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# Waste Characterization as an Element of Waste Management Planning: Lessons learned from a study in Siem Reap, Cambodia

**Abstract**

We assessed the study area in Siem Reap, Cambodia as a potential site for the introduction of a community-based waste management (CBWM) system. Our analysis included a household survey, a waste characterization study, and key informant interviews conducted in the summer of 2004. In the waste characterization study, we found that waste generation per capita was low (0.34 kg per capita per day, on average) compared to communities in other developing countries. We did not find a statistically significant relationship between household waste production and either income or expenditures. We observed that the waste stream in the study area was mostly organic in nature (66% by weight) and contained few recyclable materials (5% by weight). Our results illustrate the importance of a waste characterization study for assessing how many collection vehicles will be needed for a CBWM program, whether composting is a feasible option, whether recovery of recyclables will be a significant income source for the program, and whether social programming is needed to change household awareness and waste behaviours. We found that the household survey results on household attitudes and membership were a valuable complement to the waste characterization study, as they provided us with information about household size (and therefore allowed us to calculate per capita waste generation), the local residents' willingness to separate waste streams at the source, and residents' willingness to participate in and pay for

CBWM services. We conclude that the waste characterization study and the household survey together are important tools for planning a CBWM program.

**Keywords**

Household waste characterization; waste composition; waste generation; hoarding, community-based waste management; Cambodia.

## Introduction

Waste collection in the developing world is an issue of growing concern, especially since municipal authorities in many areas are either unable or unwilling to provide waste collection services to all residents in their jurisdiction. On average, up to 50% of residents lack collection services in urban areas of low and middle income countries (Klundert and Anschütz, 2001). Siem Reap, Cambodia (see Figure 1), where we conducted our study, is quite typical in this regard, in that the town collects only 50% of the total waste generated (Siem Reap Department of Environment, 2003).

