by randomly selecting 556 sampled households for face-to-face interview to examine the relationship between waste generation and socio-economic factors. The results of the questionnaire showed that waste discharge (kg/household/day) varied between house types: 1.8 (flat), 1.9 (single house) and 2.7 (villa house). Respondents (91%) had access to waste collection service with collection fee of USD1-2 was acceptable (74%). Respondents (95%) sorted recyclable waste before discharge, leading to a 17% of waste reduction and generating approximately USD570/household/year. 92% of respondents were interested in environmental issues. Most respondents (91%) had never heard of the 3Rs. The results also showed that 1) household waste generation was positively correlated with waste sorting activity, monthly income, household size, house type and house floor area, and 2) people were willing to participate in environmental programs.

Another survey was conducted on commercial solid waste in August 2013. Waste samples were collected from 52 commercial sectors including hotels, restaurants, internet cafés, guesthouses, beer gardens, markets, schools, microfinance agencies and shops. The waste was collected daily for two weeks and separated into 23 categories. The results showed that composition of commercial solid waste were food (50-60%), followed by plastic and paper (30-40%) and glass (5-6%). The waste generation in kg/table/day was 4.83 (large restaurants), 3.36 (medium restaurants), 2.23 (beer gardens), 1.94 (internet cafés); in kg/room/day was 0.69 (3-star hotels), 0.45 (large guesthouses), 0.37 (medium and small guesthouses), 0.097 (small hotels) and in kg/person/day was 0.153 (family marts), 0.15 (ministries), 0.12 (council of ministers), 0.12 (supermarkets), less than 0.10 (shops and schools). Sorted waste was food, followed by glass bottles, paper, PET bottles, aluminium cans and steel. The remaining recyclable materials were food, plastic, paper, steel and aluminium cans. Well sorting activity was conducted by internet cafés and restaurants, followed by family marts, schools, beer gardens and guesthouses. If food waste and other recyclable materials were completely sorted, 61% of current waste could be minimized. Composition and characteristics of household solid waste and commercial were quite similar, the author assumed that calorific value, moisture content and C/N ratio were also similar. The appropriate treatment methods for both household solid waste and commercial solid waste were composting/anaerobic digestion, while incineration was not applicable for the current waste.

Keywords: *Phnom Penh; Household solid waste; Commercial solid waste; Waste generation; Waste composition; Recycling; Composting; Socio-economic; Integrated solid waste management; Calorific value; Incineration; Anaerobic digestion; Greenhouse gas emission.*

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List of Abbreviations

Abbreviations	Meanings
CCPS	Cambodian Inter-Censal Population Survey
CINTRI	Name of Waste Collection Private Company
CIPS	Cambodia Inter-Censal Population Survey
CPCB	Central Pollution Control Board
CSARO	Community Sanitation and Recycling Organization
CSW	Commercial Solid Waste
DoE	Department of Environment
DPWT	Department of public works and transport
GHGs	Greenhouse Gases
GDP	Gross Domestic Product
GPC	General Population Census
HDPE	High-density Polyethylene
HSW	Household Solid Waste
JICA	Japan International Cooperation Agency
LDC	Least Developed Country
MoE	Ministry of Environment
MoEF	Ministry of economy and finance
MoI	Ministry of interior
MPP	Municipality of Phnom Penh
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NIS	National Institute of Statistics
PAD	Pacific Asia Development
PET	Polyethylene terephthalate
POS	Public Opinion Survey
PPWMA	Phnom Penh Waste Management Authority
SMC	Steung Mean Chey (dumping site)
SWM	Solid Waste Management
3Rs	Reduce- Reuse- Recycle
UNDP	United Nations Development Programme
UNTAC	The United Nations Transitional Authority in Cambodia

CHAPTER 1

INTRODUCTION

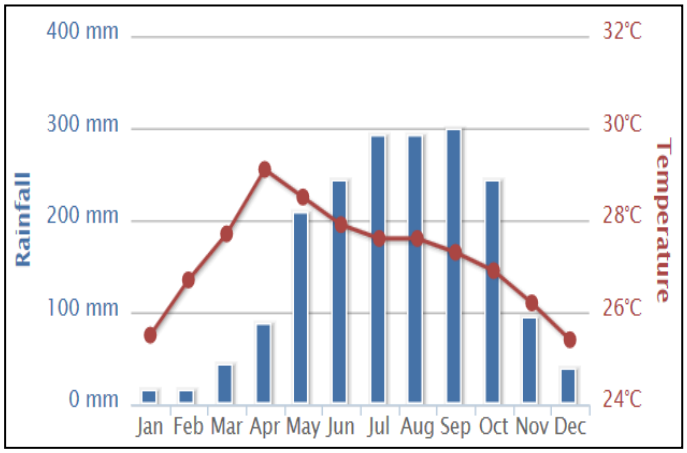
1.1 Overview of Cambodia

1.1.1 Geography

Cambodia is an agricultural country located in Southeast Asia. It borders with Thailand to the west and the north, Laos to the north, the Gulf of Thailand to the southwest, and Vietnam to the east and the south. It has a total land area of 181,035 square kilometers (Fig. 1-1).

Figure 1-1. Map of Cambodia

Cambodia has a tropical climate with two distinct monsoon seasons, rainy season (May to October) and dry season (November to April), which set the rhythm of rural life. From November to February, the cool, dry northeastern monsoon brings little rain, whereas from May to October the southwestern monsoon carries strong winds, high humidity, and heavy rains. The average temperature in Cambodia is 24°C-26°C. The mean annual temperature for Phnom Penh, the capital city, is 28°C. The Average monthly temperature and rainfall in Cambodia from 1990-2009 was presented in Fig. 1-2.



Source: http://sdwebx.worldbank.org (retrieved on 09-Jan-2015)

Figure 1-2. The average monthly temperature and rainfall in Cambodia from 1990-2009

The last official population census was conducted in 1962 with population of 5.7 million prior to 1998 with a population of 11.4 million with an annual growth rate of 2.5% by National Institute of Statistics (NIS, 1999). There was no further confirmed information about Cambodia's population until 1992. The United Nations Transitional Authority in Cambodia (UNTAC) registered 4.3 million voters aged 20 and over. The Socio-Economic Survey of Cambodia conducted by the NIS in April 1994 estimated the country's population as 9.87 million. The NIS carried out the Demographic Survey in March 1996 covering 20,000 households and estimated the population as 10.7 million. This remained as the only source of population until the census conducted in March 1998. The 1998 General Population Census of Cambodia carried out for the first time in 36 years provided a comprehensive population data base which proved very useful to the Royal Government of Cambodia in implementing development programmes in the country. A wide range of population and socio-economic statistics are needed for monitoring progress, making assessments, and guiding further policy formulation. The 2004 Cambodia Inter-Censal Population Survey (CIPS) showed that the annual growth rate had declined to 1.8%, with a total population of 13.1 million (NIS, 2004). The 2008 General Population Census (GPC) showed that the annual growth rate decreased to 1.54%, with a total population of 13.4 million and approximately 1.3 million inhabitants living in Phnom Penh (NIS, 2009). The proportion of the population living in rural areas is 80.5% and in urban areas is 19.5%. The population density in the country as a whole is 75 persons/km^2 and 4,571 persons/km^2 in Phnom Penh. The average size of the Cambodian household is 4.7 and 5.0 in urban areas. The total male to female sex ratio is 94.7. The literacy rate among adults age 15 and older is 78% with the male adult rate of 85% being considerably higher than the female adult rate of 71%. Currently, it is estimated that approximately 28 percent of the total population lives below the poverty line (NIS, 2008).

1.1.2 History

Cambodia was under French colonization from 1863 to 1953. Cambodia took backed the full independence from France on 9th November 1953, led by Prince Norodom Sihanouk. In March 1970, a military coup led by General Lon Nol overthrew Prince Norodom Sihanouk. On 17 April 1975, the Khmer Rouge ousted the Lon Nol regime and took control of the country. Under the new regime, Democratic Kampuchea, called the Khmer Rouge's radical and genocidal regime (1975-1979) which caused nearly 2 million Cambodian people dead because of starvation, malnutrition, mistreated and over load

working. On 7 January 1979, the revolutionary army of the National Front for Solidarity and Liberation of Cambodia defeated the Khmer Rouge regime and proclaimed the country the People's Republic of Kampuchea and later, in 1989, the State of Cambodia. The country's most important political event was the free elections held in May 1993 under the close supervision of the United Nations Transitional Authority in Cambodia (UNTAC). At that time Cambodia was proclaimed the Kingdom of Cambodia, and is a constitutional monarchy.

1.1.3 Economy

The economy of Cambodia has seen rapid progress in the last decade. Per capita income, although rapidly increasing, is low compared with most neighboring countries. The main domestic activity on which most rural households depend is agriculture and its related sub-sectors. Manufacturing output is varied but is not very extensive and is mostly conducted on a small-scale and informal basis. During 1995, the government implemented firm stabilization policies under difficult circumstances. Overall, macroeconomic performance was good. Growth in 1995 was estimated at 7% because of improved agricultural production (rice in particular). Strong growth in construction and services continued. Inflation dropped from 26% in 1994 to only 6% in 1995. Imports increased as a result of the availability of external financing. Exports also increased, due to an increase in textiles, and log exports.

After four years of solid macroeconomic performance, Cambodia's economy slowed dramatically in 1997-98 due to the regional economic crisis, civil violence, and political infighting. Foreign investment and tourism fell off. Also, in 1998 the main harvest was hit by drought. But in 1999, the first full year of peace in 30 years, progress was made on economic reforms and growth resumed at 4%. The long-term development of the economy after decades of war remains a daunting challenge. The population lacks education and productive skills, particularly in the poverty-ridden countryside, which suffers from an almost total lack of basic infrastructure. Recurring political instability and corruption within government discourage foreign investment and delay foreign aid. On the brighter side, the government is addressing these issues with assistance from bilateral and multilateral donors. However, Cambodia still remains one of the poorest and least developed countries in Asia, with the gross domestic product (GDP) per capita estimated at approximately 3.3 million Riels or US$ 805 in 2010 (US$ 1 = 4,087 Riel) (International

Monetary Fund, 2011). Agriculture, mainly rice production, is still the main economic activity in Cambodia. Small scale subsistence agriculture, such as fisheries, forestry, and livestock, is another important sector. Garment factories and tourism services are also important components of foreign direct investments.

1.2 Research background

Global challenges have put pressure on the unsustainability in many ways with the unplanned urbanizations and rapid growth of middle class families with changing lifestyles. Rapid urbanization, industrial development and population growth are the root causes of the tremendous increase in volume of wastes which are the burden and challenge for planners, policy makers and the like. Good waste management planning is very essential to be made for the next decades in an immediate manner. Every waste treatment options and technologies should be characterized with their contribution to avoid the environmental deterioration and to reduce the threat of global warming. For example, the movement to resource-recovery based solution from dumping or landfill-based systems (Burley, 2007; Burley et al., 2007). Recently, mineral and energy sources are rapidly depleting, so the consideration of the wastes as resources and not as wastes are taken into account. Therefore, a multidimensional approach is required to manage the generated solid waste and problem of climate change, furthermore can cause severe health effect to human. Based on the U.S Public Health Service identified 22 human diseases that are involved with improper solid waste management (Tchobanoglous et al., 1993). The people who work on waste in developing countries seldom use protected material from harmful, direct contact and any injury.

In recent years, climate change has become an issue of major international concern because of greenhouse gas (GHG) emissions. Solid waste is one of the contributing factors and some researchers have identified that the landfill disposal of solid waste generates large amounts of greenhouse gases such as CH_4, CO_2 and N_2O (Houho et al., 2009; Paolo et al., 2009; Papageogiou et al, 2009). This indicates that the amount of organic waste, the largest component of the waste stream, needs to be reduced and waste diversion methods including recycling, thermal treatment and composting need to be evaluated. Sorting of waste at source and promotion of recycling/composting are required in order to reduce the quantity of waste generated and the burden imposed on landfills (McDougal et al., 2002; Zeng et al., 2005).

A number of municipal services including waste collection service are rare completely provided or lacked to the illegal settlements (Wong' Ombe, 1995). According to Chanthy et al. (2006) identified that in Cambodia the wife/mother or female (72%) of the household are usually more in charge of waste management tasks. In Phnom Penh, household waste composition generation is covered 63.3%, 15.5%, 6.8% by food, plastics, grass and wood waste, respectively (Seng et al, 2010). Mongtoeun (2014) have showed that food waste (66.20%) is abit higher compared to previous study (63.3%) by JICA (JICA, 2005) and 62% in Chittagong, Bangladesh (Sujauddin, 2008). The result also indicated that the food waste increase proportional to income increase (Mongtoeun, 2014; Sujauddin, 2008). Composting is a good choice for organic waste reduction which influence on global warming as a result of GHG emissions. Based on Community Sanitation and Recycling Organization (CSARO) operation on composting is about 10tonnes per year in 2005 (50-60 tonnes of organic waste) (CSARO, 2005). There is no official recycling in Cambodia and regulation also not yet established. However, informal recycling is more contributed to waste reduction which is approximately 9.3% of the amount going to landfill (Seng et al, 2010). Based on the research conducted by Shimelis (2011) indicated that waste generation has high positively correlated with family size, income, and education levels. A major chunk in developing countries, often more than half by weight, of this MSW is made up of compostable materials (CPCB, 2006).

Most of the Asian countries are experiencing enormous trends to manage urban wastes including Cambodia as well. Cambodia is one of the least-developed countries (LDP) (UN-OHRLLS, 2014), however, in the last two decades the development (urbanization, lifestyle changes and rapid growth population) of the country was remarkably noticed. At the same time, municipal solid waste generation has drastically increased year by year, especially in the capital city, Phnom Penh. However, the information on municipal solid waste (MSW) was not available before 1994 due to lack of responsible ministry. Ministry of Environment (MoE) established in 1993. Then, the information of MSW had been presented but the reliability is still, somewhat, limited or low. The MSW generation from 1994-2002 seems very low with the amount of 0.05 kg/capita/day (MoE). Actually, the generation rate was higher than that due to lacking of efficiency of collection and lacking of data management. The annual waste generation dynamics in Phnom Penh indicated that waste increased from 0.136 million tons in 1995 to 0.361 million tons in 2008, and it is estimated to be 0.635 million tons in 2015 (JICA,

2005). Klundert and Anschütz (2001) indicated that up to 50% of urban residents are lacking of collection service in low and middle income countries. Siem Reap Department of Environment reported that only 50% of total waste generated has been collected (DoE, 2003), while 60% of waste generated was collected in Phnom Penh city in 2003 (JICA, 2005) and 82.1% in 2009 (CITRI, 2010). In terms of tipping fee, each household has to pay approximately USD1-2 per month to waste collection company, CINTRI. CINTRI has paid to landfill (Dang Kor landfill) which is managed by municipality of Phnom Penh (MPP). Comparing to Lao PDR, only 40-70% of the total waste was collected (UDAA, 2009), in Vientiane capital, the payment fee is USD1.25-2.25 per month (IGES, 2012). The payment for the new landfill is USD0.7/ton which is much lower than the sanitary landfill cost that cost from USD10-USD15/ton according to the Strategic SWM Plan and Action Plan (JICA, 2005). While Vientiane capital, Laos PDR, the disposal fee to open dumping is UDS 5.4/ton (UDAA, Vientiane Capital, 2009; IGES, 2012).

Improper management of municipal solid waste (MSW) could contribute to uncleanliness, insanitation and unaesthetic of the city. In addition, it is directly related to public health impact and environmental issues such as soil contamination, water and air pollution. Disposal of organic waste at dumping sites can emit some greenhouse gases (GHGs) such as CH_4, CO_2 and N_2O, especially huge amount of methane, under both aerobic and anaerobic condition by bacterial decomposition. Burning of plastic waste can produce toxic gas such dioxins and furans. In Phnom Penh city, environmental impacts of MSW are increasing remarkably due to increasing of waste generation and the capacity of sanitary landfill is limited. For instance, Dang Kor landfill is almost full before the schedule.

MSW in Phnom Penh contains a large percentage of organic waste (mostly kitchen waste, paper and garden). These wastes can be used as a resource recovery through composting and methane production. On the other hand, the reduction of organic waste to landfill which can significantly contribute to global warming. Therefore, the promotion of utilization of organic waste is significant as a whole. The current situation of MSW in Phnom Penh was investigated through field survey and interviews with households to identify the attitudes and practices on household solid waste generation, separation and recycling activities. However, the information of waste characteristics is required to determine appropriate technology for waste treatment.

1.3 Solid waste management in Phnom Penh: *challenge and opportunity*

Municipal solid waste management has caused a number of problems for the Phnom Penh Municipality. MSWM seems hard to draw attention from the public. People seem don not care about the impacts caused by improper disposal of solid waste or even they know about it but they ignore. These problems have been addressed for quite a long time, but an effective solution does not seem to be in place yet. For waste packing and storage, some residents don not pack and store their waste properly. Normally they mix all kinds of waste in one plastic bag resulting in difficulty separating for recycling and composting purpose. Due to collection time is not well scheduled, waste piles are seen on the pavement or on the streets scattered by dogs who looked for food and scavengers who looked for recyclable materials. As a result, making difficulties for the collectors resulting uncleanliness, labor need and time consuming. Attitudes and habits of people are also important regarding to waste management. Even trash bins are available at public places, people just throw their waste in an improver way making out of the bins. Interestingly, some people throw their waste out of the car window or motor bikes while they are driving. It is an unbelievable situation, it happened. Presently, MSW is disposed at landfill, Dang Kor landfill, after open dump site was full and completely closed in 2009. By doing so, potential recyclable items are not recovered leading to loss resources and have effects on both public health and environment.

1.4 Problems for waste management in Asian region

Most of the Asian countries are developing countries. Waste generation is low compare to the developed countries. However, it keeps going up while in developed countries remain stable or little change in decreasing due to material design, high technology and quality improvement. In addition, there is still high percentage of people do not receive waste collection service. Open dumping is a common method in treating the city waste, while incineration is not adapted and recycling activities are conducted by information sectors. The problems of solid waste management in major cities in Asian countries mentioned below.

1.4.1 Solid waste management policy and legislation

All countries listed in Table 1-1 have established legislation for environmental protection. Most of these countries have also set up different ministries or institutions to handle the environmental issues. The legislation for water and air pollution control are

comprehensive and well established, while solid waste management is not much paid attention. Sometimes, the laws and legislations on solid waste management exist (only on paper), but the point is that efficiency of implementation and enforcement are still poor. Solid waste management is still very much a municipal government responsibility. A long term strategy on solid waste management is still lacking in the developing Asian countries. Like many other developing countries in the world, concerns in the region are growing in both the governmental and public sectors for an effective and economic management of solid waste. The lack of awareness, technical knowledge, legislation, policies, and long-term strategy are major issues for solid-waste management in Asian developing countries.

1.4.2 Sources and quantities of solid waste management

The sources and quantities of solid waste vary from one place to another depending on various factors such as economics, culture, heritage, industrialization, season and so on. The sources of solid waste in developing countries are mainly domestic waste (municipal waste), commercial waste, medical waste (hospital waste, clinic waste, etc.), and hazardous waste (industrial and factory waste). In general, the amount of solid waste generated in the cities is much higher than in rural areas. The generation rate in rural areas can be as low as 0.15 kg/cap/day, while in the urban areas can be reached 1.00 kg/cap/day. The generation rates of major Asian cities reported are listed in Table 1-1. The composition of solid waste varies significantly in the different cities in the region. Even within a city the composition varies with location and time. However, in developing countries, the municipal solid waste contains dominant organic components than other materials. The average percentages of organic matter in the solid waste in major cities in Asian countries ranged from 50-70%.

Table 1-1. Solid waste generation rate of major Asian cities

Country	**City**	**Generation rate (kg/cap/day)**
India[a]	Delhi	0.47
Bangladesh[a]	Dhaka	0.50
Sri Lanka[a]	Colombo	0.62
Vietnam[a]	Hanoi	0.63
Lao PDR[c]	Vientiane	0.64
Philippines[a]	Manila	0.66
Cambodia[b]	Phnom Penh	0.74
Thailand[a]	Bangkok	0.88
Singapore[a]	Singapore	0.94
Taiwan[a]	Taipei	0.95
Malaysia[a]	Penang	0.98

[a] Asian Productivity Organization Tokyo (2007)
[b] JICA (2005)
[c] IGES, Lao PDR (2012)

1.4.3 Storage, collection, transport, treatment and final disposal

Since dumping waste on the roadside or in other public places (normally temporary disposal) is a common practice in Asian developing countries, street sweeping is one of the important activities in the waste management system. The municipalities employ sweepers to sweep the city streets and public areas by using simple tools and facilities. Major streets are generally swept on a daily basis, sometimes more than once a day, while other streets are swept less frequently. Sweeping waste, together with other household waste, is commonly placed in plastic bags or other containers and stored at the collection centers/points. Community containers are placed at the roadsides to be collected by vehicles or hand-operated carts. Collection frequency of household waste is generally once a day or one every two days or three days depending on the areas. The lowest collection frequency is twice weekly. However, the collection area coverage in a city can be as low as 50%. Once collected, domestic solid waste is transported to disposal sites by open trucks and/or compactor trucks. Sometimes, the waste is flown out of the trucks. As for industrial solid waste, most major cities in Asian countries contract out to private sectors for the collection and transportation to the appropriate disposal sites.

The main disposal methods for municipal solid waste in Asian developing countries are open dumping and sanitary landfill. Overall the environmental condition of the uncontrolled dumpsites is extremely vulnerable, with severe environmental pollution and human health. On open dumping grounds, foul odors and air pollution are dangerously affecting the surroundings. Rodents are spreading pathogens in the surrounding areas and the workers are highly exposed to disease and hazardous waste. Some cities dispose of their waste in sanitary landfills. However, leachate treatment may not be commonly practiced in some cities due to resource constraints. Leachate from open dumping or sanitary landfill may cause serious water pollution if no proper treatment is provided. Furthermore, greenhouse gases are highly produced due to organic waste contains predominantly of the total waste.

1.5 Objective of study

The overall goal of this research is to know the current situation of household solid waste management in general, waste generation rate, waste composition, the potential for

recycling, and appropriate treatment methods in particular. The research goal is to ensure that the sustainability of environment and economic, and acceptability in society are achieved.

In order to achieve the above goal, the following objectives are set:

1. To study on waste composition, discharge amount and characteristics of household to identify the way of discharge practice, recycling potential and treatment and disposal options.
2. To identify the correlation between waste generation and 3R practice, and other socio-economic factors such as household size, education, monthly income and the like.
3. To evaluate the behavior and attitude of household on 3Rs practice in order to identify the participation rate for waste reduction.
4. To evaluate the appropriate treatment options based waste composition, moisture content and calorific value. In addition, the scenario analysis was conducted to assess greenhouse gases (GHGs) emission/reduction, environmental benefit, economic benefit and investment cost.

1.6 Scope of study

In this research study, the author has focused on household solid waste and commercial solid waste. The study area is Phnom Penh city, the capital of Cambodia (the details can be seen in section 2.1).

1.7 Dissertation outline and organization

In order to achieve the proposed objectives, the dissertation covers seven chapters as following:

Chapter 1, "Introduction"

This chapter presents the overview of Cambodia, and background of solid waste situation in Phnom Penh city.

Chapter 2, "Literature review"

The literature review relating to this study is presented. This chapter provides the current situation of municipal solid waste management in Cambodia, including information on waste generation, composition, collection and transport, and disposal, and national policy

and regulation in the capital city, Phnom Penh. 3Rs-reduce, reuse and recycle are the main concept MSWM system in the city.

Chapter 3, "Methodology"

Chapter 3 mentions the whole process of methodology in the entire study.

Chapter 4, "Household Solid Waste Generation and Recyclability in Phnom Penh"

The main section of the dissertation describes the analysis of "Household Solid Waste Generation and Recyclability in Phnom Penh". This chapter mentions in details of household solid waste generation and composition, the relationship between waste generation and socio-economic factors. Furthermore, treatment options on household solid waste were evaluated as well in order to minimize waste to landfill.

Chapter 5, "Commercial Solid Waste Generation and Recyclability in Phnom Penh"

This chapter is also main part of the dissertation describing the current status of commercial solid waste management in Phnom Penh. The commercial solid waste is the second largest portion of municipal solid waste. The information of waste generation and composition from commercial sectors are described.

Chapter 6, "Design of Appropriate Municipal Solid Waste Management in Phnom Penh"

This chapter provides guides for improving municipal solid waste in Phnom Penh, including raising awareness of the residents, introducing waste separation at source, increasing waste collection efficiency, and improving organic waste management under the 3Rs (reduce, reuse, recycle) concept. The introduction of technologies that are appropriate for organic waste utilization is included. Composting and anaerobic digestion are found applicable under the local conditions in Cambodia. Small scale implementation of these methods at households, communities and disposal site is recommended. However, the efficiency improvement of these methods should be more investigated. Incineration and gas recovery in a large scale are not appropriate due to high technical skills and capital investment.

Chapter 7, "Conclusions and Recommendations"

Conclusion and recommendations discussed the results of both household and commercial solid waste generation and composition in Phnom Penh city. This section summarized the

main conclusion of the dissertation and also showed the feasible suggestions/recommendations for managing and improving HSM management in Phnom Penh city. More recommendations for future study and the possible development are represented.

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CHAPTER II
OVERVIEW OF MUNICIPAL SOLID WASTE MANAGEMENT IN PHNOM PENH

2.1 Overview of Phnom Penh City

2.1.1 History of Phnom Penh

Phnom Penh became the capital of Cambodia since 1862 without interruption. The transformation of Phnom Penh from a bustling small port of wooden houses into a modern city started in 1865 when it became the new royal capital. It accelerated by 1890, as the French administration introduced new concepts to customary land laws: streets as public spaces that could not be encroached, and land as an individual private property, officially registered in a cadastre. Cambodia adopted the Civil Code in 1920, hence strengthening the role of private ownership, and the official separation between urban and rural spaces. After World War II, the French administration started to redesign Phnom Penh to the needs of its expected industrialization, increasing density in residential areas and preparing a zoning and a master plan for the growth of the city, but the 1953 independence cut short these efforts. From 1956 to 1970, under an independent administration, Phnom Penh then doubled its size. It also regained some national identity as architects adapted the legacies of French to Khmer architecture such as an Angkorian-style Olympic stadium, a national theatres and the like (Ministère de la Culture du Cambodge and Atelier Parisien d'Urbanisme 1997:27-59). The abandonment of Phnom Penh under the Khmer Rouge régime that emptied cities of their inhabitants and did not maintain their infrastructures from 1975-1979. During the subsequent occupation by Vietnamese authorities from 1978 to 1989, and then until 1998, the continuing civil conflicts, political instability, and relative wealth of Phnom Penh compared to the rest of the country, did not make urban development a priority. Urban issues came back on a national agenda only since the end of 1998.

2.1.2 Demographics and economy information of Phnom Penh

Phnom Penh was built at the intersection of the Mekong, Tonle Sap and Basac rivers at the end of the 14th century. The city then developed by reclaiming wetlands, surrounding new perimeters by dikes, and land-filling these reclaimed compartments. As most of Phnom Penh was established on inundated areas, protecting the city from floods by maintaining dikes and pumping stations has always been a major public concern. Yet, the

management of hydraulic infrastructures was almost abandoned between 1972 and 1990, destroying the city's drainage and pumping systems. From the early 1990s, diverse missions from bilateral development agencies and development banks have planned the rehabilitation and extension of the water network, but it was only by 1998, with the return of political stability that the city started to address the problem with several projects to improve water supply drainage and sewerage. It has now become a priority of the Municipality. Phnom Penh had a population of 1 million in 1998, 94% living in urban areas, and the remainder living in peri-urban districts with semi-rural economies. Out of this population, approximate 35,000 families lived in low-income settlements (UNDP, 1999). Based on an estimated annual growth of 8%, the population of Phnom Penh is about 1.16 million, with 214,620 urban poor or 19.7% of the population in 2002 (Royal Government of Cambodia, 2000; Slingsby, 2000; Squatter and Urban Poor Federation, 1999). Phnom Penh population has increased from 1.3 million in 2008 (NIS, 2008) to 1.5 million in 2012 (Facts Phnom Penh City, 2012). It is estimated to be 2.2 million in 2014 according to the world population review (World Population Review, 2014).

In 1999, 9.9% of the working population worked in agriculture, 22.2% in transformation and manufacturing, and 67.9% in services such as tourism and garment manufacturing. The unemployment rate was 12.6% (Royal Government of Cambodia, 2000). The functions of political and economic capital enable him to have a GDP from approximately 1.4 billion dollar (2003), 28% of the national GDP, that is to say approximately 1.140 $ per capita, three times more than the average of the country (MPP, 2013). Total land area of Phnom Penh has expanded from approximately 374 mk^2 (JICA, 2005) to 678 km^2 in 2010 (MPP, 2012). Phnom Penh is divided into 9 districts (khans) with 96 communes (sangkats) with an average population density of 4,572 km^{-2} and mean household size of 5.1 (NIS, 2008). At the end of 2013, 3 new districts (khans) were created with the approval of Prime Minister Hun Sen, Prime Minister of Kingdom of Cambodia. However, the structure and administrative have not yet declared as mentioned in Table 2-1.