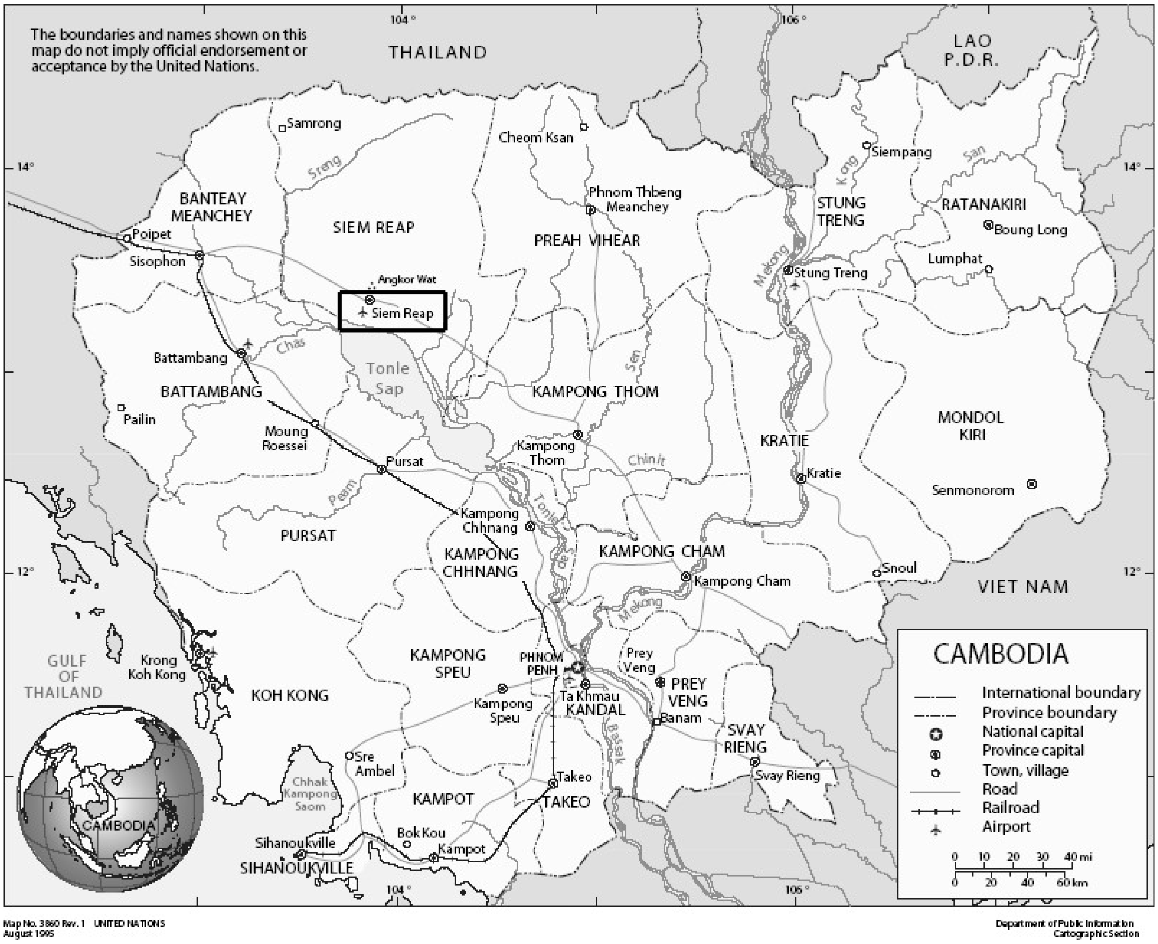


Figure 1. Map of Cambodia; Town of Siem Reap highlighted
(adapted from United Nations Development Programme, 2004)

When municipal governments are unable to collect all of the waste that is being generated, alternative waste management solutions may be appropriate for the unserviced areas of the town. One such alternative is community-based waste management (CBWM), a system that relies on community members to administer and participate in waste-related issues, including the collection, transportation, and diversion of waste. Generally, a CBWM system collects household wastes from individual residences (primary collection) and deposits them at a central location for municipal pick-up (secondary collection). The collection system often involves the employment of hired waste collectors, or may entail householders bringing their trash to a central location (Ali and Snel, 1999; Khulna City Corporation and Swiss Agency for Development and Co-operation, 2000).

In order to assess the feasibility of introducing CBWM to Siem Reap, researchers from the Royal University of Phnom Penh and the University of Toronto collaborated with local and provincial government officials to identify one area in the town without waste collection service that could serve as a pilot project for a community-based waste collection program and, possibly, a source separation system. The study area we chose consists of approximately 1,000 households located along both sides of the Siem Reap River to the south of the central part of town. This is a linear study area, and it contains parts of two commune administrative districts. We investigated local attitudes and waste management behaviours in the study area by means of a household survey and a waste characterization study. The purpose of the waste characterization study was threefold: to estimate the quantity of waste requiring collection; to better understand the variation in waste production rates within the study area; and to assess the feasibility of including composting and recycling as a part of the CBWM program. This paper describes the results of the waste characterization study, selected results from the survey and several lessons learned in conducting a waste characterization study for the purposes of assessing CBWM feasibility.

*Waste management issues in Siem Reap*

Siem Reap (home to 85,000 residents) is the gateway to the archaeological ruins of Angkor Wat, which is a UNESCO World Heritage Site attracting one-third of Cambodia's tourist dollars (D'Monte, 2005). The aesthetic appearance of Siem Reap is clearly very important for its image as a tourism destination. That image is not helped by unsightly litter floating down the Siem Reap River, which runs through the middle of town, or scattered piles of waste in areas that have no collection service. In an attempt to reduce the amount of floating litter, the local government has constructed a barrier across the river upstream of Siem Reap (see Figure 2), but this barrier only mitigates the visual surface pollution, not the pollution that is contaminating the river as a source of drinking water, a habitat for fish and a recreational space. A private company hired by the local government uses boats to collect any floating litter downstream of the barrier.

Figure 2. Barrier to waste across the Siem Reap River upstream of the Town of Siem Reap

Waste collection services are not provided to the entire town of Siem Reap for a number of reasons. First, collection services have been contracted to a private waste hauler and some parts of the town are outside of the waste hauler's contracted service area. For residents who are outside the service area, there are substantial costs associated with either obtaining a contract with the hauler for the transportation of waste to the local dumpsite, or with obtaining direct access to the dumpsite. Second, outside of the central town, the poor quality of local infrastructure limits truck access to houses. Most roads in the peri-urban area are dirt roads and become almost impassable in the rainy season. Finally, many of the residents living directly adjacent to the river do not have legal tenure on their land, and government eviction of these residents presents an occasional threat. It is possible that the municipality is withholding waste services to deny legitimacy to these settlers. Illegal settlements often lack a number of municipal services, including waste collection (Wang'ombe, 1995).

The lack of waste collection services in the study area has become a more pressing problem in recent years because of the changing waste stream. A representative from one local authority commented that people used to bury their waste in their gardens as compost, but are unable to do so any more because of the increased plastic content (Om Caat, 2004). Plastic goods and packing are readily available in Siem Reap; we therefore expected to find a high proportion of plastics in the waste stream when conducting our waste characterization study, along with the high proportion of organics traditionally found in waste streams in the developing world (as discussed in the results section below).

## Methodology

### *The household survey*

In order to collect information about residents' socio-economic characteristics, their attitudes towards waste, waste management behaviours (disposal and waste separation), and willingness to pay for collection services, we designed a survey and administered it to 300 households in the study area in the summer of 2004. The questionnaire contained a total of 21 questions related to the feasibility of introducing a CBWM program, but only the data that were useful for the waste characterization study will be reported on here.

Because we suspected that waste behaviours and incomes might vary by location relative to the river, the sample was drawn from four strata: households located on the east side of the river, households located away from the river along the east road, households along the west side of the river and households along the west road (see Figure 3 for a schematic of the study area, and Figures 4 and 5 for photos). Residents living along the river are illegal squatters and dwell in substantially lower quality housing than those living on the road side.