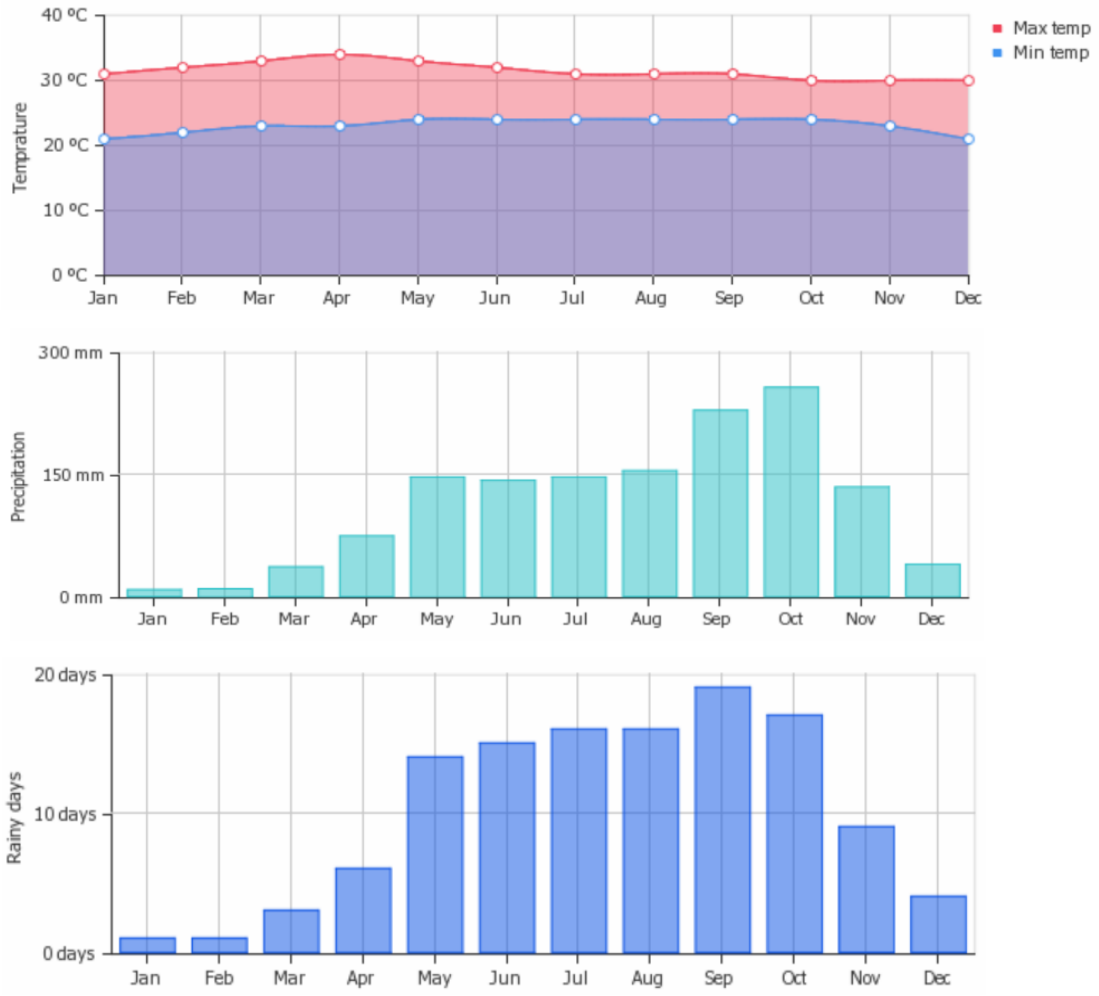
Table 2-1. Characteristics of Phnom Penh city

Districts (khans)	Population	No of communes (sangkats)	Area (m^2)	Density (person/km^2)
7 Makara[a]	91,895	8	2,228,027	44,395
Chamkar Morn[a]	182,004	12	10,788,213	17,468
Doun Penh[a]	126,550	11	7,412,767	17,479
Toul Kork[a]	171,200	10	8,432,543	21,977
Mean Chey[a]	327,801	8	44,000,448	2,951
Russey Keo[a]	196,684	12	63,948,255	1,827
Sensok[a]	147,967	3	40,021,647	1,606
Por Senchey[a]	183,826	13	230,384,385	798
Dangkao[a]	69,319	15	117,758,500	589
Chbar Ampov[b]	N/A (new)	8	N/A (new)	N/A
Chroy Changvar[b]	N/A (new)	5	N/A (new)	N/A
Praek Phnov[b]	N/A (new)	5	N/A (new)	N/A

[a] Phnom Penh Capital Hall (2010)
[b] http://khmerization.blogspot.jp/2013/12/new-districts-signed-into-being-by-pm.html

2.1.2.1 Climate in Phnom Penh

Cambodia has a warm (hot) weather throughout the country throughout the year. The annual average temperature for the whole country is 26 ºC. Phnom Penh is not an exception. The yearly average temperature of Phnom Penh is 28 ºC. Although the monthly rainfall average in Phnom Penh is about 110mm, but mostly it comes down in the rainy season, which lasts from May to November. The months October, November and December have a nice average temperature (no rain and not so hot). Even though, on average, the temperature is always high. Most rainfall (rainy season) is seen in May, June, July, August, September, October and November. Phnom Penh has dry periods in January and February. On average, the warmest month is April for the whole country. On average, the coolest month is November. October is the wettest month. January is the driest month (the details can be seen in Fig. 2-1).



Source: http://www.weather-and-climate.com (2015)

Figure 2-1. Average monthly temperature, rainfall and rainy days in Phnom Penh

2.2 Background of solid waste management in Phnom Penh

2.2.1 Organization arrangement system

Solid waste management (SWM) in Phnom Penh was changed over last few decades due to many factors such as instability, and difficulties in management and financial. Forty years ago, solid waste was not a serious issue due to low population density, 0.39 million in 1962 (MPP, 2009). After Pol Pot regime (1975-1979), Department of public works and transport (DPWT) under municipality of Phnom Penh (MPP) was responsible for SWM until 1994. At the national level, it is clear that SWM is within the jurisdiction of Ministry of environment (MoE). However, MPP, DPWT, Department of environment (DoE) and Phnom Penh waste management (PPWM) are involved in SWM, but the responsibility and the relationship among the three are not clear. A French contractor called Pacific Asia Development (PAD) signed a 50-year franchise agreement with the Municipal Council. The contract with PAD did not last long. In July 1995, the agreement was cancelled, and

the individual Khans (Districts) took over collection services for some time. Then in January 1996, a Cambodian company called PPC took over waste collection on a temporary basis. In December 1996, an East German company called ENV received another 50-year franchise agreement, but ENV decided to leave Cambodia after the fighting in July 1997, presumably because it considered the business environment was too risky. The Municipal Council then asked a Cambodian company called PSBK Ltd, which had been sub-contractors under ENV, to take over waste collection and dumpsite operation. This arrangement was formalized in January 1998 when the Council entered into another 50-year franchise agreement with PSBK. Management of waste disposal and cleansing services are carried out by PPWM under the DPWT. In 2001, Phnom Penh waste management authority (PPWMA) was established to be responsible for solid waste collection and disposal, and also dumping sites or landfill as a whole (Khunchhun, 2007). The PPWM statute was made based on such a situation, but it has not been approved as of July 2003 by either the Ministry of interior (MoI), the Ministry of economy and finance (MoEF), or the MoE. On the other hand, Prakas No. 80, which was issued jointly by the MoI and the MoE on February 25, 2003, stipulates that a SWM plan should be formulated mainly by the DoE of each municipality.

The jurisdiction of SWM in the city should be unified without delay. The immediate approval of the PPWM statute is expected in view of the clarification of the jurisdiction. In 1997, a private company (PSBK) signed a contract with MPP to manage the MSW for the next 50 years. However, in 2002, new private company (CINTRI) took over and has monopolized waste collection in the city since then under the supervision of MPP. The MPP is also responsible for waste collection and management in some parts of Phnom Penh including poor neighborhoods and squatter communities where there are limited road access. Moreover, PPWM is weak in terms of property (machinery and facility), human resources (both quality and quantity) and finance. The contract between MPP and CINTRI was amended and currently executes waste collection in the National Immunization Program (NIP) area and landfill operation in the Steung Meanchey Dumping Site (SCMDS). The supervision of waste collection and cleansing works being provided by CINTRI and PPWM in MPP as a whole is hardly done. The system for monitoring and control of the SWM should be established. Brief description of agencies responsible for waste collection was mentioned in Fig. 2-2 below.

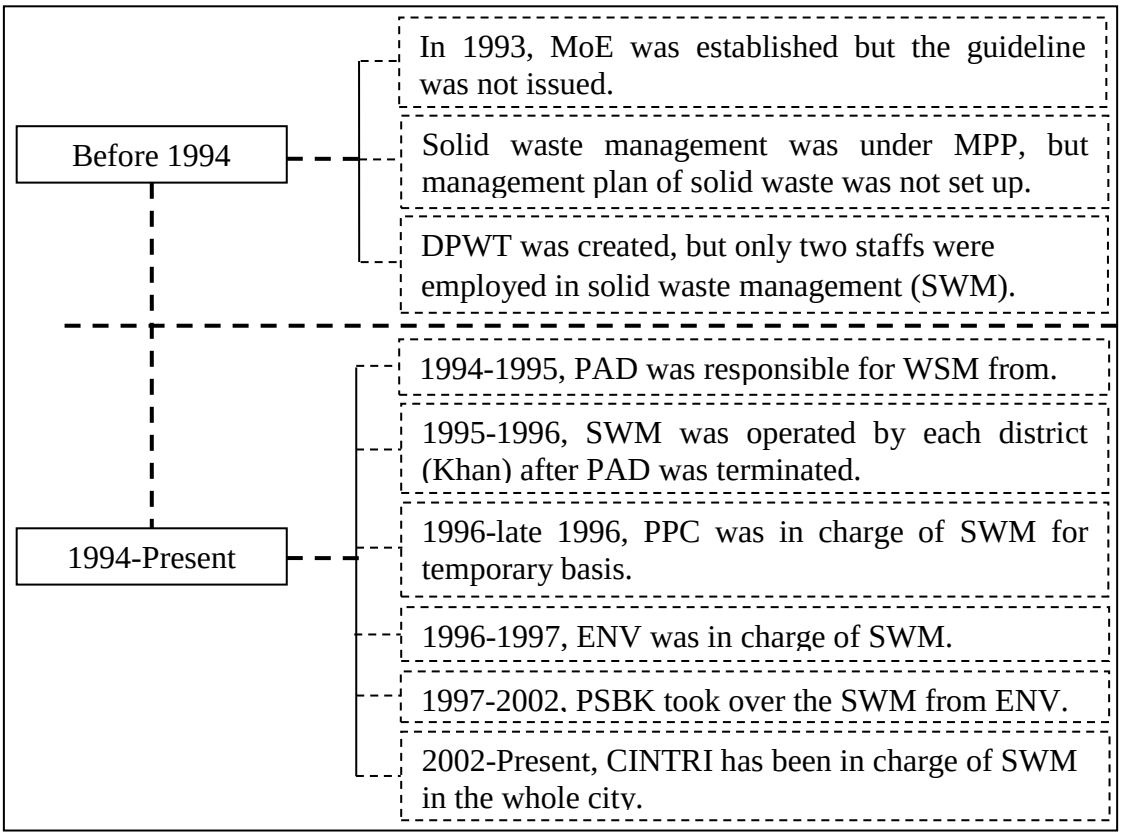


Figure 2-2. Administration and changes of private contractors for PPMSW

2.2.2 Legal system

There is a Sub-Decree, established in April 1999, which is the fundamental law on SWM. Since it only sets an overall framework, the following issues should be solved. Although MoE has issued a ministerial declaration to supplement the Sub-Decree, detailed regulations, standards and guidelines should have been established have not been well prepared yet. The Sub-Decree on SWM stated that waste is divided into hazardous waste (HW) and non-hazardous waste (non-HW), but does not define or categorize waste. It is hence not practically possible to separate HW and non-HW. Though the classification of non-HW and HW is reasonable as a broad one, a more detailed classification is necessary for proper SWM, especially for identification of the producers who are responsible for the disposal of the solid waste. The Sub-Decree on SWM states that the local authorities are responsible for the disposal of HW from domestic sources. However, the domestic sources in the Sub-decree included clinics and hospitals. This might need to be examined. The collection, transport or storage of hazardous waste from factories requires the approval of MoE, but the responsibility of supervision is not clearly placed.

The Sub-Decree on SWM stipulates that the municipalities that are responsible for non-hazardous waste management have to prepare waste management plans. However, no municipalities in the country have developed the plan. By-laws on SWM and guidelines on waste discharge and others to ask people for cooperation are necessary for the municipalities to properly carry out SWM. There are, however, no such by-laws or guidelines. MoE stated that it detected nine cases of breach of the Sub-Decree on SWM and its ministerial declarations and collected 44.23 million Riels of fines in 2002 following the Law on Environmental Protection and Natural Resources Management issued in January 1997.

2.3 Current situation of solid waste management system in Phnom Penh

2.3.1 Waste generation and composition

Recognizing that the quantity and composition of waste are essential in waste management planning. A dozen of researches have been conducted to estimate future waste generation in the cities (Dyson and Chang, 2005; Beigl et al., 2004; Jiang et al., 2009; Chung, 2010). In these context, the database of waste generation with high accuracy is required in order to forecast an acceptable future waste generation. In general, it is hard to predict the amount of waste generated due to limited information. For instance, in Cambodia information of solid waste management is limited. The data on SWM is incomplete, inaccuracy and varied among involved agencies. Different sources give different data which means the reliability is still low. For the last few decades, average municipal solid waste generation in Phnom Penh has increased rapidly from 403 tons/day in 1994 to 670 tons/day in 2003 (MoE, 2004), then from 796 tons/day in 2004 to 1602 tons/day in 2011 and in 2013 was 1881 tons/day (Landfill office, 2013), and it is predicted to be approximately 2150 tons/day in 2015 and 2784 tons/day in 2020 (Seng, 2013). The calculation of waste generated is difficult. It is influenced by a couple of factors, especially GDP. Normally, the increased of waste amount is associated with the increase of income (GDP per capita). Normally, total amount of waste generated was estimated based on amount of waste disposed at dump sites/landfills with annual waste growth rate of 10-20%.

Table 2-2. Population, GDP, daily waste generated and collected (tons) in Phnom Penh

Year	Population [e, f] (million)		GDP [e, f]		Amount of waste generated (ton/day)				Amount of waste collected (ton/day)
	Cambodia [density-km^{-2}]	Phnom Penh	USD (million)	USD capita^{-1}	[a]	[b]	[c]	[d]	
1986[g]	7.762	0.561	-	-	-	-	-	-	-
1993[h]	9.653	0.810	-	-	-	-	-	-	-
1994	9.752	0.812	2,760	248	-	403	-	-	-
1995	10.148	0.855	3,420	297	379	404	-	-	-
1996	10.560	0.901	3,481	295	398	424	-	-	-
1997	10.990	0.949	3,387	281	396	422	-	-	-
1998	11.436	1.000	3,105	253	470	501	-	-	-
1999	11.656	1.007	3,515	282	532	568	-	-	-
2000	11.881	1.014	3,651	288	608	575	-	-	-
2001	12.110	1.022	3,970	312	-	585	-	-	-
2002	12.344	1.029	4,276	331	-	594	-	-	-
2003	12.581	1.037	4,591	356	-	669	704	679	499
2004	12.824	1.044	5,265	402	-	633	726	796	584
2005	12.963	1.108	6,278	468	-	741	782	916	673
2006	13.103	1.177	7,265	534	-	900	913	1,037	761
2007	13.245	1.249	8,332	623	-	955	955	1,157	850
2008	13.389 [75]	1.326	9,895	739	-	1,004	988	1,278	938
2009	13.400 [81]	1.400	10,305	769	-	-	-	1,399	1,027
2010	14.700 [83]	1.450	11,687	795	-	-	-	1,479	1,086
2011	14.900 [84]	1.550	12,650	849	-	-	-	1,602	1,176
2012	15.500 [86]	1.880	14,043	906	-	-	-	1,784	1,309
2013	15.800 [87]	2.280	15,191	964	-	-	-	1,881	1,381
2015[i]	-	-	-	-	-	-	-	2,150	1,765
2020[i]	-	-	-	-	-	-	-	2784	2,285

[a] Kum et al. (2005)
[b] MoE (2004)
[c] JICA (2008)
[d] Landfill office (2013)
[e] MoP (2008)
[f] Ministry of Economy and Finance, National Bank of Cambodia, IMF
[g] Mori (2000)
[h] MoP (2001)
[i] Seng et al. (2013), total amount of waste generation projection in 2010.

The gross generation rate of Phnom Penh MSW per capita was 0.74 kg/day, which is quite similar to four Lao PDR major cities: Vientiane (capital), Luangprabang, Savannakhet, and Champasak (0.6-0.7 kg/capita/d) (IGES, 2012). For the household solid waste (HSW) generation per capita was 0.487 kg/day. However, HSW generation in rainy season (0.498 kg/cap/day) was higher than dry season (0.476kg/cap/day) (Table 2-3) (JICA, 2005).

Table 2-3. Waste generation by sources and season

Generation sources [%]	Unit	No of generation sources	Daily generation rate (kg/day)		
			Rainy season	Dry season	Average
Household waste [63.0%]	kg/cap/day	1,199,414	0.498	0.476	0.487
Commercial waste (restaurants) [5.0%]	kg/table/day	27,808	1.940	1.387	1.664
Commercial waste (other shop) [16.3%]	kg/shop/day	33,524	4.566	4.437	4.502
Market waste [10.2%]	kg/stall/day	51,766	1.700	1.945	1.823
School waste [0.8%]	kg/student/day	385,013	0.018	0.021	0.020
Street sweeping waste [0.3%]	kg/km/day	56	47.235	59.510	53.373
Hotel waste [0.3%]	kg/room/day	13,385	0.199	0.263	0.231
Office waste [0.2%]	kg/office/day	368	2.946	4.174	3.560

Source: JICA, 2005

There are different sources of municipal solid waste in Phnom Penh. The generation source include households, commercials, construction, markets, streets, and the like. However, household solid waste is predominant accounting up to 63%, followed by commercial sectors (JICA, 2005). While in Vientiane, Lao PDR, household waste composed of 75% (SEA, 2000). In Phnom Penh, the main composition of household solid waste was food waste (63.3%), followed by plastics (15.5%), grass and wood (6.8%), and paper and cardboard (6.4%). The other categories including metals, glass, rubber/leather, textiles, and ceramic/stone, accounted for less than 3%. Informal sectors play a key role in recycling which accounted for about 9.3% of all (JICA, 2005). While in Vientiane, Lao PDR, food waste contained in low proportion at the percentage of 30% (this figure collected from different sources since 1998, so the accuracy and reliability is low) (IGES, 2012).

2.3.2 Waste collection service in Phnom Penh

In Phnom Penh, solid waste is generated from three waste sources: municipal solid waste (residential and commercial waste), hazardous waste (factory and industrial waste) and medical waste (hospital, clinic, etc.). And those collection services are conducted by three agencies: Municipality of Phnom Penh (MPP) is responsible for municipal solid waste (MSW), SAROM trading Co. Ltd, is responsible for hazardous waste and Phnom Penh Waste Management Authority (PPWMA) is responsible for medical waste, respectively. Due to lacking of financial resources for waste collection and disposal system, in 2002 MPP had franchised out municipal solid waste collection service to a private waste hauler, CINTRI, and was completely provided in 2009 for the whole city (urban and peri-urban) under monitoring/supervising of MPP. Since then storage and discharge practices of the waste have changed from burning, burying, dumping in back yard, disposing in water body, etc., to collection and disposal due to vacant space scarce caused by fast population

growth and urbanization. However, municipal solid waste management (MSWM) has still poor performed in both sanitation and environment because of minor illegal dumping and individual disposal are existing. Improper operations are caused by a couple of factors including technical, economic, political, regulations and human resources. It seems that legal system arrangements and resources are the major challenges for improving MSWM in Phnom Penh (Kum et al., 2005; JICA, 2005). In addition, operation and maintenance (O&M) of machinery is also a plus because CINTRI's machinery for waste collection, transport, and road cleansing, being in use for 8 to 25 years which break down frequently. CINTRI is somehow able to keep the machinery in working condition. However, the collection schedule has not been punctual resulting in improper disposal for householders. And PPWM itself does not have the human resources, equipment or facilities to operate and maintain its machinery. When machinery breaks down, the repair work is entrusted to a private service shop. All facilities/machinery operated at landfill are rental, and the rental company carries out the repair work at a small shop set up on-site.

2.3.3 Waste storage and discharge

Since there is no discharge rule, the waste is never disappeared from the city because people discharge waste after the collection service done. Street vendors and cars parked on the sidewalk disturb a cleansing works and the wastes discharged by them are littered on it. There are waste piles on the sidewalk and carriageway making a mess even in the city center, degrading city beauty and public health. At the present time, the packaging and storage of waste are depending on householders and owners of each source. There is no uniform storage bins have been introduced in Phnom Penh. In general, plastic bags (usually reused plastic bags) are used to store household waste and some small commercial sectors. Restaurants, hotels, schools, shops and offices generally use their own bins or containers in different sizes for on-site storage prior disposal; and industrial waste is normally kept in hauling containers before collection. However, under collaboration between PPM and CINTRI, in public places such as parks, gardens and some streets, the public trash bins are provided for temporary storage to avoid littering and to make city cleaner, but normally they are over flowed due to small size and irregular collected. Interestingly, bad habit of people who do not care whether they properly throw the waste.

In Phnom Penh, kerbside and bell collection are the common practices for municipal solid waste by using collection trucks running though the street according to a planned

schedule. In the places where waste collection service is provided, wastes are dumped on the street for temporary, sadly the waste can be blown by wind or washed out by rainfall into the drain and ditch of the drainage system, contributing to littering of the city and polluting water body, respectively. Handcarts are also used to collect waste from narrow roads to the collection points where the trucks can not access. Recently, handcarts with hoppers have not practiced. However in particular places such as markets, hospitals and populated areas, waste containers with a capacity of 0.6 m^3 were provided by CINTRI. Inconsistency, in collection time and irregular schedule are also the problems for current collection practices (Seng et al., 2010; Kum et al., 2005). Mori (2000) indicated that waste collection service was available only in a particular places such as at residential areas (mainly with good infrastructure), shopping centers, restaurants, and hotels, all of which were covered by 70-80% (Mori, 2000). Although, recently the findings showed that collection service has been improving up to 90%. The collection frequency and collection time are still under uncertainty making people disappointed (Mongtoeun et al., 2014). The situation of waste storage, discharge and collection practice can be seen in Fig. 2-3 and waste flow is illustrated in Fig. 2-4.

Figure 2-3. (a), (b) waste storage and waste collection points; (c) Handcarts collected waste from narrow roads; (d) Trucks collected waste from collection points with collectors.

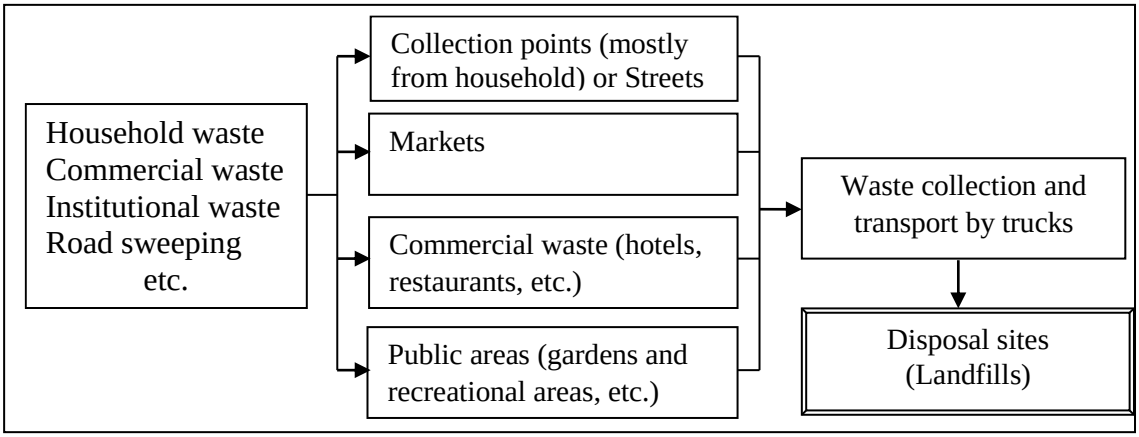
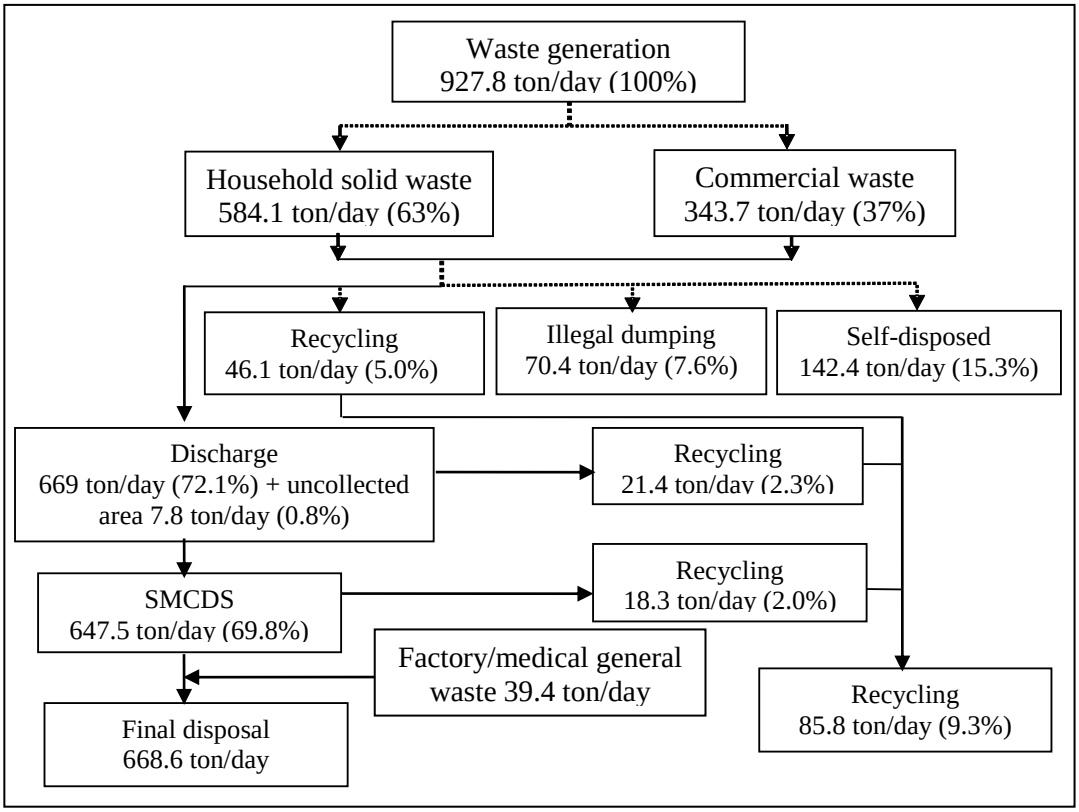


Figure 2-4. Simple waste flow in urban areas in Cambodia

2.3.4 Final waste disposal

In Phnom Penh city, open dumping and landfill are only means of waste disposal. Municipal solid waste (MSW) collected was transported to an open dumping site, Steung Mean Chey Dump Site (SMCDS), with the area of about 6.8 ha, located at 7 km from the city center (from Wat Phnom), and operated since 1965. Since waste is piled up to a height of more than 5m on average, it is getting difficult for the collection vehicles to access to the working face. Accessibility to the site is particularly poor in the rainy season. Improving accessibility and securing a landfill area are urgent issues. The site is a typical open dump, posing seriously negative impacts on the surrounding environment. Infectious hazardous waste is disposed of without being distinguished from municipal waste. The most problematic matter is that the remaining service life of the site is nearly nil and a residential area is approaching less than 100m away from the site due to rapid urbanization. Therefore, a new disposal site must be constructed as soon as possible and the existing site must be closed. More than 500 waste pickers are working without any rules. Their resource recovery activities interfere with landfill operations. This dumping site (nicknamed smokey mountain because the smoke occurs due to firing because of methane generation) was planned to close in 2007 due to its fullness. However, the new landfill has not yet finished. Therefore, this dumping site has continued to use until 2009. Since 20 July in 2009, a new landfill, Dangkor Landfill, has been operated at Khan Dangkor with the area of about 26 ha which is located about 15 km from city center. Currently (2011), about 1200tons/day of waste is being disposed of in this new landfill at a cost of USD 0.75/ton which paid by CINTRI to MPP (JICA, 2005), because the landfill is managed, controlled and operated by MPP. The result of informal interview with the Phnom Penh municipal

officer and CINTRI's officer in 2012 indicated that the amount of waste disposed at the landfill has increased to 1400 tons per day. The amount of waste disposed at landfill and recycling were shown in Fig. 2-5.



Source: Kokusai Kogyo Co., Ltd (2005)
Figure 2-5. Diagram of waste flow in Phnom Penh

Fig. 2.6 shows the current practices of MSW in Cambodia. Generally, waste from generators (households, business sectors) are disposed at dump sites/landfills without any precaution. However, recyclable materials are recovered by waste collectors, waste pickers and waste buyers, a kind of informal sectors because formal sectors have not yet established. Most of recyclable materials are exported to other countries such as Thailand, China and Vietnam. In the case of food waste, NGO (CSARO) plays an important role in making compost in order to reduce organic waste to landfill in the capital city, Phnom Penh.

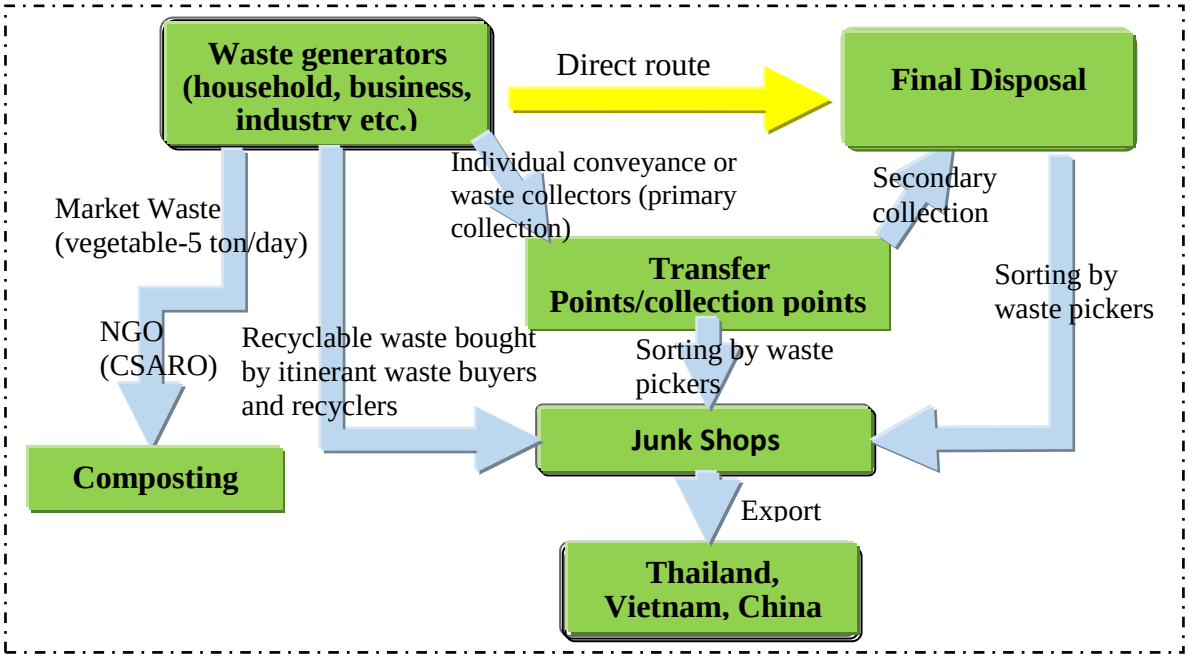


Figure 2-6. Flow diagram of current practices of MSW in Cambodia

2.3.5 Recycling and treatment

In Cambodia, waste treatment is limited compared to other countries. Besides the small amounts of recyclable materials were sorted out by waste pickers and few local NGOs, wastes were dumped at landfill without any precaution/treatment. The recycling rate of the city is 9.3% (85.8 tons/day) of total waste generation (JICA, 2005), which is comparable to that in Japan (13.1% in 1999). Recycling systems in the two countries are, however, largely different. In Japan, recycling is done by community groups (5.1%), recycling facilities and machinery, while in Cambodia, informal sectors play an important role in collection and separation of value materials for recycling. The recycling system of individual recyclers is well developed. Informal recycling carried out by waste pickers at beginning of waste stream and at waste disposal sites is especially active. The majority of recovered materials are exported to Vietnam and Thailand, only small amounts are domestic recycled. At the SMC disposal site, there are more than 500 waste pickers engaged in resource recovery. There are two kinds of waste recycling, plastic and paper recycling, were taken into consideration for their possible implementation in Phnom Penh city. These two categories, as well as organic matter, make up a significant percentage of total waste (JICA, 2005).

2.3.5.1 Characteristics and amount of recyclable materials

The items of waste that waste pickers collected at the disposal site were summarized in the Table 2-4 below. There are 9 main types of recyclable materials collected by waste pickers collected at Steung Mean Chey Dumping Site (SMCDS). The most collected recyclable materials are paper, plastics and metals accounting for up to 70-80%. The organic waste (food waste) recovered from the disposal site was reused as feed for livestock such as pigs, but in low percentage due to its uncleanness and hardness to separating because it was mixed with others. The average amount of recyclable materials collected by waste pickers was 28.1kg/person/day, and the main items of recycle materials were plastics and metals.

Table 2-4. Characteristics and amount of recyclable materials (RM) at SMCDS (waste pickers)

Characteristics of RM		Percentage	Amount of RM	
		(%)	kg/cap/day	%
Paper	Paper	20	1.3	4.6
	Cardboard	43	4.8	17.1
Plastics	Bottle (PET)	70	0.1	0.4
	High density plastic	69	8.6	30.7
	Soft plastic	80	3.1	11.0
Metals	Aluminum can	78	0.1	0.4
	Steen can	70	0.2	0.7
	Steel	44	2.4	8.5
Glass bottle		56	2.0	7.1
Cloth		2	0.0	0.0
Organic waste		17	2.4	8.5
Others		9	3.1	11.0

Source: JICA (2005)

2.3.5.2 Composting and recycled products

Composting projects could difficulty be successful in Phnom Penh and Cambodia as a whole, because farmers do not pay much attention on compost compared with chemical fertilizer. So compost could not find a direct use. Paper materials are normally separated, collected and exported to overseas. Plastic bags and bottles are collected and reused as materials for various purposes and other handmade articles conducted by informal sectors and NGOs. The recycling activities, in domestic, are hard to be enlarged because the market of finished products is limited and also the organization of medium-scale projects could be difficult. Few plastic factories are in place, producing plastic bags from already pelletized plastic material (LDPE and HDPE) imported. Using recovered

Figure 2-7. Recycled products and making compost from market waste (vegetable) by CSARO

plastic as raw material seems very small. So, the expansion of using domestic recovered materials should be encouraged. NGOs such as Community Sanitation and Recycling Organization (CSARO) carry out recycling, composting, although on a small scale with production capacity of about 4-5 tons/day. The promotion of compost is one of the effective ways to raise the waste recycling rate, especially market waste (vegetable waste) (Figure 2-7). However, the market of compost is unstable because farmers intend to use chemical fertilizer more than compost. So it is necessary for raising awareness of farmers in terms of improving soil quality by using compost.

In order to improve waste management and to extend the implementation of the 3Rs, the MoE developed a 3Rs national strategy in 2009. The purpose of the 3Rs is to ensure the waste volume has reduced under economically and environmentally sound and under the line with technological development.

The 3Rs strategies are to:

i) Develop 3R policy and regulations for effective waste management,
ii) Raise awareness and improve technical skills for responsible officers to deal with the application of 3R initiatives,
iii) Develop appropriate pilot projects focusing on household waste management, and
iv) Disseminate the 3R policy and regulations in the public and private sectors.

Currently, the implementation of 3R policy is still poor. Only informal sectors and few NGOs have carried out 3Rs (reduce, reuse, and recycle) in the community, while most of the recyclable materials have exported to other countries such as Vietnam and Thailand.

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CHAPTER III

METHODOLOGY

3.1 General framework

In the past, dumping and burning is the popular way in terms of solid waste management. However, these practices are being challenged due to the increasing value of land, inadequate space, and the limited carrying capacity of the environment which cause water, soil and air pollution, ultimately posing a threat to human health. Many countries in the Asian region, unsuitable technology and lack of manpower to effectively treat the generated waste are the point. In the recent years, 3R (Reduce, Reuse, Recycle) initiatives, replication of good practices and educational campaigns have been promoting the values of integrated waste management and resource consumption.

Fig. 3-2 illustrates the entire research framework which mentioned two main parts including household survey (household waste analysis, street waste analysis, and questionnaire survey) and commercial waste survey and Fig. 3-3 shows the flow diagram of research methodology. There are three kinds of solid waste in Cambodia, namely municipal solid waste, medical waste and hazardous waste (industrial waste). Municipal solid waste is generated from many sources such as household waste, commercial waste and others. The distribution of each source can be seen in Table 2-3. Our research target is municipal solid waste generators (MSW) — household and commercial sector. The result of this research can be used i) to identify the waste generation and composition, ii) to evaluate the potential for recycling materials, iii) to evaluate the appropriate treatment options for household solid waste based on physical and chemical analysis, iv) to find out the correlation between waste generation and socio-economic factors and attitudes, habit and behaviors of people toward waste discharge and recycling activities. Assessment of 3Rs approach and scenario analysis regarding to waste reduction and GHG emission were conducted.

To achieve the above objectives, the data collection was conducted as below:

1- **Secondary data**-collected the previous information and research from NGOs, Government Agencies, institutes, and internet and so on.

2- **Primary Data-**The aspects of solid waste management (SWM) in the city observed and collected. In order to collect all these information, three procedures were proposed in this research study which are mentioned below:

- **Household Survey**

(i) Household waste analysis: 26 households have joined in this survey.

(ii) Street waste analysis: 20 waste collection points (temporary storage) were selected with a total of 42 waste bags (2 or 3 waste bags from each collection point), total 317 kg, were collected in order to analyse the physical composition.

(iii) Questionnaire survey: 556 households were randomly selected for face-to-face interview from 9 districts (khans) in the capital city, Phnom Penh.

- **Commercial waste survey:** 52 waste generators from commercial sector were joined in this research.

3.2 Study area

Phnom Penh, the capital city of Cambodia with a land area of about 679 km^2, was selected as study area due to high economic growth, urbanization, rapid population growth and development which resulted in increasing the waste amount. Phnom Penh is divided into 9 khans (districts), namely 7 Makara, Tuol Kouk, Doun Penh, Chamkar Mon, Russey keo, Mean Chey, Saen Sokh, Por Senchey, and Dang Kao (Figure 3-1 and Table 2-1), in which contain 96 sangkats (communes) with a population density of 4,571 persons/km^2, which is the highest one of all cities in Cambodia (NIS, 2008). The population in Phnom Penh increased from 0.82 million in 1994 to 1.327 million in 2008 with the annual growth rate of 3.57%, which is higher than that of the whole country (2.3%). The details of Phnom Penh Characteristics can be seen in Table 2-1. Gross domestic product (GDP), an economic development index, slowly increased from 1994 to 2003. However, it started significantly increase from 2003 to 2008 with a capita average annual growth rate of 22.84%. Phnom Penh population has increased from 1.3 million in 2008 (NIS, 2008) to 1.5 million in 2012 (Facts Phnom Penh City, 2012). It is estimated to be 2.2 million in 2014 according to the world population review (World Population Review, 2014). GDP increased from 4,591 million (US$) in 2003 to 10,339 million (US$), as GDP per capita increased from US$ 345 in 2003 to US$ 739 in 2008 (NIS, 2008), US$ 931 in 2012 and 1,000 in 2013 (United Nations, 2014). The annual generation of waste increased from 0.136 million tons in 1995 to 0.36 million tons in 2008, and this value is expected to increase to 0.635 million tons in 2015. In 2003, about 60% of the total waste generated was

collected in the city (JICA, 2005). By 2009, this figure had risen to 82.9% of total generated waste of about 1200 tons per day (CINTRI, 2009), then continue increasing to 1602 tons/day in 2011 and 1881 tons/day in 2013 (Landfill office, 2013). The details of amount of waste generated and collected from 1994-2013 shown in Table 2-2.

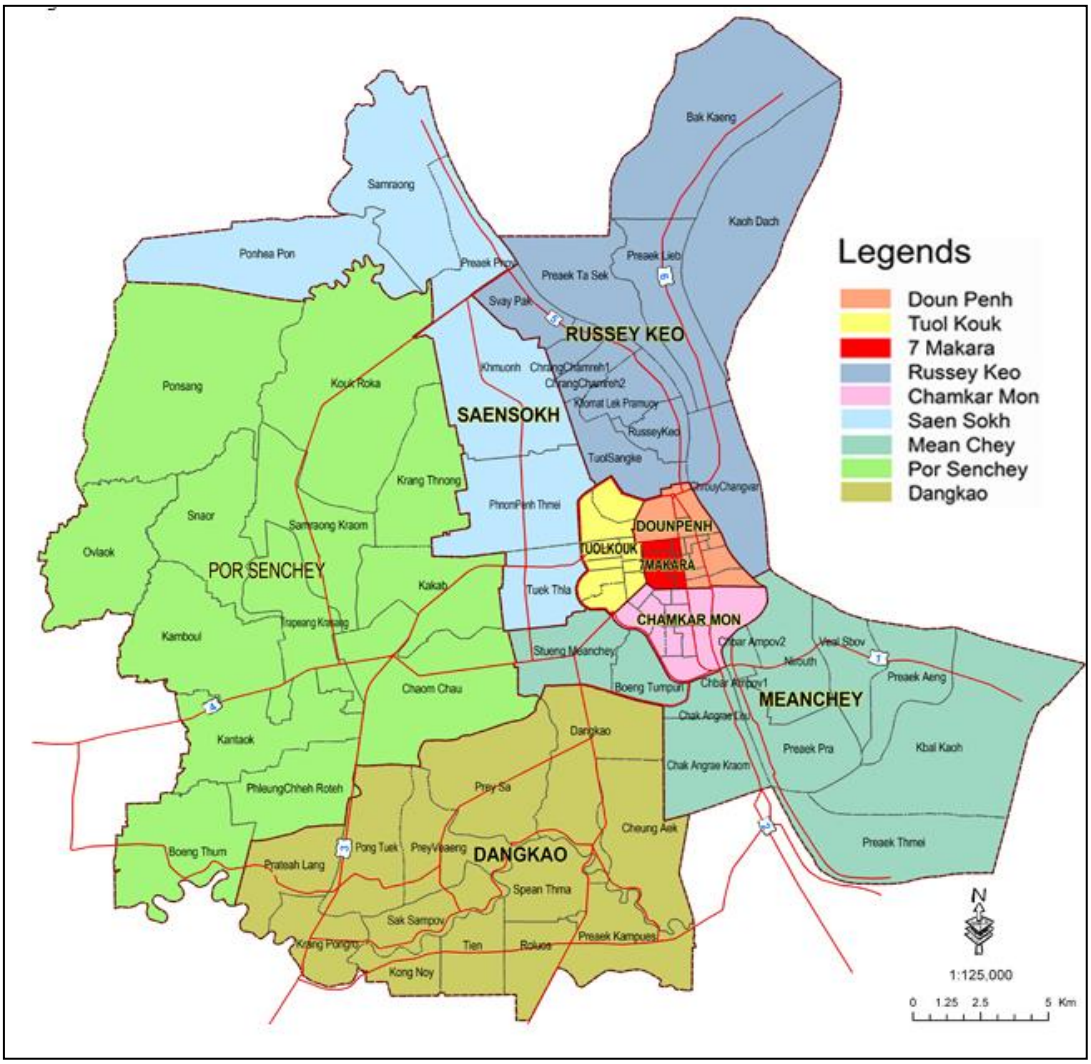

Figure 3-1. Map of Phnom Penh city (source: MPP)

Research Framework

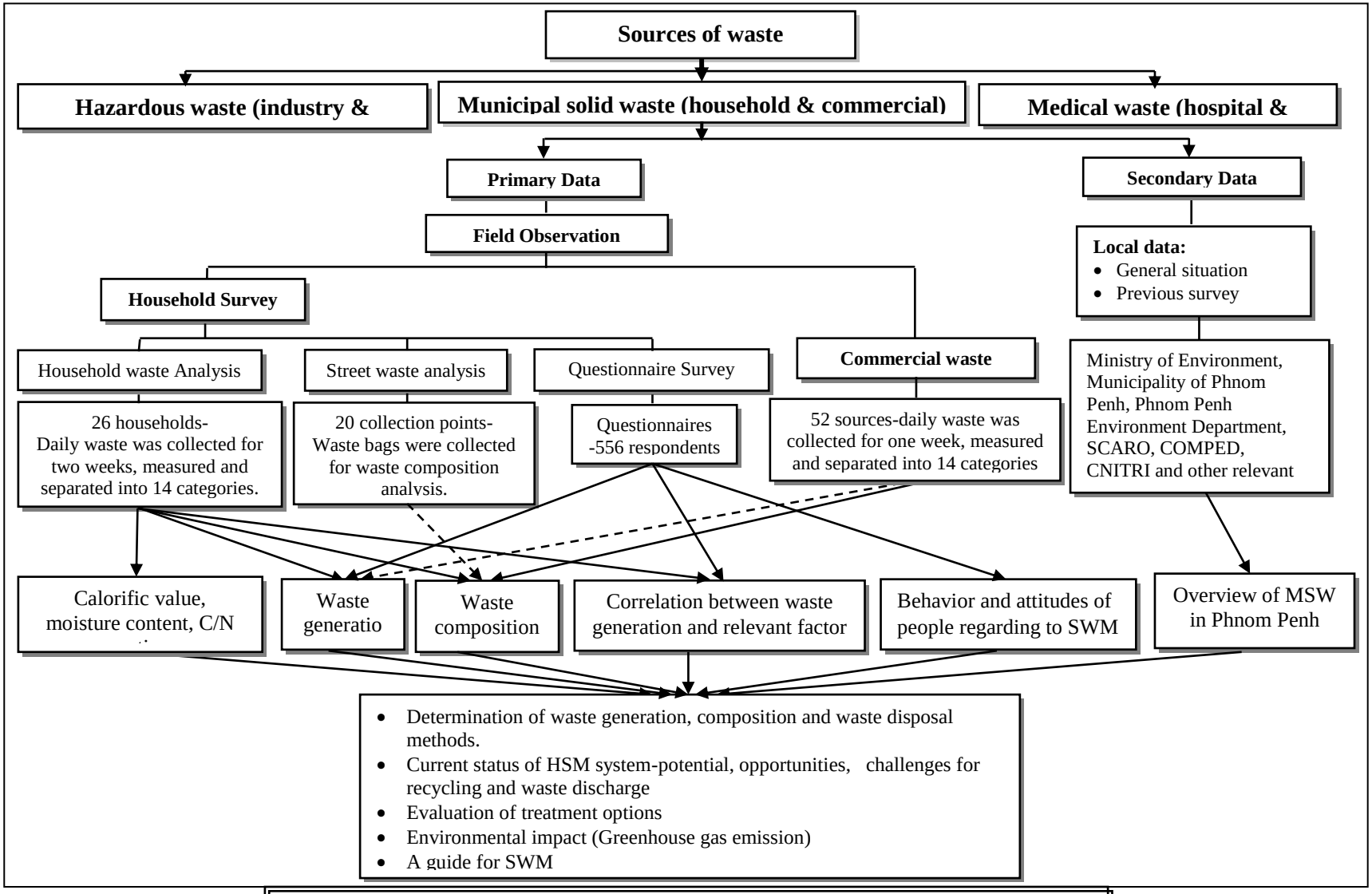

Figure 3-2. Schematic methodology for research design

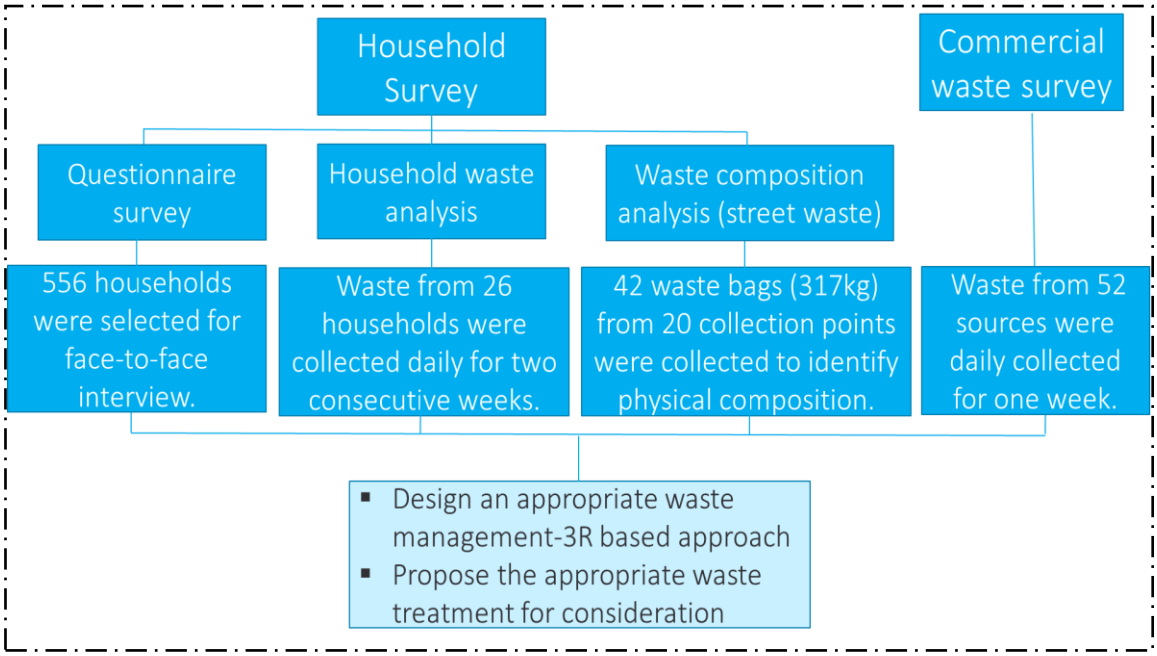

Figure 3-3. Flow diagram of research methodology

Below questions might be very useful to make the goal of research to be achieved:

- How much waste generated in Phnom Penh (PP) per day per capita?
- What is the beneficial to implement 3R in Cambodia context?
- What are the lessons learned from other countries can be implemented in Cambodia?
- What kinds of benefits are likely to appeal to different decision makers and stakeholders?
- How different policy tools/measures can contribute to improved coordination between infrastructure, financial mechanisms, and stakeholders for sustainable resource circulation?
- How to motivate different stakeholders to participate in and contribute to the 3Rs implementation?
- How to fill gap in data necessary for policy making and decision?
- How to upscale or replicate local good practices?
- How to achieve targets specified in the national strategies?

3.3 Scope and Limitation of Research Study

Household solid waste (HSW), commercial solid waste (CSW) and street waste (from collection points) were selected and collected for this research study. The research was conducted in Phnom Penh, capital city of kingdom of Cambodia.

This study was conducted in Phnom Penh, the capital city of Cambodia (Fig. 3-1). Phnom Penh city consists of 9 khans (districts) divided into 96 sangkats (communes). It has a total population of approximately 1.4 million, a land area of about 679 km^2, and a population density of 4,571 persons/km^2, which is the highest for any city in the country by National Institute of Statistics, Ministry of Planning of Cambodia (NIS, 2008).

In order to collect information on current status of household solid waste management (HSWM) and commercial solid waste management, and to evaluate potential treatment options in Phnom Penh city, we have conducted four kinds of survey namely:

i) **Questionnaire survey**- we selected 556 households from different income level: low (USD0-USD500), middle (USD500-USD900) and high (>USD900). The purpose of this survey is to obtain the information of household demographic and socio-economic characteristics and to define the factors influence on waste generation rate. Furthermore, the information related to waste separation, recycling, how to store, and dispose the waste was collected as well.

ii) **Waste composition survey** (street waste analysis): waste bags were collected from collection points along the road in order to check the composition of waste and compare with the result from household waste survey.

iii) **Household waste survey**

   a) We analysed the characteristics of household solid waste in order to understand its physical composition at the beginning of the waste stream,

   b) We analysed household waste generation in order to identify any daily discharge factors which may be influenced by household lifestyles, and related factors, and

   c) We analysed the chemical properties and calorific value of the waste in order to evaluate various waste treatment options.

iv) **Commercial waste survey**- we selected 52 sources of commercial sectors in order to determine waste generation, composition and potential for recycling materials.

The detailed procedure of each survey are mentioned in section 3.4-3.6 below.

3.4 Questionnaire survey

3.4.1 Questionnaire structure

The questionnaire contains 55 questions, most of which were closed-ended. The questionnaire is divided into two sections: i) general information and socio-economic aspects, and ii) solid waste generation and disposal, and awareness and willingness to

participate in SWM in terms of 3R principle. In the first section, questions covered the topics such as age, gender, education, family size and monthly income, while data on house floor area and house type were compiled by each interviewer. In the second section, information was collected on waste generation amounts, waste separation, waste storage and discharge, and householders' willingness to participate in waste separation in order to assess the respondents' levels of awareness and attitudes to waste management in terms of 3Rs. In the data analysis stage, the results were analysed and compared among income strata to identify the differences by economic situation of the household. The details of questionnaire sample sheet are illustrated in Appendix 3.

3.4.2 Sampling and interview methods

The survey was conducted by face-to-face interview at each household targeting the respondents at the age of 18 years old or over including those who receive collection service and without collection service. It was covered over the night khans (districts) in the city. But we focused on residential areas. The percentage of respondents from two Khans (central of the capital), Doun Penh and 7 Makara, were selected in lower percentage due to the majority of people are doing business which is a kind of commercial dominant area.

In Cambodia, mail-boxed questionnaire or e-questionnaire is not commonly used because of its effectiveness and furthermore, the collected data is less reliable. Information on solid waste disposal and level of people's awareness with regard to solid waste management, and socio-economic situation of each household are inquired. Moreover, in order to achieve stratified random sampling method, sampled households were divided into three different income levels—low socio-economic income strata-LSIS, middle socio-economic income strata-MSIS, and high socio-economic income strata-HSIS—to analyze the relationship between waste generation and socioeconomic aspects. In practice, it is difficult to know the household income level before the interview. Therefore, interviewer evaluated the income level based on apparent properties of the household, such as house types, vehicle ownership, and location and so on. In addition, interviewers tried to select the person who is in charge of waste management in the household. As a result, a total number of 556 households were obtained in this survey.

3.5 Waste composition survey (street waste analysis)

In order to examine the composition of street waste (assumed that it is a kind of household waste) in Phnom Penh, but only western part of the city was studied. 42 waste

bags were collected from 20 roadside collection points along residential streets (hereinafter referred to as street waste). Waste of the collection points mainly come from households, however, commercial waste might be included in some areas, but in small amount because normally business's owners have stored their waste at their places before the trucks come to pick up. In total, 317.1 kg of waste in 42 plastic bags was collected, well mixed and then sorted into 14 physical component categories: food, plastics, textiles, rubber, paper, grass, metal, glass, ceramics, aluminum, PET bottles and others. The total weight of each category was then measured. This survey was conducted on the first and second of September 2012. Three waste categories were analysed, namely, combustible waste (food, plastic, rubber, textiles, paper, garden, others), non-combustible waste (metal, glass, ceramic, others), and recyclable waste (paper, aluminium cans, PET bottles). The recyclable waste was separated out first, regardless of combustibility, and then the combustible and the non-combustible fractions were separated and weighed.

3.6 Household waste survey

3.6.1 Analysis of household waste

Before the analysis was carried out, a questionnaire survey was conducted to determine monthly household income strata: low (USD0-500), middle (USD500–900) and high (>USD900). A total of 556 households were randomly selected and the household owners were interviewed face-to-face from the 13th to the 30th of August 2012. 30 households (10 from each consumption stratum) were randomly selected from questionnaire result (556 respondents) for this study. Of these, 26 households agreed to actively participate in our survey. Every evening, after dinner or in the early morning of the next day depending the real situation, each household provided us with the day's waste sorted by category and placed in plastic bags which were provided with the code. The householders were asked not to add waste from the next day to make sure the waste generated by the day. We collected all the bags from each household and bring to the experiment area in order to separate by category and weigh them individually by using micro scale with high accuracy. This was carried out for two consecutive weeks, from the 11th to the 24th of September 2012. The total amount of household waste collected over this period came to 708.5 kg which is 27.3 kg/household in average.

3.6.2 Analysis of chemical properties

On the last day of the waste separation survey, a small amount of the waste from each category was sampled regarding to each proportion in order to get representative. However, while the amount of waste is huge, the reduction is necessary by using quartering method mentioned below and Figure 3-4:

- ***Step 1-Mixing:*** The waste was well mixed. The bigger items (i.e cardboard, textiles, etc.) were cut to smaller then mix again.
- ***Step 2-Dividing and reduction:*** After well mixing, divided into four with the same volume. Then discard the two parts with the opposite site.
- ***Step 3-Repetition:*** The repetition of two steps above is continuing until the volume of the remaining waste is reduced to appropriate amount (500g-1000g), the sampling was conducted.

Diagram sampling technique

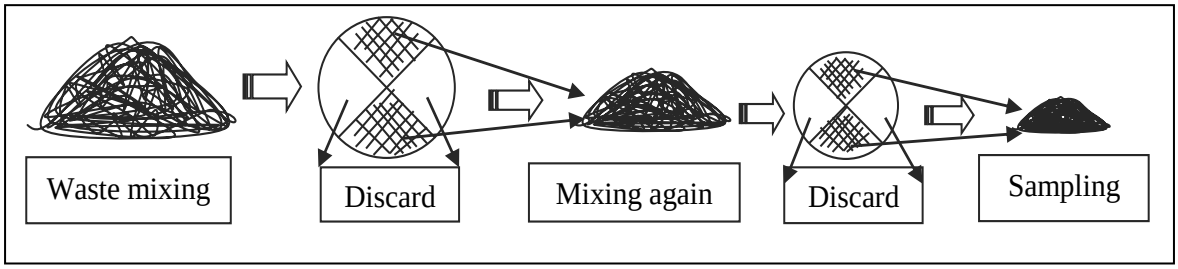

Figure 3-4. Quartering method for sampling

Then its moisture content, chemical composition and calorific value were analysed. The analysis procedure was as follows:

a) Weigh each waste component (Ww [%]).
b) Dry the sample at 105°C for 24–48 hours until the weight stays constant, even with further drying.
c) Weigh each dried waste component (Wd [%]).
d) Using a small dried sample, measure the heating value with a digital bomb calorimeter (OSK 2000 model DCS-196).
e) Also using a small dried sample, measure the carbon, hydrogen and nitrogen content with a CHN element analyser (PerkinElmer Co., 2400 II).
f) Incinerate the dried waste at 800 ± 2°C for 3–4 hours in a furnace (Yamato Muffle Furnace FO 3000) and measure the amount of ash remaining.

The following equations (1–4) were used to calculate the water content (W_0 [%]), low heat value (LHV [kcal/kg]) and high heat value (HHV [kcal/kg]):

Water content, $$W_o = \frac{(Ww - Wd)}{Ww} x100 \quad (1)$$

Lo Heat Value, $$LHV = HHV - K(W_o + 9H) \quad (2)$$

High Heat Value, $$HHV = H'h \frac{(100 - W)}{100} \quad (3)$$

Hydrogen content, $$H = h' \frac{(100 - W)}{100} \quad (4)$$

Where,

W_o = water content in total waste (%) W = water content of burnable waste (%)

Ww = weight of waste before drying (g) Wd = weight of waste after drying (g)

K = constant equal to 6 kcal/kg H = hydrogen content (%)

$H'h$ = calorific value obtained using the meter (kcal/kg)

h' = hydrogen content obtained by analysis (%)

Ash content, $$A = \frac{A_f}{Ai} x100 \quad (5)$$

Where

A = percentage of ash remaining after combustion (%)

A_f = sample weight after incineration at 800°C (mg)

Ai = original sample weight (mg)

Combustible content, $$B = 100 - (W_o - A) \quad (6)$$

Where

B = Combustible matter (%)

W_o = water content (%)

A = ash content (%)

3.7 Commercial waste survey

A private company, CINTRI, is in charge of waste collection and the transportation and disposal of municipal solid waste (MSW) under the supervision of the Municipality of Phnom Penh (MPP). However, MPP is responsible for managing, controlling and monitoring the landfill, Dangkor landfill, which is located about 15 km from the city center (Wat Phnom). Our study focused on five types of commercial establishment which were deemed to be the most significant producers of waste in the commercial sector which includes food services (restaurants, internet cafés and beer gardens), offices (microfinance agencies and ministries), schools (primary schools, institutes and universities), shops (phone shops, clothing shops and groceries), markets (supermarkets and family marts), hotels (3-star and small), and guesthouses. A variety of data were collected to characterize each of these commercial activities, including the size of each establishment (all establishments), the number of employees (all establishments), the number of guests (hotels, guesthouses, restaurants, beer gardens, shops, markets), the number of students (primary schools, institutes, colleges/universities), the number of bedrooms (hotels, guesthouses), the number of tables (restaurants, beer gardens, internet cafés), and the amount of waste generated and its composition (all establishments). A waste characterization analysis was then carried out on the waste produced. This research was undertaken from 22 July to 28 August, 2013, with the waste from 52 commercial sources (2 microfinance agencies, 3 internet cafés, 10 restaurants, 8 guesthouses, 2 beer gardens, 5 hotels, 4 markets, 6 shops, 7 schools, 4 ministries, and 1 council of ministers) collected daily for seven consecutive days. Labelled and coded plastic bags of different sizes were distributed to each source to store the waste in prior to collection. The amount of waste collected from each source was weighed and the results recorded, then the waste was separated into 23 different categories.

3.8 Expected Outcome

After the research conducted, the outcomes will be expected to be as following:

1. Outcome can be used as guide for waste management due to lesson learned.
2. Policy-relevant output/proposals from the research in relation to general policy-relevant challenges associated with resource circulation.
3. Common and interesting challenges/issues in 3R policy research which will be useful to have inputs from quantitative/environmental economics approach.

3.9 References for chapter 3

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CHAPTER IV

HOUSEHOLD SOLID WASTE GENERATION AND RECYCLABILITY IN PHNOM PENH

4.1 Result of household waste analysis

4.1.1 Household solid waste generation and characteristics

Before conducting a household waste analysis, a questionnaire survey was conducted involving 556 respondents. The results of questionnaire survey were presented in details in the next section. From the 556 households surveyed, 26 households actively participated in this analysis. Table 4-1 shows the results of household solid waste generation rate with regard to income distribution during the survey period. The results show that 42% of the 26 sampled households could be categorized as low-income and 34% as high-income. Waste generation rate varied among the different types of household and were positively correlated with family income. This means that the amount of waste being generated increased along with the increase of the socio-economic status of each household. The waste generation rate in kg/household/day was found to be 1.50, 1.96 and 2.50 for low-, middle-, and high-income families, respectively. It was also found that average waste generation per person per day showed a strong positive correlation with monthly income (Table 4-1).

A study by Cairncross (1993) revealed that developing countries generate less waste per person than developed countries because of their lower purchasing power and consequent lower level of consumption. Many researchers have indicated that variation in municipal solid waste (MSW) generation and composition are associated with lifestyle, household size, socio-economic factors, industrialisation, and climatic and seasonal changes (Bolaane et al, 2004; Fehr et al, 2000; World Bank, 2001; World Bank, 2003). Hassan (2001) reported that the higher the level of economic growth and urbanisation, the greater the amount of solid waste generated (Hassan et al, 2001). This finding is compatible with the results of the current study — more income, more waste. The gross municipal solid waste in Phnom Penh was 0.74 kg/cap/day (JICA, 2005). Comparing waste generation in developing countries (more details can be seen in Table 1-1), Troschinetz et al. found that the MSW generation rate is typically similar, in the range of 0.30 to 1.44 kg/capita/day (Troschinetz et al, 2009).

The results from household waste analysis showed that waste generation was 1.99 kg/household/day or 0.40 kg/capita/day, while the results from the questionnaire survey was 2.11 kg/household/day or 0.42 kg/capita/day (Table 4-1). In both studies, the recyclable wastes, removed for sale before collection, was excluded from calculation in terms of waste generation. If the sorted recyclable wastes are included, the waste generation rate is higher than that. Since both results were similar, the data can be considered highly reliable. JICA (2005) stated that household waste generation in Phnom Penh in 2003 was 0.487 kg/capita/day (JICA, 2005). Yatim (2010) reported 1.70 kg/household/day or 0.34 kg/capita/day in Selangor, Malaysia (Yatim et al, 2010). In another Malaysian study, the Johor Bahru district produced a similar result of 1.78 kg/household/day or 0.42 kg/capita/day in urban areas and 2.12 kg kg/household/day or 0.48 kg/capita/day in rural areas (Badruddin, 2004). In Chittagong, Bangladesh (2007), household waste generation was found to be quite low — 1.3 kg/household/day or 0.25 kg/capita/day (Sujauddin et al, 1993). Our results of 2.11 kg/household/day or 0.42 kg/capita/day are, therefore, almost the same as these findings for other Asian countries.

Table 4-1. Household distribution in terms of income category and waste generation

		Waste Generation			
		Household waste analysis		**Questionnaire**	
Family Income (USD)	Households	kg/hh/day	kg/capita/day	kg/hh/day	kg/capita/day
0-500 (low)	11 (42%)	1.50	0.30	1.72	0.34
500-900 (middle)	6 (24%)	1.96	0.39	2.15	0.43
Over 900 (high)	9 (34%)	2.50	0.50	2.47	0.49
Total	**26 (100%)**	**1.99**	**0.40**	**2.11**	**0.42**

4.1.2 Physical composition and daily discharge of household solid waste

Fig. 4-1 indicates the waste composition of street waste and household waste. Physical composition was categorized into 3 main components namely combustible, non-combustible and recyclable. The results showed that combustible, non-combustible and recyclable composed of 91.5%, 8.1%, 0.4%, for household waste and 89.7%, 8.9%, 1.4%, of street waste, respectively. In both cases, the combustible percentage was the highest, and that for recyclables was the lowest (Fig. 4-1).

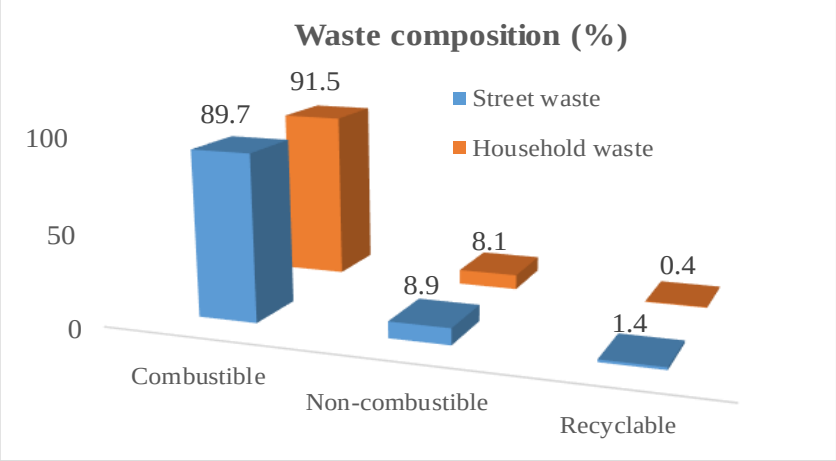

Figure 4-1. Waste composition of street waste and household waste

As shown in Fig. 4-2, food scraps (including vegetable/food waste and fruit waste) were the predominant component of combustible waste (66.86%), followed by plastics (9.79%), others (8.59%), and paper (4.37%). The high proportion of food scraps has also been reported in other Asian cities at a similar economic level to Phnom Penh. For example, 62% in Chittagong, Bangladesh (Sujauddin et al, 1993), and 65% in Nablus district, Palestine (Al-Khatib, 2010). By examining the data from the questionnaire survey, it was found that one of the major reasons for this high figure was the frequent preparation and consumption of meals in each household (Mongtoeun et al, 2014). The proportion of recyclable materials was very low because it had already been sorted, stored at home or sold to waste buyers.

The percentage of organic waste (defined as food, paper and grass waste) in the total amount of waste collected in this study was 72%. This can be compared with reported values of 80-88% in Iran (Moghadam et al, 2009), 68% in Gaborone/Botswana (Badruddin, 2004), 52-65% in Nigeria (Imam et al, 2008), 54-78% in Jordan (Abu-Qdais, 2007), 80% in Malaysia (Kathirvale et al, 2003), 69% in Beijing-China (Qu et al, 2009), and 65.5% in Cape Haitian (Philippe et al, 2009). Overall, the average percentage of organic waste reported for developing countries accounts for 50-80%, which is indicated in the result obtained in our research. As the moisture content of organic waste was high (63%) in this study, composting or methane fermentation could be used for organic waste recycling.

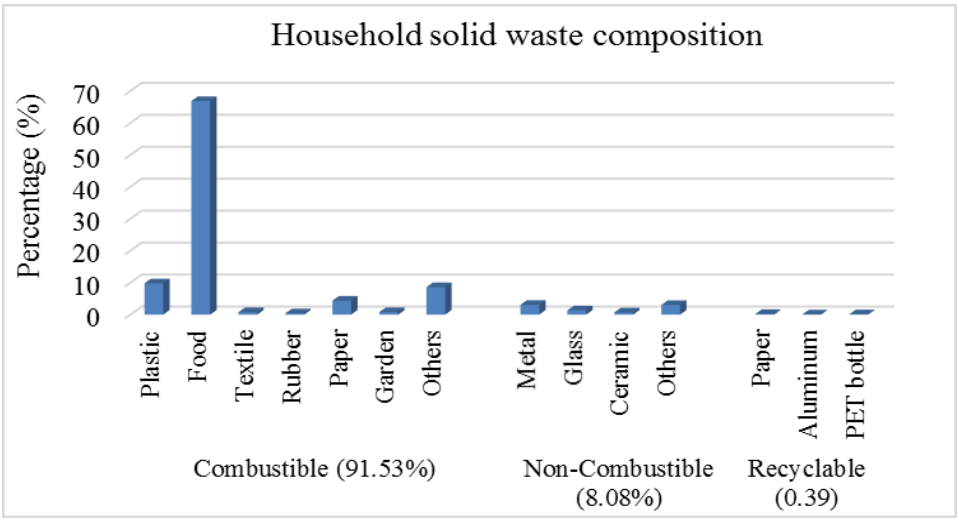

Figure 4-2. Composition of HSW (% by weight) in Phnom Penh

Fig. 4-3 represents the composition of street waste in 2012 and 2013. The results of both studies showed that biodegradable was the predominant (60-64%) followed by plastics (16-17%), paper (8-12%) and inorganics (5-6%). The composition of street waste and household waste is not much different. So it means that most of the street waste is coming from household and might be small proportion of it comes from business waste. However, business waste contains quite similar composition as household waste (see in chapter 5).

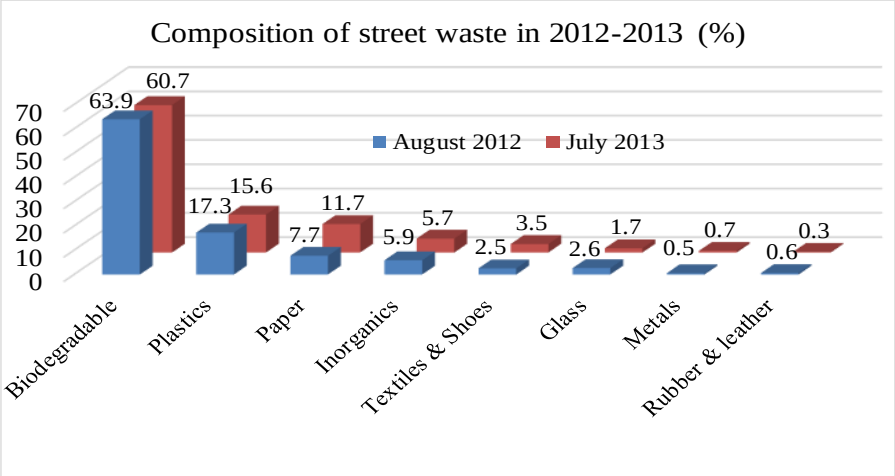

Figure 4-3. Composition of street waste in 2012-2013

Fig. 4-4 shows daily changes in the levels of household waste discharge in Phnom Penh city. The daily average over a week was 0.40 kg/capita/day. No particular days could be identified with especially large or small discharge levels. However, on Tuesday, Wednesday and Thursday, discharge levels were generally the highest and levels on Friday

and Saturday were generally lower than those on Sunday and Monday. There was a drop between Tuesday and Friday, and then the discharge level gradually increased again. The reason for this seems to be the habit of eating outside the home at the weekend. Therefore, it could be better to collect household waste more often during weekdays, and to collect business waste at the weekend.

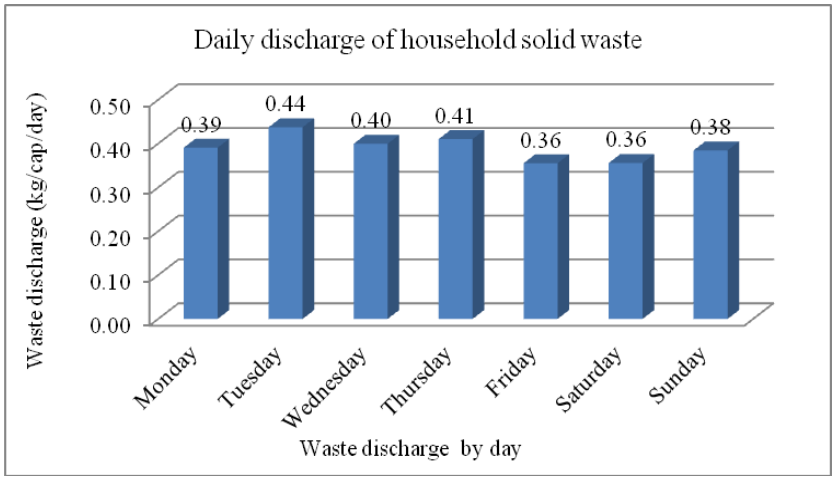

Figure 4-4. Daily household solid waste discharge

Table 4-2 presents the variation of waste generated by each category. Waste category varies among income level. It is indicated that low income families produced more food waste than middle- and high income families. This may be due to bigger household size and buying food in bulk (some parts are uneatable). For plastic waste, high income families produced less than low- and middle income families. The reason for this is, somewhat, not clear.

Table 4-2. Waste composition by income level

Waste generation by category (%)	**Household monthly income (USD)**		
	0-500	**500-900**	**>900**
Food	72.27	63.05	67.26
Plastic	13.56	13.07	9.59
Paper	7.23	26.60	11.20
Metal	6.34	39.20	4.96
Glass	18.63	20.79	24.46
Garden	7.71	1.77	4.75
Textiles	12.12	3.25	2.01
Ceramic & stone	8.48	12.93	14.97
Rubber & leather	2.77	5.60	1.43
Battery	0.00	1.53	0.95
Other organics	16.87	8.36	24.63
Other inorganics	14.08	11.58	10.02

4.1.3 Relationship between waste generation and household Size

Fig. 4-5 shows the relationship between waste generation and household size. The household waste analysis results show that the quantity and composition of generated waste in each household per day was dependent on household size. However, waste generation data (kg/household/day) also produced a positive correlation with family size. The increase in waste generation rate was proportional to increasing household size. In contrast, waste generation (kg/capita) was higher in smaller households than larger ones. This shows that a big family can share consumable materials and food with each other, resulting in less waste production, per person.

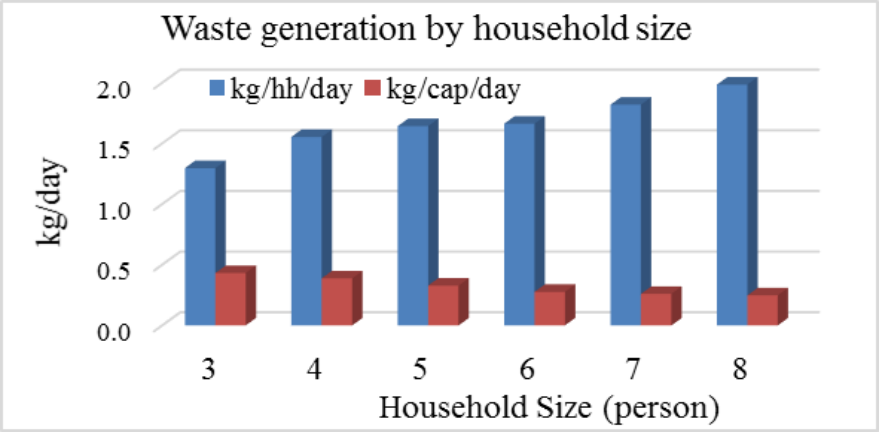

Figure 4-5. The relationship between waste generation per day and household size

4.1.4 Chemical composition and composting

Table 4-3 shows the chemical content, moisture content, ash content and combustible percentage for each category of waste. The results show that food, garden detritus and other organic wastes have a high moisture content (up to 60% or more) but a low combustible percentage (10-18%) compared to PET bottles and plastics that have a lower moisture content (1-6%) and higher combustible percentage (over 60%).

Table 4-3. Physicochemical analysis of HSW

	Waste Component	Chemical Content (%)				Moisture (%)	Ash (%)	Combustible (%)
		C	H	N	S & O			
Combustible	Food	41.49	5.45	1.87	51.18	78.37	11.11	10.52
	Garden	38.02	5.07	2.02	54.89	76.58	8.33	15.09
	Plastics	69.93	20.34	0.10	9.63	20.40	5.98	73.62
	Paper	33.45	4.68	0.02	61.85	47.30	15.57	37.13
	PET bottles	68.52	6.97	0.12	24.39	31.50	0.16	68.34
	Textiles	60.95	5.93	0.59	32.53	43.60	4.47	51.93
	Others	48.15	6.33	1.31	44.21	68.23	12.95	18.82
Non-combustible	Aluminium	-	-	-	-	10.60	-	-
	Metals	-	-	-	-	5.10	-	-
	Glass	-	-	-	-	3.20	-	-

4.1.5 Proximate analysis and energy content

Table 4-4 shows the low heat value (LHV), and proximate analysis results for household waste in different cities of Asian countries. The waste samples had a C/N ratio of 20:1 and moisture content of 63%, which means that such waste is suitable for composting, but also in anaerobic degradation process. As mentioned above (Fig. 4-1), food waste was the largest single component of total waste. Since organic materials accounted for more than 60% of the total waste, composting could be an important treatment option to address solid waste disposal issues in terms of waste volume reduction in Phnom Penh. The carbon-to-nitrogen ratio (C/N) and the moisture content are the most critical factors when evaluating suitability for composting. The optimum C/N ratio range for organic wastes is between 20:1 and 25:1, and the optimum moisture content is in the range of 50-60% (Tchobanoglous, 1993). The low heat value (LHV) for household solid waste in Phnom Penh was 894 kcal/kg which is lower than the minimum level (1,500 kcal/kg) needed to support stable incineration in an incinerator. At present, incineration is not, therefore, the best treatment option for household solid waste in Phnom Penh. The moisture content (63%) of household solid waste in Phnom Penh is similar to those values reported for Bogor-Indonesia (Novita et al, 2012) and Iskandar-Malaysia (Norbaizura et al, 2012). However, in this study, the LHV (894 kcal/kg) is low compared to Bangkok-Thailand [28], Kuala Lumpur-Malaysia (Kathirvale et al, 2003), Iskandar-Malaysia (Norbaizura et al, 2012) and Bogor-Indonesia (Novita et al, 2012).

Table 4-4. Comparison of waste characteristics in different cities

City/Country	Calorific Value (kcal/kg)	Moisture (%)	Ash (%)	Combustible (%)	References
Phnom Penh, Cambodia	894	63.1	9.9	27	This study
Kuala Lumpur, Malaysia	2,180	55	9.3	31.4	Kathirvale et al., 2003
Iskandar, Malaysia	1,591	60.3	8.2	31.6	Norbaizura et al., 2012
Bangkok, Thailand	1,233	40.4	28.29	31.32	Thaniya, 2009
Bogor, Indonesia	2,049	63.73	-	-	Novita et al., 2012

The results show that the second-largest waste component group in Phnom Penh is plastic and paper, so source reduction and source separation should be encouraged for recycling purposes. However, most of the plastic and paper are dirty and only present in small pieces, most of which cannot be recycled. Therefore, the best way to carry out waste treatment in Phnom Penh would be in two steps: (i) separating out organic waste for

composting, and then (ii) incinerating the rest for energy recovery. In this scenario, waste separation into biological waste (food and green waste only) and other waste is an important first step. (The recyclable waste category is not taken into account during this separation process because valuable waste has, typically, already been sorted and sold within the household before waste collection). By means of such separation, the combustibles in the other waste category can be sorted out in order to reduce the moisture content while, in terms of composting, the large farming area surrounding Phnom Penh city should be a good customer for all the compost produced. In Phnom Penh, the Community Sanitation and Recycling Organization (CSARO), an Environmental NGO, is now producing compost on a small scale of 5 tons/day from market food waste (vegetable). Expanding such activities to include the whole city would be one waste treatment option.

4.2 Results of questionnaire survey

4.2.1 Socioeconomic factors and characteristics of the respondents

Fig. 4-6 shows the distribution of respondents, in total 556, face-to-face interviewed from 9 Khans (districts) in Phnom Penh city. The result represents the people in Phnom Penh city (residential area) accounting for 19.2% from Saen Sokh, followed by Mean Chey and Tuol Kouk (15.8%), Por Senchey (11.2%), Russey Keo, Chamkar Mon and Dang Kao with the same proportion approximate 11% and 7 Makara and Daun Penh is low (2.5% and 4%, respectively). Low percentage in 7 Makara and Doun Penh are not our target because these areas are business zones. It was found that 66% of respondents were female and 34% were male with the average age of 35 years old.

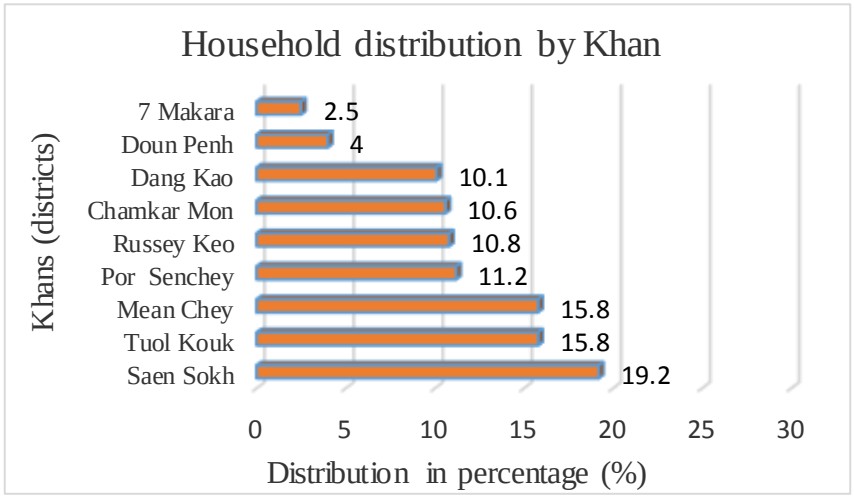

Figure 4-6. Household respondent distribution from each khan (district)

Fig. 4-7 shows the distribution of respondents as household size. The result shows that there are 4 to 6 members in their family in dominant. It was found that the average household size is 5 members. This figure shows similar number (4.9) to 2008 census of the National of Institute of Statistics (NIS), Ministry of Planning (NIS, 2008). The household size in Phnom Penh looks stable from 2008 to 2013 while it decreases from 5.5 to 4.9 during 1998-2008.

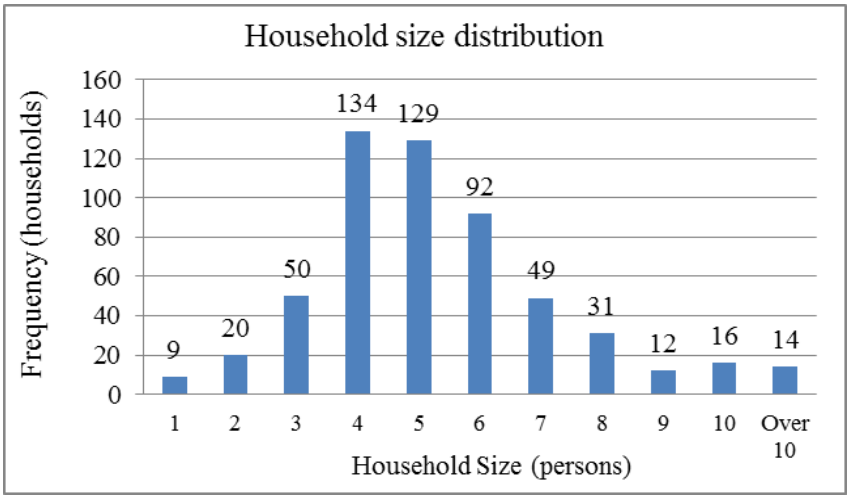

Figure 4-7. Distribution of respondents in terms of household size

Fig. 4-8 shows the percentage of household monthly income. The average of monthly income is USD827. As for the income level, respondent selected one from low (USD0-500), middle (USD500-900) and high income (over USD900) which compost of 70%, 16% and 14%, respectively. Since same question in the questionnaire survey by JICA was 60%, 30%, 10%, respectively, income level distribution in our survey seems to be appropriate. It seems that the low income group is easier to communicate and they are intended to give information than the middle and the rich people.

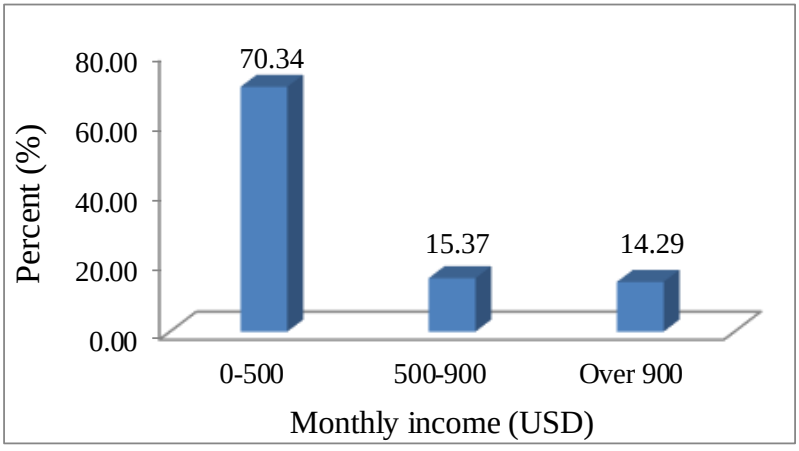

Figure 4-8. Income level of respondents

Table 4-5 shows the education level of family members. The result shows that each family member has education level in university (23.38%), high school (21.73%), primary (21.3%), and secondary (19.93%). while professional, master and PhD are the lowest (0.42%-2.61%).

Table 4-5. Education level of family member

	Illiteracy	Primary	Secondary	High School	Professional	University	Master	Ph.D	Total
Percent (%)	8.59	21.30	19.93	21.73	2.61	23.38	2.04	0.42	100
Frequency	244	605	566	617	74	664	58	12	2840

4.2.2 Household solid waste generation

4.2.2.1 Relationship between waste generation and household size

Fig. 4-9 shows data of waste generation per household per day and waste generation per person per day. The result of ANOVA test revealed that the amount of waste generation per household per day increased in accordance with the number of family members increased at a significant level of 5% for the three [$F(10, 545) < 3.59$, $P < .001$], which showed a statistically significant difference between waste generation and income level. On the other hand, waste generation per capita per day declined steadily with increasing household size – presumably because more people in a single home could share such things as foods, consumable materials and other items, leading to less waste production per person. This result, same as other studies, has also been reported elsewhere (Dennison et al, 1996; Norbaizura et al, 2012). However, the findings by Thanh et al (2010), Qu et al (2009) and Ojida-Benitez et al (2008) showed positive correlation between household size and per capita waste generation (Thanh et al, 2010; Qu et al, 2009; Ojeda-Benitez et al, 2008).

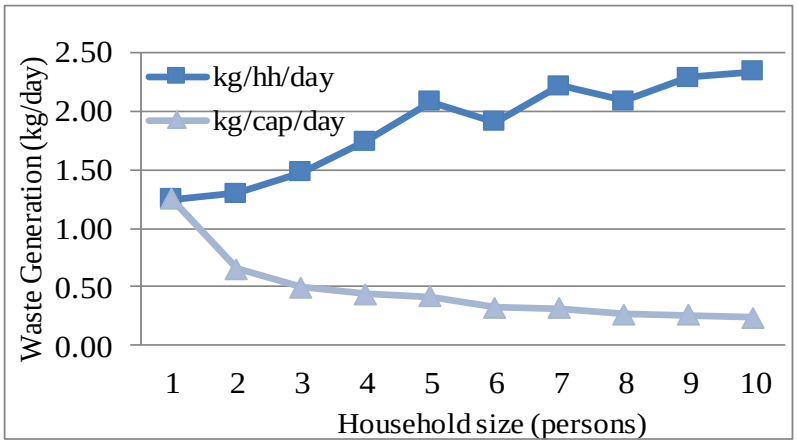

Figure 4-9. Relationship between waste generation and household size

4.2.2.2 Relationship between waste generation and house floor area

When asked about house floor area, respondents selected one of the following alternatives: 35 m^2, 55 m^2, 75 m^2 or 95 m^2. Fig. 4-10 shows the relationship between waste discharge and house floor area. These results show that smaller households (35 m^2) discharged less waste (1.6 kg/day) than larger households (95 m^2), which produced 2.24 kg/day. This means that waste discharge is correlated to house floor area. On the other hand, levels of daily waste generation have been higher than the amount of waste discharge because many salable waste materials were actively sorted out and put aside at home. An approximate regression analysis carried out between waste discharge and floor area data produced a high correlation coefficient (r^2=0.91). Therefore, it is obvious that household waste generation is proportional to house floor area at 5% level for the three condition [F(8, 547) < 6.21, p< 0.001]. Since the trend is for bigger households to live in the larger houses, this is another way in which larger house size can be considered proportional to income.

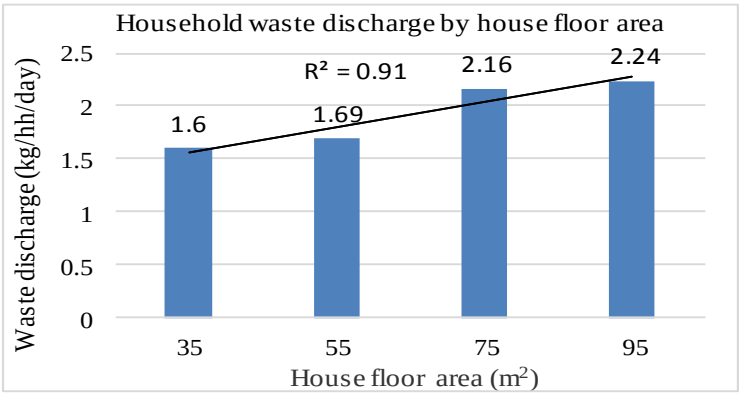

Figure 4-10. Relationship between waste generation and house floor area

Table 4-6 shows the relationship between waste generation and the occupation of respondents. Results identify that the people who work for NGOs, housewives, and students produced more waste than others with the amount of more than 2 kg/household/day.

Table 4-6. Occupation of respondents

Occupation	Frequency	Percentage (%)	Waste generation (kg/day)
Farmer	1	0.18	2.25
NGO staff	21	3.78	2.13
Housewife	79	14.21	2.02
Student	136	24.46	2.00
Vendor	193	34.71	1.91
Retired	10	1.8	1.90
Government staff	49	8.81	1.84
Company staff	56	10.07	1.74
Professional worker	11	1.98	1.43
Waste picker	1	0.18	0.75

4.2.2.3 Correlation between waste generation, household income, household expense, house floor area and household size

Fig. 4-11 shows the expense, income, waste generation, house floor area versus household size. The results indicate that waste generation was correlated with monthly income, expense and household size, with correlation coefficients of 0.96, 0.97 and 0.94, respectively. However, the households with higher income produced more waste than middle- and low-income households with strong correlation coefficient. This reflects the fact that wealthy families have more purchasing power than lower income families. The average amount of solid waste generation per household per day was 2.47 kg, 2.16 kg and 1.74 kg for HSIS, MSIS and LSIS, respectively, with P = .001 (<.05). This result is supported by some published findings (Nilanthi et al, 2006; Ojeda-Benitez et al, 2008; Qu et al, 2009; Richardson et al, 1974), but not others (Bruvoll, 2008; Hockett et al, 1995; Manavari et al, 2011). The daily discharge rate is also according to the number of persons that makes up a household. The average amount of solid waste discharge, excluding sorted waste at home, throughout the city was 2.13 kg per household per day or 0.41 kg per person per day. The researchs conducted by Shimelis (2011) and Sankoh (2012) confirmed that waste generation has a high positive correlation with household size and monthly income (Sankoh et al, 2012; Shimelis, 2011).

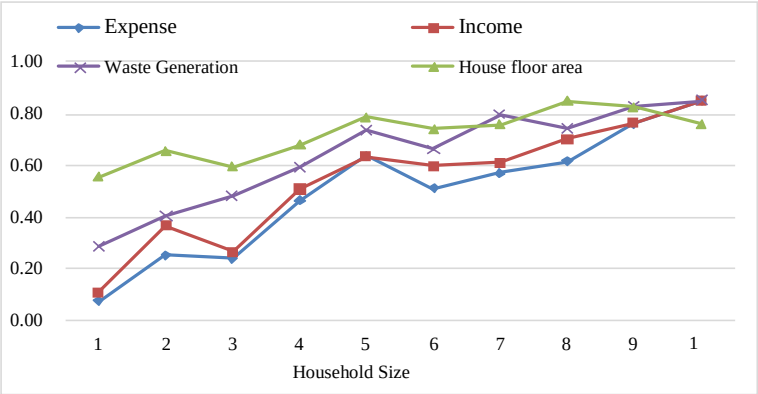

Figure 4-11. Expense, income, waste generation, house floor area versus household size

As shown in Table 4-7, waste generation per capita per day from flats and single houses was similar, at 0.34 kg and 0.35 kg, respectively, while that of villa houses was higher at 0.45 kg. The average monthly income for flats and single houses was USD426-605 per household and that for a villa was USD1450 per household. Interestingly, among all the house types studied, villas produced most waste, presumably reflecting the relatively high income of their occupants, whereas there was no significant difference in

waste generation between flats and single houses – both of which were associated with relatively low incomes.

Table 4-7. Relationship between house type and waste generation

House types	House floor area (m^2)	Waste generation	
		kg/hh/day	kg/cap/day/
Flat	61.6	1.81	0.34
Single house	60.3	1.89	0.35
Villa	96.3	2.20	0.45

4.2.3 Physical composition of household solid waste (HSW)

Fig. 4-12 presents the composition of household solid waste in Phnom Penh city. The result of the household waste survey is briefly explained in this section (Mongtoeun et al, 2014). In July 2012, a total of 42 waste bags were selected at random from storage points at several places throughout the city. These bags were then opened and the waste inside was separated into three groups: group-1 (recyclable waste which included paper, metal cans and PET bottles), group-2 (combustible waste such as food, non-recyclable items, plastic, rubber and textiles), and group-3 (incombustible waste such as metal, glass and ceramics – with the exception of metal cans which were included in group-2). The weights obtained for group-1, -2, and -3 were 89.7%, 8.9% and 1.4%, respectively. After dividing the combustible waste fraction into seven further categories, as shown in Fig. 4-12, food waste was found to comprise the largest single component, accounting for 65.5%, followed by plastic at 19.2%. In Ho Chi Minh City which has similar economic status, food waste contained up to 80% (Tran et al, 2014).

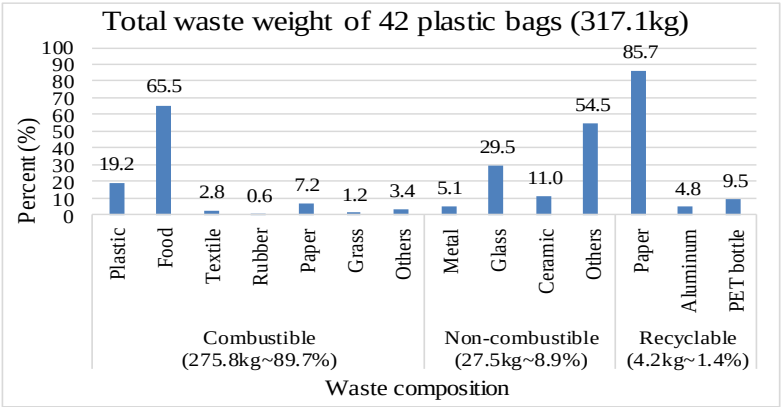

Figure 4-12. Composition of household solid waste

4.2.4 Solid waste management system in Phnom Penh

4.2.4.1 Collection service and collection time

A private company, CINTRI, is responsible for the waste collection service for

municipal solid waste (MSW) throughout the city. CINTRI collects this waste on a daily basis from urban areas and markets, and collects waste 3 times a week from peri-urban areas (JICA, 2005). The present fleet of collection vehicles used by CINTRI for municipal solid waste management is very old and in poor condition. Vehicle breakdowns are common, making collection management difficult and resulting in unreliable service. Table 4-8 shows the results obtained from questions about the waste collection service in Phnom Penh city. The results show that 91% of people had access to a collection service while the rest (9%) disposed of their waste by various methods such as burning, throwing it out onto open spaces, or throwing it into a water body- accounting for 48%, 29% and 15% of all non-collected waste, respectively. Most people (89%) recognized that a private company (CINTRI) the one who is responsible for waste collection. Waste heaps are a common method for waste collection in many parts of Phnom Penh. However, containers (0.6 m^3) were also used for a certain areas, but it was found that waste was overflowed and scattered on the ground due to the container volume is too small or the collection frequency is not enough. This waste on the ground creates conditions similar to waste heaps. Both types of waste collections, waste was easily washed out or scattered by water, wind or animals resulting in drainage system blockage.

Table 4-8. Waste collection service in Phnom Penh

Receive collection service (90.6%)			**Do not receive collection service (9.4%)**				
Know service provider			**Disposal methods**				
Know	Not know	Not sure	Burning	Throwing to open space	Throwing to water body	Burying	Other
89.3%	7.9%	2.8%	47.8%	28.9%	15.4%	3.9%	4.0%

Fig. 4-13 provides details of the waste collection times throughout the city. These results show that the collection time varied from area to area. Most residents disposed their waste in proper places, but in some cases the discharge time was inappropriate. In the tropical climate, waste rapidly decomposes so people do not want to keep it long at home resulting in an inappropriate time for waste discharge. In addition, an irregular collection time also leads to the discharge of waste at an inappropriate time. However, an “irregular” collection time was the most common (38%), followed by in the morning (20%), in the afternoon (13%) and at night time (11%). Because the collection time was irregular, people often disposed of their waste at the wrong time - causing it to be scattered or allowed to accumulate and be left behind. So it is necessary for the collection service company to determine the pattern of people’s daily life and their preferable collection time before deciding the collection day and time. On the other hand, local residents also have to realize

the importance of waste discharging rules and realize their responsibility.

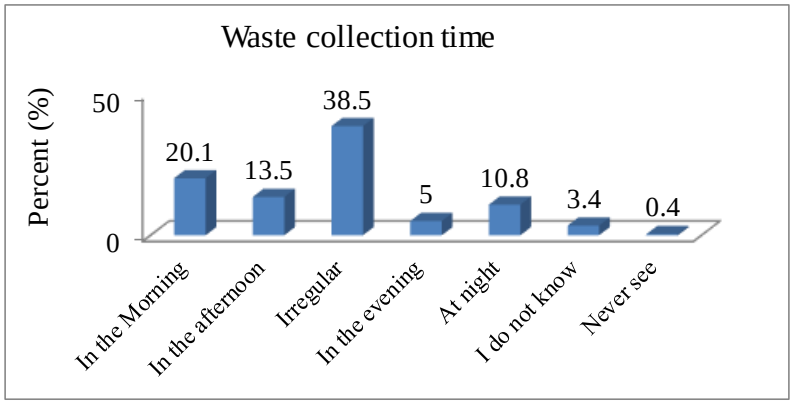

Figure 4-13. Waste collection time

4.2.4.2 Household behavior and attitudes towards HSW management

The questionnaire results showed that most respondents (82%) were willing to participate in environmental programs, and that they were interested in recycling (47%), waste separation (37%) and composting (17%). Most respondents (92%) expressed their interest in environmental issues. However, it is unclear how the respondents define the term environment or what criteria they had when they chose the answer they are interested in environmental issues. It can be assumed that the meaning of environment is mixed with that of hygiene. Though they were more interested in solid waste issue (69%) than air pollution (42%) and water pollution (24%). This shows that people living in the city paid most attention to solid waste and air pollution. In terms of waste separation at source, 95% of respondents replied that they already carried out waste sorting prior to disposal, and that the reason for doing this was for future sale (94%). They also replied that the main solid waste problems were the scattering of rubbish (71%) and bad odors (46%). Of these respondents, 17% reported that they saw waste piles along roads and in open spaces “very often” and 40% reported that they saw such waste “often”.

Table 4-9 shows the waste storage materials before disposal from households. The results show that people use different storage materials to keep their waste before discharge accounting for plastic bag (70.24%), followed by plastic bag & plastic container (16.01%), plastic container (6.03%), plastic bag & carton box (4.33%), plastic bag & metal container and other materials (< 1%). The reason why people use more plastic bag because it is cheap and easy to get. Normally, when people go to market and buy food, plastic bag are always provided by sellers with free of charge.

Table 4-9. Waste storage materials

Storage Materials	Percentage (%)
Plastic Bag	70.24
Plastic Container	6.03
Metal Container	0.56
Carton Box	0.38
Wood Container	0.19
PB+PC	16.01
PB+MC	1.88
PB+CB	4.33
PB+PC+MC	0.19
PB+PC+CB	0.19

PB: Plastic bag PC: Plastic container
MC: Metal container CB: Carton box

4.2.4.3 Perception toward waste management in Phnom Penh

Fig. 4-14 shows the respondents' level of satisfaction with the collection service provided by the waste collection provider, CINTRI. The respondents used "satisfaction", "neutral" and "unsatisfaction" to express their opinion of the waste collection service. Most of respondents showed that their opinion with neutral (56%) followed by unsatisfied (28%) and satisfied (16%). This means that people feel hard to judge the current waste collection service. However, collection efficiency had been improved recently, but it seems that the collection service was still considered poor in terms of the collection schedule, collection frequency and cleanliness. The respondents tended to be more neutral with the collection service, but the inappropriate or irregular collection time and waste left on the street after the collection service were main reasons for dissatisfaction.

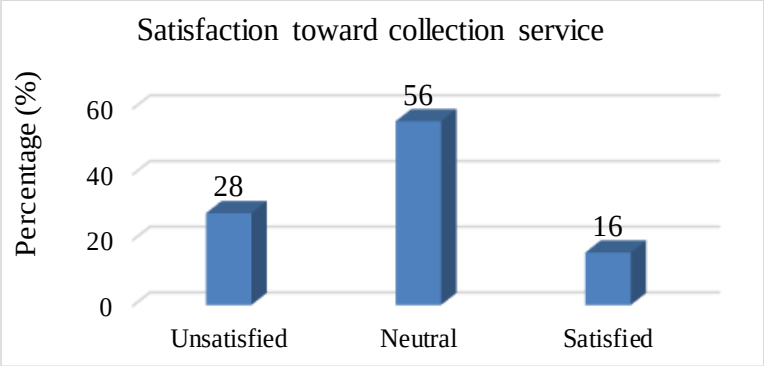

Figure 4-14. Levels of satisfaction with the waste collection service

Table 4-10 shows the results of the questionnaire survey regarding respondents' participation in various organized environmental programs. The results show that 23% of respondents have participated in some environmental programs (quite a low figure) and

that the program organizer was usually a NGO (38%), local authority (27%) or school (20%), while CINTRI accounted for only 4% of such programs. It was found that people in Phnom Penh had a relatively low level of involvement in environmental programs and even less involvement in solid waste programs which is being provided by CINTRI.

Table 4-10. Level of people's participation in organized environmental programs

Participated in environmental program	Organizer of the program				
22.7%	NGO	Local Authority	Schools	CINTRI	Other
	38.1%	27.0%	20.0%	4.0%	10.9%

Fig. 4-15 shows the results of response regarding waste sorting activities carried out within households – with the sorted waste being sold to informal waste buyers throughout the city. Aluminum cans were the most common items sorted, followed by PET bottles, paper, plastic bags, metals, textiles and food (97%, 67%, 34%, 32%, 22%, 6.7% and 0.76%, respectively). A high degree of waste sorting was carried out at home (94%). However, the reason for carrying out such sorting of waste was to obtain extra income, not for any waste management reason.

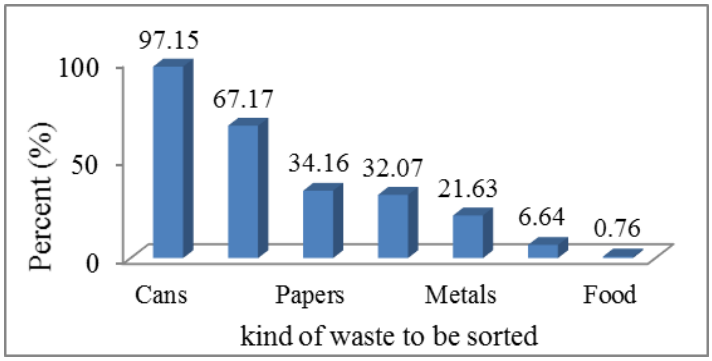

Figure 4-15. Rate of recyclable waste sorting in the household

Fig. 4-16 shows the awareness of people about treatment at final disposal site. Most people do not know about treatment at final disposal site at high rate of 65%, with knowing is 28%, and with do not care is 7%.

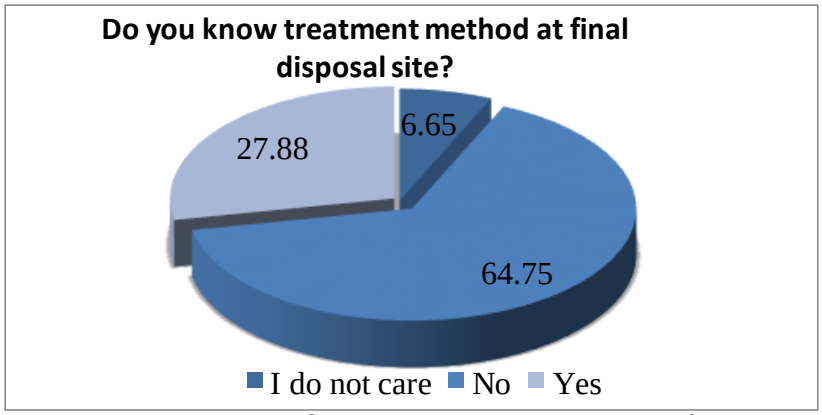

Figure 4-16. Awareness of respondents on treatment at final disposal site

Table 4-11 shows the results of response to questions about recyclable waste sorted for sale. Glass bottles, papers, steels and aluminum cans are the two main items of recycling. At present, people in the MPP store recyclables at home for several months before a buyer comes to their houses to collect them. Most respondents (94.8%) sorted their waste prior to disposal. Moreover, 92.1% of them sold the sorted waste to informal junk buyers. It is necessary to check whether or not more frequent visits by the waste buyers will promote recycling activities. By analyzing the relationship between waste generation and the sorting activity, it can be seen that total waste generation would have been even higher without this sorting (i.e., 0.438 kg capita per day and 0.365 kg per capita per day, respectively). Thus, waste sorting effected a 17% reduction in the total amount of waste. Furthermore, the average extra income from selling valuable materials was estimated at approximately $1.56 per household per month.

Table 4-11. Waste generation, waste reduction and income obtained from sorting

Waste generation	Without sorting (5.2%)	With sorting (94.8%)			
		Generation	Waste reduction (%)	Not for sale (8%)	For sale (92%)
kg/hh/day	2.28	1.90	16.7	$0/hh/month	$1.56/hh/month
kg/cap/day	0.438	0.365			

Table 4-12 shows the questionnaire results regarding food waste management by each household. It was found that most waste was disposed of along with other waste (27%), or used as animal feed (25%), given or sold to animal raisers (20%), used for home composting (18%), or disposed of in the back yard (15%).

Table 4-12. Food waste management

Dispose with other waste	**Animal feed**	**Give or sell to animal raiser**	**Composting**	**Dispose of in the back yard**
27.0%	25.4%	20.5%	18.2%	15.1%

Table 4-13 present the way of dealing with recyclable materials after sorting at home. The result show that 92% sell their recyclable after sorting. The majority, they sell to street waste buyers (95%), sell to waste buyer and keep for own use (215), and sell to waste buyer and sell to junk buyer (5%). For those do not sell the recyclable materials, keeping for neighbor (42%), keeping for own use (16%), and give to waste picker (14%).

Table 4-13. The way of dealing with recyclable materials

How do you do with recyclable waste such as cans, papers and metals?		
Selling	92.09 %	1.56 $/HH/month
Not sell	7.73 %	0 $/HH/month
If not sell, what do you do with it?		
Keep for own use	16.28 %	
Keep for neighbor and relative	41.86 %	
Keep for CINTRI worker	9.30 %	
Give to waste picker	13.95 %	
If sell, who do you sell to?		
Sell to waste buyer	94.53 %	
Sell to waste buyer and Sell to junk shop	5.27 %	
Sell to waste buyer and Keep for own use	20.51%	
Sell to waste buyer and keep for neighbor and relative	1.17 %	

Table 4-14 present the advantage of waste separation. The result shows that waste separation is for extra income (70%), waste reduction (57%), and environmental protection is (37%). This is the habit and attitude of people, to do something with benefit is more active than that without benefit.

Table 4-14. The advantages of waste separation

Advantages of waste separation (%)					
Waste reduction	Extra income	Environmental protection	Natural resource conservation	Unscattered	Being easy for waste collector
57.01	69.06	37.41	8.27	3.42	3.60

4.3 Conclusions

This study shows that the overall level of household solid waste generation, per person, in Phnom Penh was lower in 2012 than reported in the JICA study of 2005, and that waste generation is strongly and positively correlated with family income and household size. Household waste contains a high proportion of combustibles (~90%), of which food waste (66.2%) is the main component. The combustible materials in street waste consist of food (58.76%), plastic (17.27%), paper (7.71%), textiles (2.54%), garden detritus (1.11%), rubber (0.59%), and other materials (9.30%), while in household waste these numbers are 66.20% (food), 9.80% (plastic), 4.50% (paper), 0.70% (textiles), 0.80% (garden detritus), 0.30% (rubber), and 8.50% (other), respectively. Thus, food waste is predominant in both cases. The organic matter content is high (~70%) and the characteristics of Phnom Penh HSW make it suitable for organic treatment by means of composting. The results of questionnaire (55 questions) from 556 respondents showed that waste generation and the amount and type of waste discharged from each household were highly dependent on household socio-economic parameters. For example, the amount and

type of household solid waste discharge was positively correlated with monthly income, household size, house floor area, house type and waste sorting activities. The amount of waste discharge depended on the household type - with flats, single houses and villas accounting for 1.8, 1.9 and 2.7 kg/household/day, respectively. Similarly, the average amount of solid waste generation was 2.47, 2.16 and 1.74 kg/household/day for high-, middle-, and low-income levels, respectively. Although 91% of people had never heard of the 3Rs, they were carrying them out every day. Our study shows that the amount of waste generated could be reduced by 17% if people sorted their waste before discharge, and that this could produce extra income of approximately USD114/cap/year. We also found that while most people were not well informed about solid waste management, they were interested in environmental issues, including solid waste management. In the future, more detailed analysis of waste generation studies and implementation projects should be conducted in order to develop a model for solid waste management in Phnom Penh.

Based on these results, the component analysis shows that the moisture content (63.10%) and the low heat value (894 kcal/kg) are not suitable for the use of waste to energy (WTE) technology (incineration). However, if food waste is separated out before use, the low heat value become higher (1,429 kcal/kg) can be increased, making the waste acceptable for incineration. The C/N ratio (20:1) and the high moisture content (63%) is suitable for composting or methane fermentation. Making compost from the organic matter and using the compost as an organic fertilizer could, therefore, be a suitable way of managing HSW in Phnom Penh city. In addition, composting also contributes to the lifespan of landfills, the reduction of greenhouse gas emissions, the prevention of pollution, and the reduction of chemical fertiliser costs - resulting in long-term improvements in soil quality. However, the mixture of waste lowers the quality of any compost produced. Furthermore, the market for compost is still limited, unstable and challenging, so further investigation is necessary before planning for expanded compost production and more detailed studies should be conducted.

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CHAPTER V

COMMERCIAL SOLID WASTE GENERATION AND RECYCLABILITY IN PHNOM PENH

5.1 Introduction

Municipal solid waste (MSW) management is widely recognized as one of the most problematic areas of environmental management in the country. Because the rate of waste generation keeps increasing and the lifespan of existing landfill sites is decreasing, improved waste management has become an urgent need (Forfás, 2001). A rapid increase in the amount of municipal solid waste is one of the key issues affecting developing countries, particularly in the fast growing cities (Jin et al., 2006, Minghua et al., 2009). Cambodia is one of the developing countries in which the development of all aspects are struggling to catch up with the economic boom in the region. In Phnom Penh, the capital of Cambodia, the population and gross domestic production (GDP) are increasing rapidly due to urbanization and lifestyle changes. These trends have resulted in an increasing amount of waste over the last two decades. According to Japan International Cooperation Agency experts (JICA's experts, the population of Phnom Penh will reach 1.7 million by the year 2015. The annual generation of waste increased from 0.136 million tons in 1995 to 0.36 million tons in 2008 and is expected to soar to 0.635 million tons in 2015 (JICA, 2005). Data received directly from landfills indicate that the amount of waste received increased from 1,027 tons per day in 2009 to 1,381 tons per day in 2013 (landfill office, 20013). Collection and transport of municipal solid waste in Phnom Penh was licensed to private company, CINTRI, which is under the control of Municipality of Phnom Penh (MPP). In 2003, about 60% of the waste generated was collected in Phnom Penh city, rising to 82.1% in 2009 (JICA, 2005). This change indicates that collection efficiency has, somehow, been improved. However, many areas of the city are still without an adequate waste collection service. Collection efficiency is still low, resulting in piles of waste and scattered waste existing in the city (mostly in peri-urban areas). Illegal dumping and uncollected waste remain a major problem, leading to many social concerns such as aesthetics, environmental degradation, damage to urban infrastructure - including drainage blockages and flooded roads.

Open dumping and landfills are the common disposal methods for MSW in Phnom Penh which are generally poorly sited, designed, controlled and operated. All kinds of waste collected, except hazardous and medical waste, are disposed of at dumping sites or landfills without any form of separation/pre-treatment. This creates a huge amount of garbage which even the new landfill site—Dang Kor landfill—will be struggling to handle. This landfill is the only sanitary site available and started operations in 2009 when the old dumping site, Steung Mean Chey Dumping Site (SMCDS), was completely full and closed down. However, the Dang Kor landfill is located about 15 km from the city center (from Wat Phnom), compared to SMCDS which was only 7 km away. This increased distance could significantly affect the collection and transport of the waste. Phnom Penh MSW compose of household waste (65.6%), followed by the commercial waste (~25%) and other sources (JICA, 2005). In order to reduce amount of waste, especially food waste, to landfill there are different methods through resources recovery which include recycling, composting, waste to energy and so on. For example, the city of Madison, Wisconsin, USA can divert 59% of the waste from landfills through recycling and composting program (City of Madison, 2008). In Phnom Penh, there is no formal recycling sector for municipal solid waste (MSW), but informal sector and NGO which play an important role regarding to waste recovery mainly comporting and recyclable materials. For example, community sanitation and recycling organization (CSARO), an environmental NGO, is now producing compost on a small scale from market food waste. However, appropriate waste management solutions vary from one locality to another depending on characteristics of waste and climate condition and so on (Diem Trang et al., 2007). Waste management models can, however, improve the way in which decisions regarding waste management are taken (Eriksson et al., 2003). Waste generation rate and waste composition is essential to predict future amount of waste and to identify the generation trends, and to make good planning of collection, transport and treatment (Bandara et al., 2007; Forbes et al., 2001). To improve waste management practices, both the planning and design stages of integrated municipal solid waste management systems must be based on the accurate prediction of solid waste generation and accurate data regarding its composition.

However, the reliable database of MSW generation and composition in Phnom Penh is limited. JICA reported household waste and commercial waste generation and composition in 2005 which seemed old and not much details. Unfortunately, little information was available on commercial solid waste (CSW). The information of

commercial waste generation and composition was, somewhat, not available in overall. Therefore, study of the generation and composition of commercial waste is needed because it is the second largest component of municipal solid waste. The results from this research can be a baseline of CSW and provide useful information when selecting the most appropriate disposal methods (e.g., recycling, composting, landfilling or waste-to-energy via incineration) and designing a highly efficient waste collection system. The objectives were to predict the overall waste generation rate, determine the physical composition of the waste generated, assess the levels of recyclable materials remaining in the residue, and to evaluate the most appropriate technology for waste treatment.

5.2 Results and Discussions

5.2.1 Commercial solid waste generation by source

In order to compare waste generation rate by source, the average waste amount generated was calculated from amount of waste of each source within seven consecutive days divided by all sources with index value, kg/unit/day, such as kg/table/day for restaurants, beer gardens and internet café, kg/room/day for guesthouse and hotel and kg/cap/day for market, shops, school, ministry and office. Table 5-1 shows the amount of commercial waste generation, by source. The results show that large restaurants produced the most waste, followed by medium-sized restaurants, beer gardens, and internet cafés - accounting for 4.832 kg/table/day, 3.360 kg/table/day, 2.225 kg/table/day and 1.942 kg/table/day, respectively. This shows that most waste generation is associated with food preparation (Table 5-3). The results also show that 3-star hotels generated more waste than large guesthouses, medium and small guesthouses, and small hotels - accounting for 0.685 kg/room/day, 0.454 kg/room/day, 0.370 kg/room/day and 0.097 kg/room/day, respectively. Byer et al. (2006) found that 3-star hotels in Halong city, Vietnam, produced same amount of waste (0.685 kg/room/day ~ 0.43kg/guest/day) as 3-star hotels in Phnom Penh city. Family marts and ministries produced 0.153 kg/person/day and 0.147 kg/person/day, respectively, followed by the council of ministers (0.124 kg/person/day) and supermarkets (0.118 kg/person/day). Small shops and schools produced relatively little waste - less than 0.10 kg/person/day (Table 5-1).

Table 5-1. Commercial waste generation, by source

Units	Main sources	Waste Generation
kg/table	Large restaurants	4.832
	Medium restaurants	3.360
	Small restaurants	0.728
	Beer gardens	2.225
	Internet cafés	1.942
kg/room	Large guesthouses	0.454
	Medium and small guesthouses	0.370
	Three-star hotels	0.685
	Small hotels	0.097
kg/person	Supermarkets	0.118
	Family marts	0.153
	Clothing shops	0.096
	Groceries	0.088
	Phone shops	0.048
	Institutes	0.011
	Primary schools	0.022
	Universities	0.034
	Ministries	0.147
	Council of ministers	0.124
	Microfinance agencies	0.063

Fig. 5-1 shows waste generation from commercial sectors by source. The waste generation (kg/cap/day) was 1.66, 0.85, 0.56, 0.52, 0.42, 0.37, 0.27, 0.18, and 0.16 for large restaurants, internet cafés, beer gardens, medium restaurants, large guesthouses, 3-star hotels, medium and small guesthouses, small restaurants, and small hotels, respectively. On the other hand, schools, small shops, minimarts and microfinance agencies produce waste with less than 0.15 (Table 5-1). Byer et al (2006) indicated that 3-star hotels in Halong city, Vietnam, produced similar amount of waste (0.43kg/guest/day) as 3-star hotels and large guesthouses in Phnom Penh city.

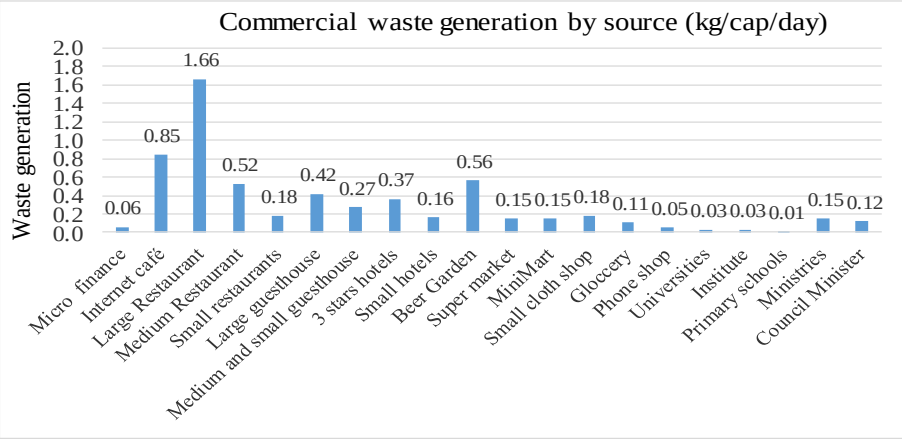

Figure 5-1. Commercial waste generation by source (kg/cap/day)

Table 5-2 illustrates the day-to-day variation in the amount of waste discharged from each source throughout the week (excluding the recyclable waste already sorted out at source). The waste generation rate varied depending on the day of the week – as noted earlier by Tochobanoglous (1993) and Vesilind (2002). The waste generation rate for beer gardens and markets was especially high at the weekend, while microfinance agencies did not produce any waste at all on Sunday and schools generated little waste over the weekend because most schools were closed (some schools were still open for private classes, but with fewer classes overall). Hotels and internet cafés generated relatively little waste on Sunday, in contrast to restaurants which showed high generation rates on Sunday, while guesthouses and shops did not show any such variation. Waste collection schedules and times could, therefore, be tailored to the waste generation source.

Table 5-2. Commercial waste generation rate (kg/source) on each day of the week

Generation Sources		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Beer gardens		41.30	31.40	38.41	49.50	46.21	53.89	50.40
Guesthouses	Large	14.20	13.07	13.32	11.38	14.23	10.55	14.73
	Medium and small	6.34	3.59	5.95	8.49	6.51	4.13	6.69
Hotels	Three-star	41.45	39.40	46.82	46.35	35.30	39.20	30.8
	Medium and small	6.04	5.30	4.30	6.95	7.82	6.99	6.17
Internet cafés		34.43	32.83	27.55	32.83	29.49	30.5	28.30
Markets	Supermarket	6.08	12.48	11.30	10.50	14.73	12.63	20.08
	Family mart	6.70	8.18	8.27	8.52	11.70	8.98	4.65
Restaurants	Large	105.17	99.14	123.88	123.47	142.97	121.68	175.25
	Medium	71.23	46.38	57.17	51.55	52.63	53.31	79.23
	Small	4.24	5.98	4.76	4.83	4.95	6.12	4.60
Microfinance agencies		15.10	13.98	14.95	11.02	8.80	8.50	0.00
Schools	Universities	44.35	61.95	29.70	52.35	38.95	30.70	20.75
	Institutes	15.35	12.79	16.13	13.13	10.51	14.34	8.83
	Primary schools	18.66	14.50	16.10	13.20	12.50	12.00	00.0
Shops	Clothing shops	1.49	1.60	0.35	3.00	1.48	0.55	1.93
	Groceries	4.83	5.05	5.05	3.68	8.35	2.80	3.75
	Phone shops	2.05	3.68	2.55	3.18	2.25	3.13	1.83

5.2.2 Commercial solid waste composition in Phnom Penh city

5.2.2.1 Composition of commercial solid waste in Phnom Penh

Fig. 5-2 represents the composition of commercial waste in Phnom Penh city. The results showed that biodegradable waste is predominant, followed by plastics and paper; and inorganics. Commercial waste composition consists of 56.70% (biodegradable), 19.32% (plastic), 14.84% (paper), 8.14% (inorganics), 1.25% (textile & shoes), 0.25% (rubber & leather), and 0.01% (wax) (Fig 5-2). Comparing to household composition indicated that the main difference is biodegradable waste, commercial sector produced less organic waste than household waste (66.8%) (Mongtoeun, 2014).

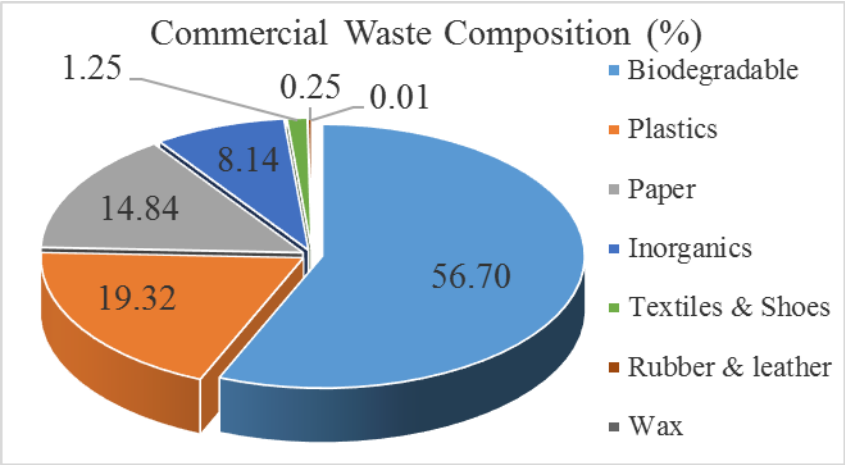

Figure 5-2. Composition of commercial solid waste in Phnom Penh

5.2.2.2 Commercial waste composition by category

Table 5-3 shows the composition of each category and sub-category of commercial waste collected in Phnom Penh city. The largest component was food waste (over 60%) followed by plastic and paper in similar proportions (15-20%) and glass (4.5%). This is similar to the results of previous research on household solid waste conducted by Mongtoeun et al., (2014). However, Phnom Penh restaurants, beer gardens, internet cafés, groceries and 3-star hotels produced more food waste (between 60-70%), than restaurants (53.4%) and hotels (57.8%) in Kathmandu, Nepal (Dangi et al., 2011). On the other hand, ministries, the council of ministers, microfinance agencies and large guesthouses in Phnom Penh produced less food waste (30-40%) - similar to the figure of 38.6% for schools in Kathmandu, Nepal (Dangi et al., 2011). Family marts in Phnom Penh produced most glass bottle waste (15.23%), followed by beer gardens (10.61%) and restaurants (5.62%). This was because family marts did not separate out glass bottles before collection, while beer gardens and restaurants did (but some glasses were still discarded with other waste). Microfinance agencies (offices) produced the highest percentage of paper waste (32.85%), followed by

ministries (offices) (23.92%), schools (19.71%) and hotels (18.87%). However, up to 70% of this paper (on average) was not recyclable. Recyclable paper mainly came from microfinance agencies (14.18%), and ministries (8.69%). In their report, JICA found that offices generated most paper waste (29.5%), along with schools (22.7%) (JICA, 2005).

Table 5-3. Waste categories and sub-categories, by source

Waste Category (%)		Micro finance	Internet cafés	Restaurants			Beer Gardens	Guesthouses		Hotels		Markets		Shops			Schools			Ministries	Council of ministers
				Large	Medium	Small		Large	Medium and small	3-star	Small	Super markets	Family mart	Clothing	Grocery	Phone	Universities	Institutes	Primary Schools		
Organics	Food	35.15	72.28	68.71	63.11	72.21	59.70	39.10	49.22	57.74	43.09	48.15	49.60	45.98	60.58	46.94	48.03	46.60	44.57	25.66	31.54
	Yard waste	0.62	0.04	0.79	-	0.92	0.39	1.61	4.14	2.57	3.67	4.67	0.07	0.03	-	1.59	0.07	0.81	4.71	24.99	33.05
	Wood/bamboo	0.42	0.06	0.83	0.08	0.28	0.15	0.38	0.49	0.33	0.19	0.17	0.71	0.48	0.31	0.90	0.54	0.36	0.49	0.28	0.14
	Charcoal	-	0.02	1.25	0.35	0.21	0.06	0.04	0.01	-	-	-	-	-	-	-	-	-	0.06	-	-
	Other organics	1.15	0.09	0.11	0.01	-	0.02	1.63	1.16	2.46	1.12	0.20	0.21	-	-	2.07	0.57	0.03	3.76	0.01	-
Paper	Recyclable	14.18	0.48	0.93	0.05	0.08	0.31	3.29	2.21	1.88	4.41	3.71	4.77	0.30	5.67	2.93	1.09	2.85	0.31	8.69	2.15
	Non-recyclable	18.67	11.66	8.41	9.14	6.05	16.70	14.98	7.81	9.69	21.25	8.59	9.42	10.64	4.49	7.86	19.15	19.69	16.08	15.23	12.18
Plastics	PET bottles	2.49	0.58	0.72	0.25	0.43	0.30	2.07	5.35	1.06	0.40	0.29	4.41	3.04	0.61	-	1.28	1.35	1.79	1.35	1.16
	HDPE	4.06	0.64	1.68	1.99	0.96	0.82	5.31	6.73	2.82	6.41	1.17	2.41	10.14	2.09	1.90	7.94	4.82	4.54	2.06	1.71
	Plastic film	0.03	0.01	0.28	0.01	-	-	0.34	-	0.01	-	0.41	0.29	-	-	0.28	-	-	-	0.03	0.02
	Plastic bags	12.07	7.68	7.22	9.02	11.77	7.58	17.29	17.54	10.45	15.27	8.46	12.14	21.01	20.22	24.36	12.14	17.83	17.06	11.10	9.35
	Plastic foam	0.88	0.04	0.06	0.07	0.32	0.24	1.25	1.27	0.25	0.17	0.98	0.35	1.59	0.72	2.29	0.69	1.25	1.40	0.79	0.46
Metals	Steel	0.17	0.63	0.52	0.35	0.09	0.51	1.03	1.24	1.42	0.48	0.17	0.52	-	2.30	0.23	0.81	0.32	0.15	0.59	0.62
	Aluminum	0.05	0.03	0.35	0.23	0.92	0.91	0.52	0.31	0.11	0.21	0.17	0.59	3.72	-	0.03	0.05	0.02	0.23	0.06	0.10
Inorganics	Electronics	1.02	-	-	0.01	-	0.02	0.15	0.11	0.01	-	0.83	-	-	-	0.04	0.01	-	-	0.33	0.06
	Stone, ceramics	0.24	2.19	1.46	1.07	0.27	0.83	4.48	0.59	0.54	0.21	-	0.37	-	0.45	2.98	4.29	0.89	0.65	3.61	1.46
	Batteries	-	-	-	-	-	0.24	0.05	0.01	0.03	0.11	0.21	0.47	-	-	0.09	0.01	0.02	0.03	0.03	0.02
	Glass	0.82	3.22	4.34	12.14	0.38	10.61	4.95	0.55	4.65	0.98	17.41	13.06	2.56	-	0.34	1.90	0.53	0.25	2.90	4.32
	Ash, dirt	-	-	1.84	1.10	4.52	-	-	-	-	-	-	-	-	-	3.58	0.17	-	-	-	-
	Others	4.69	0.03	0.21	0.64	0.15	0.15	0.54	0.06	1.34	0	3.67	0.01	0.08	0	0	0.3	0.22	0.21	0.12	0.07
Textiles		3.04	0.23	0.28	0.35	0.40	0.44	0.70	0.51	2.58	1.27	0.69	0.52	0.40	2.56	1.57	0.45	2.35	2.40	2.10	1.33
Rubber, leather		0.26	0.10	-	0.04	0.07	0.01	0.20	0.64	0.06	0.52	0.04	0.07	0.04	0.01	0.01	0.50	0.04	1.29	0.03	0.20
Wax		-	-	0.01	-	-	-	0.09	0.05	-	-	-	-	-	-	-	-	0.01	-	-	0.06
Total Percentage		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

5.2.3 Waste sorting rate, sorted waste and recyclable materials, by source

Fig. 5-3 shows the relative proportions of sorted waste and unsorted waste collected from each source. The results indicate that internet cafés and restaurants carried out most sorting of waste, followed by markets (family marts), schools, beer gardens and guesthouses. Most of the sorted waste from internet cafés and restaurants was food waste. The main reason for sorting this food waste was for subsequent use as animal feed rather than composting. On the other hand, hotels, shops and microfinance agencies carried out relatively little sorting of waste. Due to the difficulty and complexity of data collection, the amounts of waste sorting carried out at ministries and the council of ministers were unknown.

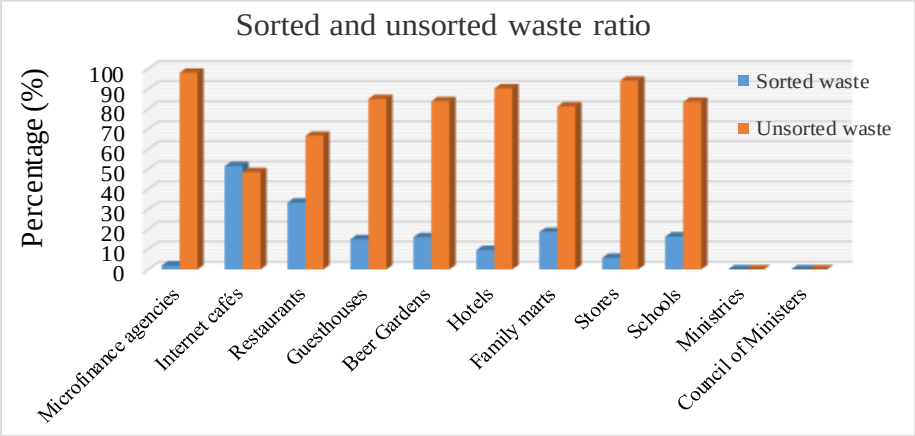

Figure 5-3. Relative proportions of sorted and unsorted waste, by source

Table 5-4 shows the percentages of sorted waste, by sector, set aside for selling and the percentages of recyclable materials found in the remaining unsorted commercial waste. The results indicate that most sorted waste was food waste, followed by glass bottles, PET bottles, paper aluminum cans and steel. Most recyclable materials remaining in the residue were paper, followed by HDPE, PET, steel and aluminum cans (see details in Table 5-4). The sorted food waste was collected by farmers for use as animal feed, mainly for swine. This food waste from internet cafés and restaurants was collected daily by farmers. However, due to the irregularity of such food waste collection at present, some owners have now refused to supply food waste anymore, which means that more food waste is being disposed of. If all food waste was completely sorted and treated, 51% of current commercial solid waste could be an be minimized through composting or animal feed and the recovery of other recyclable materials such as paper, plastic, glass, aluminum cans and steel, even in small amounts, could contribute to a further waste reduction of

approximately 10%. The Municipality of Phnom Penh should, therefore, promote food waste recycling for commercial waste.

Table 5-4. Generation rates, sorted waste and recyclable material percentages

Generation Sources		Waste generation		Sorted waste by sector for selling (%)						Remaining recyclable materials in residual (%)				
						PET		Aluminum				PET		Aluminum
		kg/day	kg/cap	Food	Paper	bottle	Steel	cans	Glass	HDPE	Paper	bottle	Steel	cans
Microfinance agencies		16.58	0.08	0.00	0.00	0.74	0.00	0.75	0.00	3.08	10.76	1.89	0.13	0.04
Internet café		93.26	1.31	27.31	0.86	0.42	1.08	0.42	3.24	0.20	0.15	0.18	0.20	0.01
Restaurants	Large	197.78	2.14	10.78	0.87	0.46	0.08	1.01	6.86	0.96	0.54	0.41	0.30	0.20
	Medium	101.52	0.73	13.84	1.42	0.46	0.43	0.65	8.31	0.92	0.02	0.12	0.16	0.10
	Small	12.19	0.26	25.92	0.00	0.52	0.00	0.84	0.00	0.41	0.03	0.18	0.04	0.39
Guesthouses	Large	38.38	0.63	0.00	0.00	0.39	0.52	6.13	23.11	0.30	0.11	0.11	0.19	0.33
	Medium and small	10.45	0.39	0.00	0.00	12.09	0.00	1.71	0.00	3.02	1.87	1.18	0.59	0.29
Beer Gardens		74.88	0.84	0.00	0.00	0.00	0.00	0.29	0.00	4.43	1.45	3.52	0.82	0.20
Hotels	Three-star	45.51	0.43	0.00	0.49	2.22	0.19	0.73	0.00	2.27	1.52	0.86	1.15	0.09
	Small	10.05	0.23	0.00	0.00	7.80	0.00	3.19	0.00	3.97	2.73	0.25	0.30	0.13
Markets	Supermarket	18.84	0.20	0.00	0.00	1.07	0.00	0.96	13.75	0.71	2.26	0.18	0.11	0.10
	Mini mart	13.66	0.25	0.00	2.66	1.35	0.24	4.95	2.77	1.43	2.83	2.62	0.31	0.35
Shops	Clothing shop	2.42	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.24	2.42	0.00	2.96
	Grocery	7.76	0.15	0.00	6.81	1.81	0.00	3.31	0.00	1.29	3.50	0.38	1.42	0.00
	Phone shop	3.14	0.06	0.00	0.00	1.14	0.00	0.00	0.00	1.68	2.60	0.00	0.21	0.02
Schools	Universities	70.15	0.04	0.00	7.98	2.33	0.00	1.18	0.00	4.92	0.67	0.79	0.50	0.03
	Institutes	30.22	0.04	0.00	3.73	11.12	5.34	0.96	0.00	2.26	1.34	0.63	0.15	0.01
	Primary schools	18.27	0.01	0.00	0.00	1.85	0.00	0.30	0.00	3.59	0.24	1.42	0.12	0.18
Ministries		80.80	0.19	0.00	0.00	0.00	0.00	0.00	0.00	1.61	5.95	1.06	0.48	0.06
Council of ministers		203.80	0.13	0.00	0.00	0.00	0.00	0.00	0.00	1.56	1.96	1.06	0.56	0.09
Average (%)		**52.48**	**0.41**	**6.10**	**1.13**	**1.05**	**0.34**	**0.85**	**3.51**	**1.77**	**1.54**	**0.87**	**0.42**	**0.13**

5.3 Discussions

The results obtained from our study of commercial waste generation and the composition of waste in Phnom Penh city, Cambodia, can be used to determine the waste generation rate and assess the potential for the recovery of recyclable materials from each source - allowing the most appropriate treatment technologies to be evaluated. There are many kinds of waste disposal including source reduction and reuse, animal feeding, recycling, composting, fermentation, landfills and incineration. However, among them, landfill is the most popularly used methods of waste disposal. But it is becoming less due to the lack of space available, GHG emissions and other environmental contamination. In Phnom Penh, all kinds of waste from households, commercial sectors, institution and street sweeping are mixed together, collected and disposed of at a dumping site or landfill. There is only one landfill in the whole city with poor control, management and monitoring. This type of waste disposal could be harmful to human health and the environment due to the prevalence of vector-borne diseases (flies, rats, cockroaches, etc.), water pollution (leachate), air pollution (GHGs), and so on. Furthermore, disposal at landfill sites is becoming more challenging because the lifespan of available landfill sites is limited. However, while new landfill sites are needed, finding them is difficult because the price of land is soaring. Therefore, to ensure better

waste management throughout the city, it is vital to study the generation and the composition of waste in order to select an effective waste management system. Based on the results of waste characterization obtained, a system for reducing, recovering and recycling food waste could be one way to reduce the amount of waste currently going to landfills. With regard to the treatment of commercial solid waste in Phnom Penh, this could include separation activities to produce animal feed from food waste, composting, and anaerobic digestion from all kinds of organic matters and the recovery of other recyclable materials such as paper, PET bottles, aluminum cans and steel. In particular, the composting of food waste and other organic materials might be the most appropriate option for CSW treatment since it is low cost and simple to implement. Composting has many beneficial environmental effects, including the improvement of soil health and structure, and a reduction in fertilizer and pesticide consumption. An additional benefit of food waste utilization is that it can lead to a reduction in GHG emissions, since organic decomposition in aerobic conditions produces more CO_2 than CH_4. If all food waste was completely sorted and treated, a reduction of approximately 51% in current commercial solid waste could be achieved through composting and use as animal feed. Other recyclable materials such as paper, plastic, glass, aluminum cans and steel, even in small amounts, could contribute to a further reduction of approximately 10%. The Municipality of Phnom Penh (MPP) should, therefore, promote food waste recycling for commercial waste and recycling activities for other recyclables. The incineration of waste is another effective method to treat municipal solid waste, especially in developed countries. However, the results of a study on household solid waste in Phnom Penh conducted by Mongtoeun (2014) indicated that its calorific value (less than 1000 kcal/kg) was too low and its moisture content (63%) was too high for efficient incineration. Since both commercial and household solid waste have similar composition and characteristics, it is hard to incinerate such waste efficiently. Incinerating commercial waste with a high food content is normally considered inappropriate but, with food waste excluded, combustion would then become possible.

5.4 Conclusions

This study surveyed and characterized the waste produced by various commercial sources in Phnom Penh, including hotels, restaurants, schools, shops, beer gardens, offices, internet cafés, guesthouses, and microfinance agencies. The waste from 52 commercial sources was collected daily, weighed, then separated into 23 categories and the results

recorded. A waste characterization analysis showed that organic waste predominated, with food waste being the largest single component. Recyclable materials, sorted by source, consisted mainly of food waste, followed by glass bottles, PET bottles, papers, aluminum cans and steel. Therefore, the potential for making use of recyclable materials is largest for food, followed by plastics, paper, steel and aluminum cans. However, aluminum cans are usually separated out in most sectors before waste collection occurs, so the residual percentage is low. Likewise, most PET bottles are also separated out before waste collection in guest houses, schools and hotels. Overall, it was found that most sorting activities were carried out in internet cafés, restaurants and schools, and less sorting was carried out in hotels, shops, and microfinance agencies. Such separation activity should be encouraged more. These results could also influence discussions regarding possible countermeasures that could be used to reduce the amount of the commercial waste destined for landfills.

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CHAPTER VI

DESIGN OF APPROPRIATE MUNICIPAL SOLID WASTE MANAGEMENT IN PHNOM PENH

6.1 General

Municipal solid waste management (MSWM) has so far been the most ignored and least studied area in environmental sanitation in Cambodia, as well as in other developing countries. But at the present time, the concern is growing in both at the governmental and other levels for the effective and economic management of solid waste. Before the collection and disposal of solid waste was only of technical and economic significance. Now, however, recovery and recycling are considered important management tools for SWM. The major impediments to appropriate solid-waste management are deficiencies in awareness, technical knowledge, and legislation.

Municipal solid waste issues in the developing countries could be one of the most complicated and cumbersome task. It has been estimated that about 20 to 30% of the waste generated in the cities of Asia Pacific region, are recycled by the informal sector. For example, in Phnom Penh, Cambodia is 9.3% (JICA, 2005) and in Bangladesh is about 4-15% of the total solid waste generated (Iftekhar et al., 2005), while in industrialized countries is undertaken by the formal sector, driven by law and a general public concern. Recently, the importance of recycling is being acknowledged. Few NGOs and community based organizations (CBOs) are actively working on 3R related issues. A long-standing practice and a complex networking of informal source separation and recycling of materials still exist. In most cases, they were compelled to focus more on reusing and recycling of waste than on source reduction.

Municipal solid waste generation has both pros and cons, but the fact of the matter is that it is impossible to live without producing some waste. Mass-production and mass-consumption by human beings have resulted in depletion of natural resources, degradation of environmental quality, pollution, global warming and human health impact. For the purpose of reducing amount of waste generated, Japan has established “Sound Material-Cycle society”, “sustainable society” and “3R (reduce, reuse and recycle)” for solid waste management (Tanaka, 1999). Municipal solid waste in Cambodia, especially Phnom Penh, is being generated at an increasing rate as a result of fast economic development and

urbanization. However, reliable data on municipal solid waste generation is rare and unreliable. The data on waste generation and composition vary among each source. Our results found that organic waste (mainly food waste), more than 60%, generated throughout the chain of food production, distribution and preparation accounting for the largest volume of the total waste. This organic waste generates greenhouse gases (GHGs), mainly methane gas, and leachate which can contaminate ground and surface water and degrade other environmental quality when disposed in dump sites or landfills. Open dump sites are a common practice of waste disposal in Cambodia, except in Phnom Penh has sanitary landfill. Therefore, the minimization of organic waste should be considered and promoted in Cambodia, while most recyclable materials were sorted out by each source. So there is no concerns regarding to recyclable materials.

Evaluation of appropriate technology for urban organic waste utilization is introduced alongside essential information for decision-making of local governments, such as technical and social advantages and disadvantages, and investment, operation and maintenance costs. The information on how to select the most appropriate technology suitable are mentioned in the next section and a set of recommendations on environmental-related social issue for local circumstances are provided in chapter 7.

The purpose of this chapter is evaluate the appropriate waste treatment options which can apply for the current situation of municipal solid waste (household solid waste and commercial solid waste, etc.) in Phnom Penh, Cambodia. The scenarios for waste treatments including: i) source separation, ii) animal feed, iii) composting, iv) recycling, v) anaerobic digestion, vi) sanitary landfill, and vii) incineration.

6.2 Current waste management and policies in Cambodia

6.2.1 Legislation and regulation on solid waste management

The government of Cambodia notified The law on the environmental protection and natural resources management, Article 13 and the sub-decree No. 36 (Article 1, 4, 11) on solid waste management in April 1999. This sub-decree is the fundamental law of solid waste management. It applies to all activities related to disposal, storage, collection, transport, recycling, dumping of household and hazardous waste. Based on this sub-decree, the Ministry of Environment (MoE) shall establish guidelines on disposal, collection, transport, storage, recycling, minimizing and dumping of household waste in provinces and cities in order to ensure the proper management of household waste (MoE, 1999).

According to this sub-decree, the authorities of the provinces and cities shall establish the waste management plans in their province and the city for short, medium and long terms. In addition, they are responsible for collection, transport, storage, recycling, minimizing and disposal of waste. As a supplement to the sub-decree on solid waste management, Ministry of Environment (MOE) and Ministry of Interior (MOI) issued a ministerial declaration (Prakas) no. 80 (Article 1, 2) in 2003 (Interministerial MOI/MOE, 2003). The objectives of this declaration are to improve the responsibility of an authority and involve institutions for efficient implementation of solid waste management in provinces and cities of the Kingdom of Cambodia, aiming to protect human health, environmental quality, scenery and biodiversity. The declaration clearly stated that disposal of waste in public spaces, streets and canals is illegal. In addition, local governments are required to provide sufficient waste bins, arrange "forbidden" signs and educate the residents on proper waste management, establish temporary waste stock (collection points), and clean and regularly dispose the generated solid waste in their administrative areas. Unfortunately, the detailed regulations, standards and guidelines, which have to be established based on the above sub-decree and declaration, are not yet complete due to lack of personnel capacities and budget constraints.

6.2.2 Integration of 3R strategy in solid waste management

In 2008, the Ministry of Environment (MoE), with support from the United Nation Environment Programme (UNEP), drafted a strategy on the 3Rs (reduce, reuse, recycle) for sustainable solid waste management in the Kingdom of Cambodia (Appendix II). The Cambodian national 3R strategy aims to establish an efficient solid waste management system through increased waste collection service, promote waste separation for recycling, enhance organic waste composting, and improve disposal sites. By 2015, the government plans to compost 20% of organic waste from all sectors. By 2020, the government plans to increase composting of organic waste from households by 40% and from business sectors by 50%. The 3R concept is very new to Cambodian national and local officials. Therefore, the Government of Cambodia plans to i) establish the 3R policies and regulations for waste management at national and local levels based on the existing environmental legal instruments and related statues, ii) organize capacity building programs for government officials, iii) implement pilot projects in the selected urban area, iv) disseminate knowledge and implicate the 3R policies and regulations in public and private sectors, and v) integrate the 3R initiatives into the national policy development.

6.2.3 Integrated Solid Waste Management (ISWM), Why Need for ISWM?

Cities are facing an increasing growth in population, GDP growth, urbanization, changing lifestyles and consumption patterns, resulting in increasing quantities of waste with the quality and composition of waste becoming more varied and changing. Industrialization and economic growth has resulted in producing more amounts of waste, including hazardous and toxic wastes. There is a growing realization of the negative impacts that wastes have had on the local environment (air, water, land, human health, etc.). Complexity, cost and coordination of waste management has necessitated multi-stakeholder involvement in every stage of the waste stream. This calls for an integrated approach to waste management. The coverage of ISWM in a management system covers all aspects of waste management; from waste generation through collection, transfer, transportation, sorting, treatment and disposal. Data and information on waste characterization and quantification (including future trends), and assessment of current solid waste management system for operational stages provide the basis for developing a concrete and locality-specific management system.

The composition of MSW differs from one country to another and place to place and it plays a significant role in determining and designing an appropriate technology for treatment and allocating the space needed for treatment facilities. The MSW generated in most developing Asian countries is dominated by biodegradable organic fractions which accounts for more than 40% with the moisture content more than 50% (AIT, 2004). Most of the developing Asian countries are in a budding stage when it comes to implementing 3R technologies. Such practices have been prompted by some private sector and NGOs to initiate recycling and proper waste management strategies.

According to Imura et al. (2005), high population growth and urbanization coupled with rapid economic growth greatly accelerates consumption rates in Asian developing cities. These consumption patterns have contributed to the increase in municipal solid waste generation and to changes in waste composition. For instance, the urban areas of China generated about 190 million tons of MSW in 2004. The recent Environment Monitor report prepared as part of the study estimated that Shanghai alone has 10% organic waste diversion through composting, and the remaining 90% land filled (World Bank, 2005).

In some Asian cities, expenditures on Municipal Waste (MW) can reach 40% of the municipality's operating budget and out of this, 70-90% is spent on waste collection. For

instance, Metro Manila in the Philippines annually spends $ 64 million on garbage collection and disposal (ADB, 2004). Cities and/or municipalities in high-income member countries are increasingly becoming comparable to that of western countries in terms of quality and quantity of waste generation. Developed countries generate waste more than 1 kg/capita/day while developing countries is about half of that.

6.2.4 3R implementation

The growth of a city is characterized by an increase in its economic and developmental activities that are typically driven by the production and consumption patterns. Over the years, these activities have been mapped with the manufacturing and construction activities. The improved standards of living and the extent of commercialization in the cities have significantly changed the consumption patterns and thereby the waste composition. The inability to fully grasp the problems of waste generation and characterization have resulted in transforming Solid Waste Management as one of the most compelling problem of urban environmental degradation. The composition of MW in advanced countries is highly inorganic and non-recyclable while cities of developing Asian countries, MW is generally organic and recyclable. The household waste contains biodegradable waste (such as vegetables, leftover foods), non-biodegradable materials (such as plastics, rubber), and hazardous material (like used batteries); thereby rendering it to be a complicated situation to handle.

There is also a dire necessity to integrate the informal sector (comprising of rag pickers, illegal or unauthorized recyclers) into the mainstream waste management process as they handle a substantial amount of waste generated, without the requisite environmental safeguards. A plausible solution to waste management would be an integrated approach which would include collective management of all types of wastes and implementation of the **3Rs** (Reduce, Reuse and Recycle) policies and strategies. However, in Cambodia 3Rs is a new concept which is difficult for people adaptation. Waste separation at source is voluntary works, but only salable materials are high sorted out in purpose of economic term. Organic waste normally they do not separate for household. Few hotels and restaurants have separated the food waste for animal feed collected by swine raisers, but in low percentage.

6.3 Current organic waste management

In Cambodia, there are four major cities namely Phnom Penh (capital city), Battambang, Siem Reap and Kampong Cham. The data on quantity and composition of municipal solid waste is not systematically collected and also out of date. The available information of municipal solid waste is mostly elucidated of Phnom Penh and in a few major cities are mentioned, even not details. The information is normally different from one source to another. For instance, the Ministry of Environment has reported that waste generation in Cambodia is approximately 520,000 tons/year (food waste~312,000 tons/year) (Sokha, 2008). In 2009, a survey conducted by Cambodian Education and Waste Management (COMPED), interviewing the waste collection companies and the local government officials in four major cities, assumed that waste generation in these cities is 1,465 tons/day or 534,725 tons/year which is slightly higher than the report of MoE (Table 6-1). Therefore, it is construed that the quantity of waste generation in Cambodia is underestimated. Consequently, environmental problems which are related to improper waste management would be higher than the expectations. Comparing with the four cities, Phnom Penh produced more waste than small cities regarding to urbanization and fast development.

Table 6-1. Municipal solid waste generation and collection in major cities of Cambodia, 2009

Cities	**Population (persons)[a]**	**Waste generation (ton/day)[b]**	**Waste collection (ton/day)[b]**	**Payment rate for waste collection service (%)[b]**
Phnom Penh	1,325,681	1,200	1,005	80
Battambang	143,656	100	51	20
Siem Reap	174,265	115	115	N/A
Kampong Cham	63,771	50	35	10

[a] Population census, 2008
[b] COMPED, 2009

In 2009, COMPED investigated waste composition at the disposal sites in Phnom Penh (landfill), Kampong Cham (open dump), Battambang (open dump), and Siem Reap (open dump) and in 2012, Mongtoeun also conducted a study on household solid waste characterization in Phnom Penh. The results were found that food waste generation is the highest (Table 6-2). The composition of the generated waste composed of food [63% (JICA, 2005), 70% (IGES, 2011), 66% (Mongtoeun et al., 2013)] in Phnom Penh, 71% in Battambang, 54% in Siem Reap, and 60% in Kampong Cham. Average of food waste generation in Cambodia was 64.1 %, and in Phnom Penh was 66.5%.

Table 6-2. Waste composition in major cities of Cambodia

Cities	Waste composition (%)							
	Food	Plastic	Paper	Metal	Textiles	Glass	Wood	Other
Phnom Penh[a]	63.3	15.5	6.4	0.6	-	1.2	-	13.0
Phnom Penh[b]	70.0	6.0	5.0	2.0	3.0	2.0	6.0	6.0
Phnom Penh[c]	66.3	10.4	4.5	3.0	1.0	1.4	0.7	13.0
Battambang[b]	71.0	10.0	2.0	3.0	2.0	4.0	6.0	2.0
Siem Reap[b]	54.0	11.0	6.0	1.0	3.0	3.0	11.0	11.0
Kampong Cham[b]	60.0	12.0	5.0	1.0	1.0	2.0	3.0	16.0
Average	**64.1**	**10.8**	**4.8**	**1.8**	**3.2**	**2.3**	**4.5**	**10.2**

[a] JICA, 2005
[b] IGES report, 2011
[c] Mongtoeun et al., 2013

6.3.1 Waste separation at source

Until now, there has been no mainstream waste separation at the generation source practiced in Cambodia. Separation of recyclable waste was carried out on a voluntary basis due to an indirect influence caused by increasing the economic value of sellable waste. Waste pickers/scavengers play an essential role in removing/separating sellable waste from waste bins/collection points and at disposal sites (landfills). For instance, more than 2,000 waste pickers are working at both the downtown and the disposal site of Phnom Penh, helping reduce waste buried in landfill. Table 6-2, food waste is predominant, that has no value in the recycling market occupies the landfill – making it difficult to separate sellable materials, emitting foul odor and greenhouse gases, making a place full of disease carriers/vectors for surrounding residential areas, and polluting/contaminating the soil and water environment. However, the result of questionnaire shows high willingness to separate organic prior discharge, but the point that the waste will be mixed while collecting. Because the Municipality of Phnom Penh (MPP) MPP has no any facility to treat organic waste. So in the next sections, organic waste is discussed in more details.

6.3.2 Utilisation of organic waste

Generally, the utilisation of organic waste is very low in Phnom Penh and Cambodia as a whole. Organic waste is utilised for two main purposes including animal feed and composting. However, only a low percentage of food waste from restaurants is collected for animal feed with an irregular basis. Also, only two composting facilities have been operated by NGOs, the Community Sanitation and Recycling Organization (CSARO) and Cambodian Education and Waste Management (COMPED) in a small scale. With respect to animal feed, some farmers claim that direct feeding of food waste is not favourable

compared with instant feed in terms of growth rate. In addition, there is also a concern on animal health due to the poor quality of food waste. Therefore, it is necessary to process food waste to a suitable standard for animal feed.

For the composting facility, COMPED established a windrow composting facility at the old disposal site (Steung Meanchey Dump Site-SMCDS) of Phnom Penh, but the performance was stopped in 2008. A new composting plant was constructed in Battambang in 2009 and it has been operating from April 2010. In Phnom Penh, some household composting is promoted by CSARO. The composting plant by CSARO in Phnom Penh has operated at a rate of 5 tons/day (1,800 tons/year) of organic waste (vegetable waste) from market (Deum Kor market) which accounts for 0.4% of Municipal Solid Waste (MSW) or 0.7% of food waste generated in this city, as a result it produced about 1 ton of compost product in a day.

6.4 Impacts of improper organic waste management and climate change

Environmental impact, climate change and global warming have become a matter of concern over the last decades. Decomposition of organic waste under anaerobic condition (without oxygen) in a landfill can generate greenhouse gases (GHGs) such as CH_4, CO_2 and N_2O. Under the United Nations Framework Convention on Climate Change (UNFCCC) through the Kyoto Protocol, the developed countries have agreed to reduce emissions of greenhouse gases. Methane is the most serious GHG emitted from the waste sector, since its global warming potential is more than 21 times higher than carbon dioxide reported by the International Panel on Climatic Change (IPCC, 2006). Methane generation per kilogram of organic waste varies depending on the extent of absence of oxygen and the type of organic waste. For example, one kilogram of food waste can release 0.42 kgCO2eq when it is dumped into an unmanaged shallow landfill (<5 m depth), but the emissions can be as high as 1.05 kgCO2eq if the same amount of waste is disposed on a deep compact landfill (> 5 m depth) (IPCC, 2006; Sang-Arun and Bengtsson, 2009). Cambodia has low capacity to invest in landfill gas capture; therefore, most of the methane from landfills and dump sites is released directly to the atmosphere. Based on amount of waste generated in Table 6-1, it is estimated that methane emissions from landfill of organic waste in four major cities in Cambodia was approximately 360,000 tons CO2eq in 2008 (assuming disposal in unmanaged deep landfills). Currently, the population growth, urban development and economic growth are increasing, resulting in increase of waste amount.

Collected wastes (mostly organic waste, >60%) are disposed at landfill (Dangkor landfill) (Mongtoeun et al., 2014).

6.5 Urban organic waste utilization technologies

There are many technologies being developed for utilising urban organic waste. It is very difficult for local governments and project developers to select the most suitable technologies without knowing the advantages and disadvantages of such technologies. The evaluation of appropriate technology is based the characteristics of the waste such as waste generation, composition, moisture content, calorific value and the like. The results of our research on characteristics of solid wastes (household and commercial solid waste) are mentioned in details in chapter 4 and 5. This information can be used as a guide in selecting some technologies that are applicable for urban organic waste treatment. Technology that is suitable for the current situation of Phnom Penh waste is discussed and examples of some waste utilisation techniques are presented below.

6.5.1 Waste reduction/prevention

Waste reduction is the most fundamental strategy to achieve sustainable waste management. Therefore, waste management authorities should make efforts to reduce the amount of waste generated at source. This practice could avoid waste generation at all stage of waste management. Waste reduction has benefits on saving resources and reducing costs for waste collection and treatment. The significance of waste reduction in developed countries is now well recognized (OECD, 2000), while in developing countries is not. There is less scope for waste reduction in most developing countries as their per capita waste generation rate is still at relatively low levels, anyway it keeps increasing, becoming a concern in near future. In these countries, however, there are a growing number of people, especially in urban areas, who generate as much waste as people in industrialised countries. Significant waste reduction requires active participation from large numbers of households by changing their consumption patterns and daily habits.

6.5.2 Animal feed

The use of food waste for animal feed has been practised for as long as humans have kept domestic animals. This practice is still common in rural areas, but mostly very limited in large cities. In Cambodia, food waste collection for animal feed is practiced by some farmers as it reduces the cost of the feed. Sometimes, the growth rate of animals raised by

food waste is slower than that of those using instant feeds. Also, there is a concern about animal health risk. Therefore, the use of food waste for animal feed is limited, and the addition of high nutrient feed is required in order to increase nutrient balance and competitiveness with instant feeds. Unfortunately, the traditional practices of using food waste for animal feed remain relatively low. Food waste from some restaurants was separated and collected by animal raisers who live nearby in the city.

6.5.3 Composting

Composting is a technique to enhance the degradation of organic matter under aerobic condition. This technique generates carbon dioxide, water and humus (compost). Major factors influencing composting process are the ratio of carbon and nitrogen (C/N) of 25:1, as well as temperature, oxygen, moisture and microorganisms. Moisture content should be maintained at 40-60%. Composting can reduce the volume of the waste, generally by 30-50%. The residual product, compost, is pathogen free. It is applicable for improving soil structure and making soil more fertile. Compost helps to improve the water-holding capacity of the soil. The use of compost can also reduce expenses for chemical fertiliser. There are three kinds of common composting: windrow composting, aerated static pile composting and in-vessel composting.

Composting has been practiced for a long time in rural areas. In general, composting is technically uncomplicated and may be an economically realistic alternative for many municipalities in Cambodia. It can be applied at various scales, from individual households, backyard composting, to large centralized facilities. However, there are some risks and disadvantages of composting; bad smells and vector-borne diseases can spread if the composting process is poorly managed. Under well-managed conditions, composting does not generate methane, reducing to global warming impact. Small emissions of nitrous oxide (N_2O) may occur if vermin-composting is employed (Hobson et al., 2005). Nevertheless several environmental agencies have concluded that when composting is done properly, it generates very small amounts of GHGs (MFE, 2002).

6.5.4 Anaerobic digestion

Anaerobic digestion (AD) is one of the main options for processing the biodegradation organic materials in MSW. Anaerobic digestion is well recognised for the treatment of agricultural waste, organic industrial waste and sewage sludge. Only in recent years it has been used for municipal solid waste management. The degradation process

occurs under an oxygen-free environment and generates gases with a high proportion of CH_4 (60-70%), and CO2 (30-40%). Methane can be used as an alternative energy for cooking, lighting, generating electricity and fueling vehicles. The use of biogas can save labour for collecting fuel wood, make cooking more pleasant, decrease the health risk that is induced by the smoke of fuel wood and charcoal, avoid deforestation, reduce greenhouse gas emissions, and improve the sanitary conditions of households and cities. In addition, discharge from the anaerobic digester can be used for soil amendment.

Anaerobic digestion has many advantages over composting in terms of products, types of waste inputs and environmental impacts. This technology is available to treat both solid and liquid waste such as food waste, vegetable and fruit residue, animal manure, and sewage sludge. It generates fewer odours and requires less space than composting. However, the investment for anaerobic digestion is higher than composting.

6.5.5 Recycling

Recycling means collecting materials from waste stream to reuse them in place of virgin inputs in the manufacturing process, rather than being disposed of and managed as waste. Recycling of waste provides economic as well as environmental benefits, and also reduces reliance on virgin materials. Recycling programmes can reduce pollution, save energy, mitigate global climate change, and reduce pressures on biodiversity. Recycling of waste materials can give many benefits such as reducing the need for disposal (landfilling and incineration), preventing pollution caused by the manufacturing of products form virgin materials, saving energy, decreasing exploitation of natural resources, and finally helping sustain the environment for next generation. Recycling of materials from the municipal solid waste stream generally involves the following steps:

(i) Collection and processing the separated materials from community and individual households and transported to a place for further treatment or processing.

(ii) Sorting, baling and bulking for onward transfer to re-processors (e.g. at a Materials Recycling Facility (MRF)).

(iii) Reprocessing to produce marketable materials and products (Re- manufacturing)

There are two types of recycling cycle including closed loop and open loop. In a closed loop cycle, materials are recycled into same materials, such as aluminum can is recycled into new aluminum can. Open loop means that the secondary product is different than the primary product and often occurs when a material is degraded or changed by the recycling

process. In general, recycling credit is based on closed- and open-loop recycling depending on the materials.

6.5.6 Sanitary landfill

Sanitary landfill is a disposal site that has proper siting, design, operation and long term environmental impact control (Johannessen and Boyer, 1999). Basically, the sanitary landfill site should have an effective liner to prevent underground water contamination, effective leachate treatment infrastructure that reduce contamination into the environment, incorporate a full set of measures to control greenhouse gas emissions, apply a compaction measure for waste and use soil cover daily, and implement plans for closure and aftercare when landfill is closed. However, many recyclable materials such as metals, glass, paper, plastic are buried in landfill.

In a landfill, decomposition of biodegradable waste occurs in three stages. In the third stage of decomposition (after the landfill closed for years), methane (CH_4) is produced. Therefore, CH_4 can be captured as a usable energy source. Capture of methane for energy use is an alternative to reduce climate impact from landfills. Landfill gas consists of 40-60% methane and it has 50% fuel equivalent of natural gas. However, landfills that installed the landfill gas collection system covering all areas within one year after the waste is deposited can achieve 60-85% collection efficiency, with 75% in average (EPA, 2010). In developing countries, the collection system is not well installed due to budget constraints, so landfill gas recovery is very low, with a large percentage of methane leaking to the atmosphere. Therefore, in developing countries, this initiative is economically attractive under high fossil fuel costs, government support, charging of environmental impact, and carbon credit trading (e.g. Clean Development Mechanism, CDM).

Currently, open dump sites (semi-controlled dumps: no lining, no compaction, and no soil cover) are commonly practiced in Cambodia as a whole, except Dangkor landfill located in Dangkor district was operated in 2009. It is the most advance landfill in Phnom Penh Municipality. However, it is hard to call a sanitary landfill. Because it is poor controlled, managed and monitored. This system is, more or less, considered as 'semi-engineered landfill': liner and leachate treatment system existed, no soil cover and no landfill gas management. Therefore, it would be very difficult for local governments in Cambodia constructing and managing sanitary landfill without international aid.

6.5.7 Incineration/Combustion

A controlled burning process called combustion or incineration is primarily implemented to reduce waste volume. In addition, recovery of energy and recyclable materials also can made. The modern technology for waste-to-energy combustion was developed in Europe during 1960s-1970s (Reddy, 2011). Incineration is a waste treatment technology for destroying waste under controlled burning at high temperatures. It can effectively eliminate the hygiene hazards associated with organic waste as well as drastically decreasing the volume of waste. Methane generation is completely avoided and the process can also generate electricity and heat which can replace energy from fossil fuels. However, the incineration process can produce fossil based carbon dioxide from plastic burning, carbon monoxide, dioxins, heavy metals and other harmful substances.

Incineration of municipal solid waste is widespread in industrialised countries. However, only few developing countries are successfully incinerating municipal solid waste. Waste in developing countries typically has a high moisture content and low calorific value compared to that in developed countries. Therefore, extra fuel, typically coal, needs to be added (Solenthaler and Bunge, 2005). As a consequence, the recoverable energy is low and the cost is high. The investment costs for incineration plants are high compared to other options, and the technology used is advanced which requires highly skilled personnel for operation and maintenance. In many cities, incineration has met strong opposition because of emission of highly toxic dioxins and other pollutants. It is possible to reduce these emissions to very low levels by advanced flue gas treatment, but this makes the investment costs for incineration plants significantly higher.

6.6 Evaluation of waste treatment technologies

Different waste management technologies have the potential to reduce the amount of municipal solid waste disposed in landfills, in addition providing electricity, heat and reduce GHG emissions. Life cycle assessment (LCA) is one of the tools used in evaluating the coordination of a number of actions to recover material and energy and to reduce environmental impact through integrated solid waste management (ISWM). This tool quantifies the environmental impacts including GHG emissions and other pollutants accompanied by energy implications and the pros and cons of the various waste management technologies. Organic waste utilisation and treatment technologies can be divided into two levels i) Household and community level – waste reduction, animal feed,

composting, and anaerobic digestion, and ii) Municipality level a) Unsorted waste – open dumping, sanitary landfill, incineration, and b) Segregated organic waste– composting, anaerobic digestion.

Promotion of waste utilisation and treatment at household and community levels could reduce the expenses for waste collection, transportation and disposal. However, budget allocation for mainstream education, training, and implementation is required. Table 6-3 describes advantages of technologies versus indicators on environmental impacts, greenhouse gas emissions, utilization and job creation. Waste reduction could reduce costs for the whole system of waste collection, transportation and disposal; however it requires active cooperation from citizens. Waste reduction is an economic incentive for individual households, but it does not recreate jobs for low-income and non-skilled labourers. Composting, anaerobic digestion, recycling and animal feed are the effective methods to manage municipal solid waste.

Table 6-3. Advantages and disadvantage of waste utilization and treatments options

Treatments / Advantages	Source reduction	Animal feed	Composting	Recycling	Anaerobic digestion	Sanitary landfill	Incineration
Creating jobs	×	×	○	○	○	○	○
Avoiding environmental impacts	○	○	○	Δ	Δ	○	○
Recovery of recyclable material	Δ	×	×	○	×	×	×
Recovery of energy	×	×	×	×	○	Δ	×
Recovery of nutrients	×	Δ	○	×		×	×
Reduce amount of waste to landfill	○	○	○	○	○		○
Reduce global warming	○	○	○	Δ	○	Δ	Δ
Reduce expense	○	Δ	Δ	Δ	Δ	×	×
Reduce GHG emissions	○	○	○	Δ	○	Δ	×
Affordable investment and available in local	○	○	Δ	Δ	Δ	Δ	×

Remark: ○ advantage, Δ likely advantage or may be advantage depends on conditions, × disadvantage

Fig. 6-1 shows waste hierarchy which proposes that waste should be managed by various methods according to its characteristics. The waste hierarchy is a strategy that ranks waste management options according to their environmental benefits (Rasmussen and Vigsø, 2005). The preference of the options represents the hierarchal structure. Thus, source reduction (prevention), composting, animal feed, anaerobic digestion and recycling are given the highest preference, while incineration and sanitary landfill are staying at low preference due to high technology, investment and operation and maintenance.

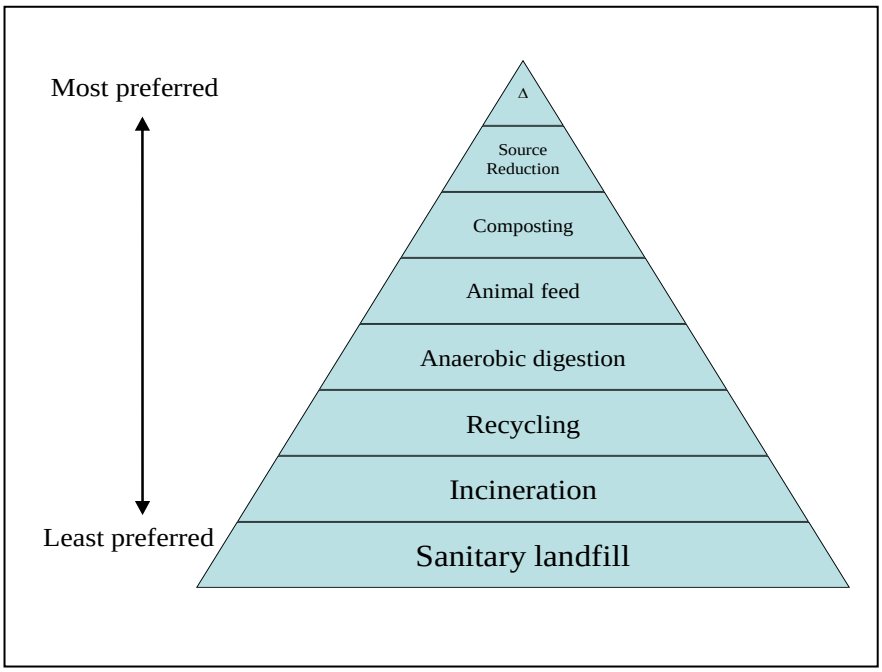

Figure 6-1. The preference of waste hierarchy

6.7 Overall discussion of treatment technologies toward Phnom Penh waste

In general, there are different waste treatment technologies such as composting, landfilling, anaerobic digestion, animal feed, and recycling are the effective and considerable approaches for better waste management. In addition, reducing greenhouse gases emission, reducing waste going to landfill, saving energy and nature, and conserving the biodiversity can be achieved as well. With increasing waste generation, the improvement of waste management, especially organic, by changing from open dumping/landfill and open burning to more environmentally, sound material cycle management and climate friendly manner options. The results of this research indicated that organic waste is predominant (more than 60%) in the waste stream in the city and

Cambodia as a whole. So the reduction of organic waste is an urgent need. Encouragement of people to separate organic waste used for animal feed, composting, and anaerobic digestion is the effective way. Despite the high potential for its use, the conversion of organic waste is, somewhat, limited. Skilled personnel and budgets can be the major challenges and constraints for municipality to carry out anaerobic digestion (medium and large scale), sanitary landfill and incineration. Therefore, contracted private companies play an important role in managing MSW, especially organic waste. Sorted organic waste can be used for animal feed, composting, and anaerobic digestion, respectively. Even animal feed is not effective due to low quality of food waste which has an impact on animal's health and its growth rate compared to instant feed. It is mainly left-over vegetables and other kinds of organic which is not fit for animal famers, however the recovery of organic waste for animal feed must be encouraged and promoted. Recycling is an effective method in reducing the volume of waste to landfill, additionally increasing economic, save for virgin material use, conserve environment and reduce pollution, even though the percentage of recyclable in the residue is low (less than 10%). Currently, informal sector play a key role to remove recyclables, formal sector should be set up in the future.

Based on current socio-economic conditions in Cambodia, small-medium scale composting and anaerobic digestion for organic waste utilisation are applicable for Phnom Penh waste. Composting can produce soil improvement materials and thus increase crop productivity. Anaerobic digestion can generate gas which is a source of energy and the residual can be used to amend soil quality. As the investment required for anaerobic digestion is higher than that for composting, cost-benefit analysis of technology adoption need be studied and considered (Table 6-4). As a result of this study, it showed that the waste contained organic (66%), moisture content (63%), and calorific value (894 kcal/kg) which is not suitable to incinerate the current municipal solid waste. If organic waste is completely sorted out, moisture content and amount of organic waste become low making calorific value increase to approximately 1500kcal/kg which is suitable for incineration.

Table 6-4 compares the requirements for implementation of anaerobic digestion, composting, incineration and sanitary landfill. Each technology has advantages as well as disadvantages. Composting is an attractive technology for developing Asian countries in terms of the investment and the flexibility of scale. Implementing sanitary landfill are generally practiced on a large scale, and so it requires high capital investment which

Cambodia is challenging, otherwise international aid may be needed which is hard to keep sustainability. Incineration is too costly or unfeasible for high moisture and low calorific value waste. Anaerobic digestion for energy recovery in medium to large scale is also expensive, but it is attractive for cities where electricity costs are high. In-vessel composting is more costly than sanitary landfill construction. Windrow composting is the cheapest option.

Table 6-4. Cost-benefit analysis of composting, anaerobic digestion, incineration and landfill

Parameters	Composting	Anaerobic digestion	Incineration	Sanitary landfill
Investment cost	Very low	Medium	Very high	Medium
Operation cost	Low	Medium	Very high	Low-Medium
Maintenance cost	Low	Medium	Very high	Low
Time requirement	4-12 weeks	3-4 weeks	Daily	20-50 years
Land requirement	Medium	Low	Low	Medium-high
Labor requirement	Medium-high	Low	Low	Low
Skill requirement	Low-medium	Medium-high	Low	Very high
Scale	Small-medium	Small-medium	Medium-large	Medium-large
Energy requirement	Low	Low	Medium-high	Low
GHG emissions	Low	Very low	Low	Medium-high

6.7.1 Options in treating MSW in Phnom Penh

Municipal solid waste in Phnom Penh can be treated by various options according to the availability and possibility of the municipality. Fig. 6-2 shows appropriate municipal solid waste, especially organic waste, treatment and potential use of their products for different types of waste. Animal feed, composting and anaerobic digestion are aligning with the Cambodian national agenda on socio-economic development and environmental protection. However, waste separation at the source (household level) is required to ensure the quality of waste input, operation system, and the product's quality. If waste separation at the generation source fails, another option such as sanitary landfill with gas recovery system should be considered.

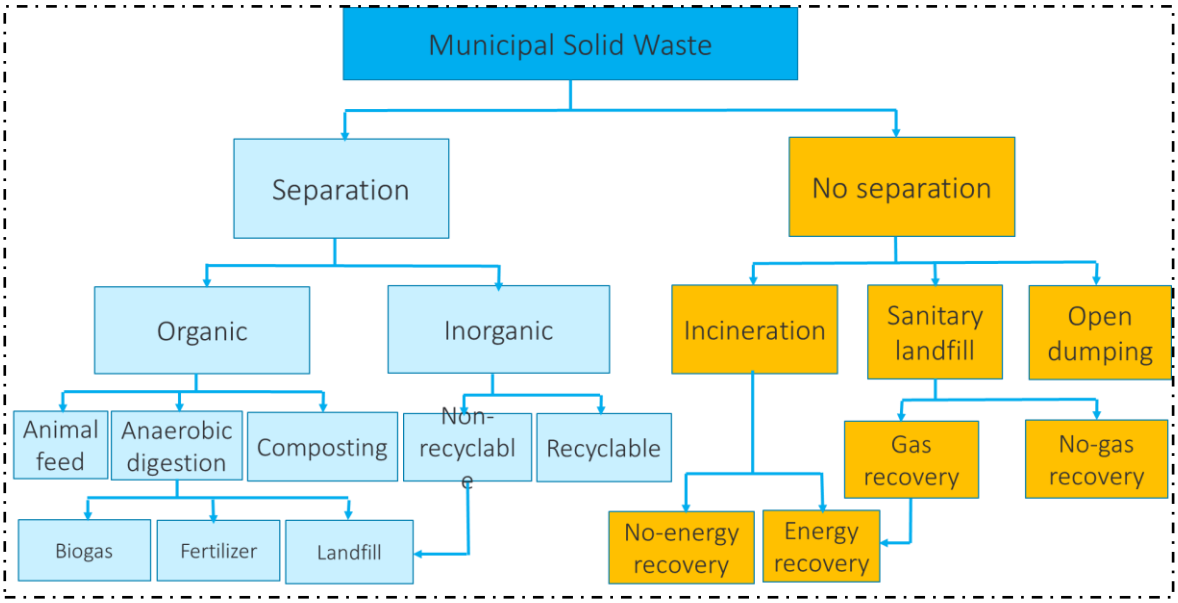

Figure 6-2. Appropriate waste treatment options in Phnom Penh

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CHAPTER VII
CONCLUSION AND RECOMMENDATIONS

The aim of this dissertation was to determine the quantity, composition and characteristics of household solid waste and commercial solid waste to evaluate the potential for recycling in Phnom Penh city, the capital city of Cambodia. Furthermore, appropriate waste treatment options, attitudes, behavior and habit towards waste packing, storage, discharge and recycling practices were evaluated. The author analyzed the relevant factors influent waste generation and composition.

7.1 Summary of results

The research background and study area were mentioned in chapter 1. Population growth, development and urbanization resulted in booming of waste generation in the city, in addition, variation of waste composition regarding to lifestyle changes. In the last decade, commercial activities have been increasing including numbers of restaurants, beer gardens, hotels, guesthouses, super markets and so on. Disposal methods of municipal solid waste (MSW) are based on amount of waste generated and its composition. The information of municipal solid waste management in Phnom Penh was old and out of date, so the updated one is necessary. Only the report published by JICA in 2005 was reliable. Without choice, some information was perforce widely quoted from other sources. Household solid waste (HSW) is the largest portion of MSW which accounted for 65.5%, followed by commercial waste (25%) of total waste. The need for updated and reliable data on solid waste is required for fundamental research, waste management design, planning and sustainable management. The creation of trustable database on MSW is essential for waste managers and planners in local and region context.

In order to approach and achieve the proposed objectives, we conducted researches on waste characterization with the waste samples collected from two different sources: i) street waste (317.1kg) obtained from 20 collection points along the streets to check the waste composition; and ii) household solid waste was collected daily from 26 households for two consecutive weeks to determine waste generation and composition, and to evaluate the appropriate waste treatment in September 2012. The waste was separated into three categories and was quantified by weight as: i) combustible (89.70%), non-combustible (8.90%), and recyclable (1.40%) for the street waste and 91.53%, 8.08%, 0.39% for

household waste, respectively. The combustible materials mainly consisted of food (58.76%), plastic (17.27%), paper (7.71%)) for the street waste and 66.20%, 9.80%, 4.50%for the household waste, respectively. The average household solid waste generation rate was 0.40kg/capita/day. The household solid waste generation rate per capita per day was positively correlated with household income, household size and house floor area. Food waste was predominant, 60-70%, C/N ratio of 20:1 and moisture content (63.10%), composting could be the good choice to treat household waste in Phnom Penh. The low heat value (LHV), at 894 kcal/kg and moisture content (63%) are not suitable for incineration. If food waste is separated out for animal feed, composting/bio-digestion, the LHV of the remaining waste becomes higher (1,429kcal/kg), making it suitable for incineration. The author also analysed the relationship between waste generation rate and some socio-economic factors. Besides waste characterization, questionnaire survey was also carried out by randomly selecting 556 sampled households for face-to-face interview to examine the relationship between waste generation and socio-economic factors. The results of the questionnaire showed that waste discharge (kg/household/day) varied between house types: 1.8 (flat), 1.9 (single house) and 2.7 (villa house). Respondents (91%) had access to waste collection service with collection fee of USD1-2 was acceptable (74%). Respondents (95%) sorted recyclable waste before discharge, leading to a 17% of waste reduction and generating approximately USD570/household/year. 92% of respondents were interested in environmental issues. Most respondents (91%) had never heard of the 3Rs. The results also showed that 1) household waste generation was positively correlated with waste sorting activity, monthly income, household size, house type and house floor area, and 2) people were willing to participate in environmental programs.

Another survey was conducted on commercial solid waste in August 2013. Waste samples were collected from 52 commercial sectors including hotels, restaurants, internet cafés, guesthouses, beer gardens, markets, schools, microfinance agencies and shops. The waste was collected daily for two weeks and separated into 23 categories. The results showed that composition of commercial solid waste were food (50-60%), followed by plastic and paper (30-40%) and glass (5-6%). The waste generation in kg/table/day was 4.83 (large restaurants), 3.36 (medium restaurants), 2.23 (beer gardens), 1.94 (internet cafés); in kg/room/day was 0.69 (3-star hotels), 0.45 (large guesthouses), 0.37 (medium and small guesthouses), 0.097 (small hotels) and in kg/person/day was 0.153 (family

marts), 0.15 (ministries), 0.12 (council of ministers), 0.12 (supermarkets), less than 0.10 (shops and schools). Sorted waste was food, followed by glass bottles, paper, PET bottles, aluminium cans and steel. The remaining recyclable materials were food, plastic, paper, steel and aluminium cans. Well sorting activity was conducted by internet cafés and restaurants, followed by family marts, schools, beer gardens and guesthouses. If food waste and other recyclable materials were completely sorted, 61% of current waste could be minimized. Composition and characteristics of household solid waste and commercial were quite similar, the author assumed that calorific value, moisture content and C/N ratio were also similar. The appropriate treatment methods for both household solid waste and commercial solid waste were composting/anaerobic digestion, while incineration was not applicable for the current waste.

The problems of solid waste management in Phnom Penh are listed below:

1. **Improper storage and discharge of waste-**most people do not pack, store and discharge properly. All wastes are mixed in one plastic bag causing difficulty in separating for treatment purpose (recycling, composting, etc.).
2. **Irregular collection schedule-** people keep their waste in front of their house at any time regardless of the waste collection schedule. If the schedule is missed, the waste is just left there unconditionally.
3. **Waste scavengers**-tear to open garbage bags searching for recyclable items that can be sold. Consequently, the garbage is scattered everywhere and it is very hard to collect.
4. **Improper waste disposal methods-**open dumping/landfill are common use as final disposal.
5. **Bad habit and attitude-** Despite the fact that rubbish bins are placed in most public places, people will just throw their rubbish anywhere they want. As a result, not all the waste is collected and cleared. Some people even throw trash from their cars or motorbikes while driving.

7.2 Recommendations for future researches

This dissertation dealt with survey and determination of household solid waste generation, composition, and the evaluation of treatment options focusing on in Phnom Penh, Cambodia. Based on the findings of the research, the recommendations toward better waste

management are made. On the other hand, recommendations for future research are suggested for better research. All recommendations are mentioned below:

1. The sampling points should be selected based the classification of urbanization and population density**.**
2. Targeted households should be selected according to household income, household size, household expenditure, education level, number of adults and children, frequency of party and eating outside and number of meal at home which effect on household waste generation with detailed composition should be done.
3. The flow of recyclable material should be analysed.
4. The variation of waste generation among the day and season should be studied because waste generation is varied among all of them.
5. Waste composition of household solid waste should be classified into at least 14 physical components and more sub-category in order to identify the relevant factors in terms of lifestyle changes.
6. Sorted recyclables should be examined because it is influent by habit of recycling activities, household attitudes towards good management.
7. Legislation should be improved because some people do not care about waste discharge and disposal, so regulations and the punishments with fining should be strictly enforced as a result they will follow.
8. Environmental education and capacity building should be promoted because when people are truly aware of the impact of their actions, they are more likely to change themselves. This kind of self-awareness is even more effective than rules and regulations pushing them with willingness to change without being forced. A strong pay attention on public awareness on the importance of proper waste segregation at source should be made. Create section of 3Rs for sustainable solid waste management in communities, local and central governments. Waste workers and scavengers should be well cared, trained and educated and respected and treated as professional resulting in increasing efficiency for waste management.
9. Promotion of organic waste utilization

   Organic materials continue to be the largest, followed by paper and paperboard, yard trimmings, and plastics. While metals, rubber, leather, and textiles exist in low

proportion. Community-based composting or household composoting should be integrated into the Solid Waste Management Program. Composting is an effective way to reduce the waste going into the main waste stream and is cost-effective in managing biodegradable organic waste. However, the success of community-based composting lies in the strong cooperation and involvement of communities. In this case, the incentive from municipality and local governments for those who (household, restaurants, ect.) actively participated in making compost and doing waste segregation should be implemented.

10. Appropriate technology

One of the essential elements in solid waste management is the technology. Finding the appropriate, cost-efficient technology is challenging for many cities and municipalities. To do this, a strong focus should be placed on state-of-the-art technologies that use sustainable design principles for implementing the 3Rs (Reduce, Reuse and Recycle) programs in municipal solid waste management. Support in the form of subsidies from the government should also be provided to stakeholders adopting local technologies that are proven to have worked effectively in managing specific types of wastes.

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APPENDICS

Appendix 1 Recording sheet

Data Recording Sheet

Name of Household: _____
Address: _____Tel: _____

	Classification																	
	Organic waste (kg)							**Non organic waste (kg)**				**Recyclable waste (kg)**						
Composition / **Dates**	Plastic	Food	Rubber and Leather	Textiles	Paper	Grass and wood	Other	Metal	Glass Bottle	Ceramic and stone	Other	Paper	Aluminum Can	Clean Foils	Clean Glass	PET bottle	Tins and Steel	Other
___/_____/2012																		
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Appendix 2

Challenges, Opportunities and Targets dealing with 3Rs initiatives

1. Challenges

- Household waste is not separated at the generation source and some hazardous waste is also included.
- There is no policy and strategic plan related to SWM.
- Open dump and landfills (low standard).
- Law and regulations/directive is weak.
- Irregular collection of wastes, thus a large quantity of waste is left uncollected.
- Lack of capacity (both budget and personnel).
- Poor public participation in waste management.
- Poverty is a crucial issue related to waste management.
- No pilot project on the 3Rs has been implemented.
- Waste fee does not reflect waste generation.
- Data and information on waste management is lacking, limited and out of date.

2. Opportunities

- Existing environmental law and sub-decrees.
- Developing legislation and guideline focusing on specific sector including household, industrial and hazardous waste management.
- Sound management of industrial waste, hazardous waste and chemical toxic waste.
- Implementation of integrated solid waste management and climate change.
- Informal recycling business.
- High possibility to raise awareness of private sector working on waste related business.
- Private sector is interested in the 3R programme.

3. Targets

- Improve waste collection and its sound management, e.g. collection times/schedule.
- Enhance waste separation at the generation source up to 10-20% at households and 30-40% at business area by 2015 and increase to 50% and 70%, respectively, by 2020.
- Compost 20% of urban organic waste and promote use of compost by 2015 and increase the target to 40% of household organic waste and 50% of organic waste generated at markets and business centres by 2020.

- Encouraging private sector/investor engaging the implementation of 3 R initiatives including the promotion of making organic fertilizers from organic waste.

Appendix 3 Questionnaire form

Household Questionnaire Survey

Introduction

This questionnaire is designed to facilitate the assessment of the current situation of solid waste management in an urban area (Phnom Penh), especially the practices, knowledge, behavior and willingness of people in term of 3R principle. The information collected by this questionnaire can be used to evaluate the status of the solid waste management based on 3Rs implementation in the country. To enable an accurate assessment, it is important that all information requested in the questionnaire should be provided as completely and accurately as possible.

Date of interview: _____/_____/ 2012

Interviewers' Name: _____

Part I. General Information and Socio-Economic Aspects

Name: _____ Age: _____ years, Sex: ❑ Male ❑ Female

Address: No_____, Group:_____,Village: _____

Sangkat/Commune:_____, Khan/District: _____

Tel: _____

1.1 Education:

(1) Primary (2) Secondary (3) High School (4) University

(5) Other _____

1.2 Marital Status: (1) Single (2) Married (3) Separated (4) Divorced

1.3 Occupation:

(1) Farmer (2) Business (3) Office work (company) (4) Student

(5) Retired (6) Housekeeper (7) Government (8) NGOs

(9) Skilled Workers (10) Other _____

1.4 Household size: (1) 1 person (2) 2 people (3) 3 people (4) 4 people

(5) 5 people (6) 6 people (7) 7 people (8) _____

1.5 How many men and women/boys and girls are there?

(1) Men: _____ *(2) Women: _____*

(3) Boys: _____ *(4) Girls: _____*

5.5 Number of HH member by education level

Education	*Number*
Primary School (6 years)	
Secondary School (3 years)	
High School (3 years)	
Higher Education-University (4 years)	
Master	

5.6 Monthly Income:

(1) 0-100 (2) 101-150 (3) 151-200 (4) 201-250

(5) 251-300 (6) 301-350 (7) 351-400 (8) 401-500

(9) 501-550 (10)551-600 (11) 601-650 (12) 651-700

(13) 701$-750 (14) 751$-800$ (15) 801-850 (16) 851-900

(17) Over 900$

5.7 **Monthly Expense:**

(1) 0-100 (2) 101-150 (3) 151-200 (4) 201-250

(5) 251-300 (6) 301-350 (7) 351-400 (8) 401-500

(9) 501-550 (10) 551-600 (11) 601-650 (12) 651-700

(13) 701-750 (14) 751-800 (15) 801-850 (16) 851-900

(17) Over 900$

1.10 How much does your family spend on the following items monthly?

Items	**Monthly expenditure**	**Items**	**Monthly expenditure**
Food		Cloths	
Electricity		Fuel for cooking	
Fuel and transport		Children education	
Health care		Wood	
Water		Other	

1.11 House Types: (1) Single house (2) Apartment (3) Flat (4) Villa

1.12 House Area: (1) 10-16m^2 (2) 17-24m^2 (3) 25-35m^2

(4) larger than 35m^2

1.13 House Ownership? (1) Own house (2) Rental House, How much per month? _____$/month

<u>Part II.</u> Solid Waste Disposal and Collection Practices at present time and awareness, behavior and willingness on SWM in term of 3R principle

To answer the following questions, you just tick (✓) or circle (〇) on each question.

2.1 Are you interested in any environmental issues?

1. Yes
2. No

If Yes, please check the following problems.

(1) Water Pollution (2) Air Pollution (3) Solid Waste 4. _____

2.2 Is there any solid waste problem in your area?

1.Yes

2. No

If yes, what kinds of problem?

(1) Bad smell (2) Scattered on the road (3) Waste not collected properly

(4) _____

2.3 How often you notice waste piles in your neighborhood or at any specific locations? If so, check the answer below.

(1) Very often (2) Often (3) Not often

2.4 Do you think it can cause any impacts to the environment or health or No?

1. Yes
2. No

If yes,

Environment: (1) Water pollution (2) Air Pollution (3) _____

Health: (1) Wounded (2) Bad smell (3) Diseases infection (4) breathing problem

(5) _____

2.5 Do you usually eat at home?

1. Yes
2. No

If yes, how many times do you cook per day?

(1) Once (2) twice (3) 3times (4) more than 3 times _____times

2.6 How often do you eat outside per week?

(1) Once (2) twice (3) 3times (4) more than 3 times _____times

2.7 Does your family often eat outside?

1. Yes
2. No

If Yes, how often per week?

(1) Once (2) twice (3) 3times (4) more than 3 times _____times

If No, how often cook at home?

(1) Once (2) twice (3) 3times (4) more than 3 times _____times

2.8 Do you have party often at home?

1. Yes
2. No

2.9 What is the estimated amount of waste produced by your home daily?

(1) 0.5-1Kg (2) 1-1.5Kg (3) 1.5-2Kg (4) 2-2.5Kg (5) 2.5-3Kg

(6) 3.5-4Kg (7) 4-4.5Kg (8) 4.5-5Kg (9) 5-5.5Kg (10) 5.5-6Kg

(11) 6-6.5Kg (12) 6.5-7Kg (13) over 7Kg

2.10 How do you manage your waste before disposal?

(1) Plastic bag (2) Carton box (3) Metal container (4) Plastic container

(5) Other: _____

2.11 Why do you use such kind of container?

(1) Avoid odors (2) Keep clean (3) Easy to handle (4) Away from flies

(5) Low cost or available free (6) Others: _____

2.12 Have you received any waste collection service currently?

1. Yes
2. No

If No, how do you discard your waste?

(1) Burying in pit (2) Burning (3) Throwing in open area (4) Others _____

If Yes, select the answer.

(1) Private company (2) Government (3) I don't know (4) _____

2.13 What kind of collection service is provided in your area?

(1) Block (bell) Collection (2) Curbside Collection (3) Communal collection

(4) Door to door collection (5) I do not know

2.14 What time is your waste collected?

(1) in the morning (2) in the afternoon (3) irregular (4) in the evening

(5) at night (6) I do not know

2.15 How often is the waste collected?

(1) Everyday (2) Every two days (3) Every 3 days (4) Every 4 days

(5) Every 5 days (6) Every week (7) I do not know

2.16 Are you satisfied with the current correction frequency and time?

1. Yes
2. No

2.17 If No, what is the most suitable time and frequency of collection?

A. (1) 5:00-7:00 am (2) 7:00-9:00am (3) 12:00-1:00pm (4) 4:00-6:00pm

(5) 6:00-9:00pm (6) Other _____

B. (1) twice per day (2) Other _____

2.18 How often do you dispose off your waste from your home?

1. Everyday
2. Every two days
3. Every three days
4. No notice

2.19 What is your opinion about solid waste collection service provided by CINTRI?

	Unsatisfactory (✓)	**Neutral (✓)**	**Satisfactory (✓)**	**Most Priority (✓)**
Collection Frequency				
Collection Time				
Payment Fee				
Collection Cleanliness				
Bell Ring				
Smelling				

Sanitary at storage				
Flies and Insects				
Overall				

2.20 Which is the most appropriate way should be selected?

(1) Good Service (2) Regular Collection (3) Cheap Fee (4) _____

2.21 Do you pay for your collection fee (monthly)?

1. Yes
2. No

If Yes, How much do you pay?

(1) Less than 4000R (2) 4000-8000R (3) 8000-12000R

(4) 12000-16000R (5) 16000-20000R (6) 20000-24000R

(7) 24000-28000R (8) 28000-32000R (9) 32000-36000R

(10) 36000-40000R (11) 40000-44000R (12) 44000-48000R

(13) 48000-52000R (14) 52000-56000R (15) 56000-60000R

(16) 60000-64000R (17) 64000-68000R (18) 68000-72000R

(19) 72000-76000R (20) 76000-80000R (21) 80000-840000R

(22) 84000-88000R (23) 88000-92000R (24) 92000-96000R

(25) 96000-100000R (26) more than 100000R

2.22 How do you think of collection fee?

(1) Too expensive (2) Expensive (3) Appropriate (4) I do not know

2.23 Do you know where the collected waste is disposed after collection at your home?

1. Yes
2. No
3. I don't care

If Yes, where?

(1) Landfill (2) Incinerator (3) Open space (4) _____

2.24 Do you know the treatment methods for the final disposal site?

1. Yes
2. No
3. I don't care

If Yes, what kinds of methods? (Answer can be more than one)

(1) Composting

(2) Incineration

(3) Landfill

(4) Recycling

(5) Gasification

(6) _____

2.25 If you have the problem associated with solid waste service, who do you contact? (Answer can be more than one)

(1) CINTRI (Solid Waste Collection Company)

(2) MoE (Ministry of Environment)

(3) PPM (Phnom Penh Municipality)

(4) Local Government/Authority

(5) Others_____

2.26 What kind of media have you got of information about Environmental Issue and protection, SWM and so on? (Answer can be more than one)

(1) Public and Private Media (TV, radios, newspapers, magazine, posters, etc.)

(2) Local Authority,

(3) NGOs

(4) At my working place

(5) Family, friends or neighbors

(6) Others_____

2.27 Have you ever heard of 3Rs?

1. Yes

2. No

2.28 If Yes, do you know the meaning of 3Rs?

1. Yes

2. No

If Yes, what are they?

(1) _____

(2) _____

(3) _____

2.29 Have you ever participated in any environmental campaign program?

1. Yes
2. No

If yes which institution or organization?

(1) Local Authority

(2) Solid Waste Collection Company (CINTRI)

(3) Environmental Organization 1._____2. _____

3. _____

And what are the kinds of environmental program?

(1) Solid Waste Management

(2) Composting

(3) Waste Reduction

(4) Recycling

(5) _____

2.30 If there are programs to improve the environmental quality, are you or your family willing to participate?

1. Yes 2. No 3. No care

If Yes, will you accept the following programs?

❑ Separation at Source

❑ Use typical type of plastic bag bought from market authorized by the CINTRI or PPM

❑ Recycling

❑ Composting

❑ Others_____

2.31 Do you think it is important to sort the waste?

1. Yes
2. No
3. I do not care

2.32 Do you make waste sorting before disposal from your home?

1. Yes
2. No

2.33 If yes, what kind of items do you make sorting for selling? (Answer can be more than one)

(1) Aluminum cans (2) bottles (3) paper (4) metals (5) plastic bag

(6) Textiles (7) _____

2.34 How much do you earn from selling recycling material per month? _____riels/month

2.35 What do you do with your recyclables (cans, paper, metal,….?

(1) Selling to street buyers

(2) Selling to junk shop collector

(3) Own reuse

(4) Keep it for neighbor or relatives

2.36 What are the advantages in term of waste sorting? (Answer can be more than one)

(1) Reduce amount of waste

(2) Earn extra money

(3) Protect Environment

(3) Conserve natural resources

(4) Others_____

2.37 What are the advantages in term of recycling? (Answer can be more than one)

(1) Reduces waste.

(2) Saves energy.

(3) Conserves natural resources.

(4) Preserves our environment

2.38 What do you do with your organic waste?

(1) Composting

(2) Animal feed

(3) Throw to open space

(4) Throw it behind my house

(5) Give or Sell to animal feeding collector

2.39 Are you willing to buy recycled products?

1. Yes
2. No

If Yes, why?

(1) Help the poor

(2) Conserve the nature

(3) Cheap

(4) Protect environment

(5) Others _____

If No, Why?

(1) Come from waste

(2) Expensive

(3) Not interested

(4) Others _____

2.40 Do you reuse any waste items in your home?

1.Yes

2. No

If yes, then which things you reuse?

(1) Plastic Bottles (2) Glass bottles (3) Plastic bag (4) _____

If No, why? (Answer can be more than one)

(1) Low quality

(2) Less sanitary

(4) Don't like

(5) Other _____

2.41 If the company has waste separation program, are you willing to participate?

(1) Yes

(2) No

2.42 Do you think it is useful to separate waste before discharging?

(1) Yes

(2) No

If Yes, Why?

(1) Reduce amount of waste

(2) Landfill can last longer

(3) Easy for collector

(4) _____

2.43 What new or expanded solid waste services would you like to have made available to you in the future?

(1) _____

(2) _____

(3) _____

2.44 Please share any additional comments, concerns, complaints or suggestions you may have regarding to improving present Solid Waste Management (SWM) in Phnom Penh City.

1- Comments:

_____

_____

_____

2- Concerns:

_____

_____

3- Complaints:

_____

_____

4- Suggestions:

Thank You Very Much for Your time and Kind Cooperation.