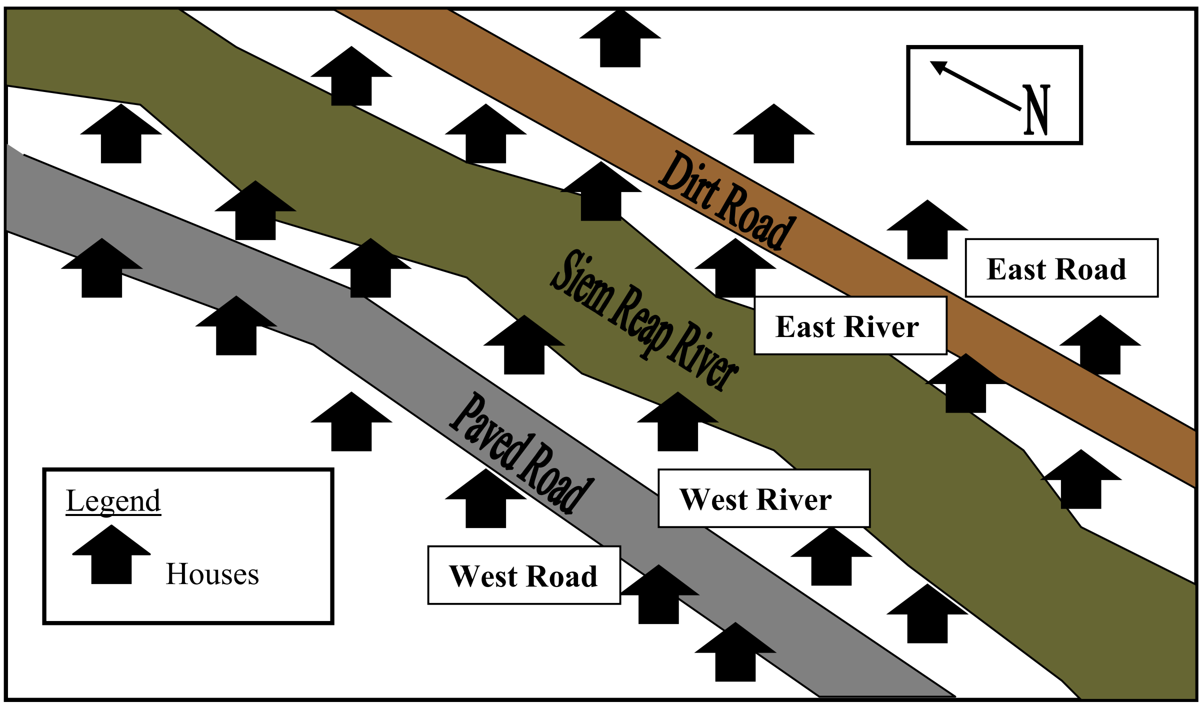


Figure 3. Schematic of household locations in the study area

Figure 4. Houses backing onto the river on the West (left) and East (right) sides

Figure 5. Houses backing onto the West River (left), and on the West Road (right)

After a random start at each location, every third house within the stratum was approached for inclusion in the sample. If nobody was home at the selected household, the next household was substituted for the missing household. The survey took place over a period of four days during daylight hours and was directed to the wife or mother of the household wherever possible, since women rather than men usually have responsibility for waste management tasks in Cambodia. This division of responsibilities was verified in the household survey, which found that wives were responsible for waste management in 43% of households, female children in 21% of households, and other female residents in 8% of households; n = 291, multiple responses to this question were allowed. We administered a short follow-up survey to the same households approximately one year after the first survey in order to assess the impact on attitudes towards waste and waste behaviour of an environmental education program that staff from the Royal University of Phnom Penh delivered to local authorities, residents, teachers and monks in the intervening period. The education program provided information about how a community-based waste management program would work, pollution sources in the community, including solid waste, and their impact on the environment. Since the follow-up survey asked far fewer questions than the original survey and focused mostly on the education intervention, the household survey results discussed below refer to the first survey, unless otherwise noted.

*The Waste Characterization Study*

We conducted the waste characterization study about one month after the household survey, and selected participants from a stratified random subset of the interviewed households (50 households were selected, but one did not participate; n = 49). The strata in the sample were monthly household income (nine strata with a range of $100 USD) and house location on either the West Road, West River, East River, or East Road, with roughly similar proportions take from each stratum. The residents of the selected households were asked to collect their waste (that is, any materials they would normally burn, bury, or throw in the river or other public spaces) each day for a week in the summer of 2004. Eight plastic collection bags were provided to each household – one for each day of the study, and one extra bag in case it was required. We recognized that we might be capturing both residential waste and the commercial waste produced by home-businesses, but this was considered acceptable because we were attempting to assess the required capacity of a potential collection system, not the percentage of residential versus commercial waste. However, while this collection method is more likely to produce an accurate estimate of the total amount of waste available for collection in the study area, it can also confound analyses of relationships between household income and waste generation. Further difficulties in these analyses are discussed below.

We chose the extended observation period of one week (as opposed to one day) to minimize waste hoarding behaviours that can skew data collection. Additionally, this observation period allowed us to take account of the daily fluctuations in waste generation that may occur within a week (Shimura et al., 2001). We weighed the collected waste at each household using hand scales. We then brought it to a sorting area where it was separated and weighed again, all on the same day. The sorting area was covered with a tarp to prevent the waste from drying out in the sun, and therefore changing the proportional weights of the high moisture organic components of the waste stream.

In deciding what categories to use in sorting the waste, we followed a "potential use" categorization (see, for example, Ojeda-Benitez et al., 2003, Bernache-Pérez et al., 2001, and Fehr et al., 2000) rather than the traditional material-based categorization. Since we were interested in the feasibility of source separation for composting and recycling, we sorted organics into high nitrogen organics (such as fruit peels and other kitchen wastes) and high carbon organics (such as dry leaves). Wood (except for wood shavings) and coconut became a separate category because they are not easily composted. Of the potentially recyclable materials, the plastics category had both the greatest diversity and the greatest quantity of material. Plastic items collected from the study area included grocery bags, netting, tubs, broken toys, bottles, and more. Because of this variety, plastic items were sorted into those that were routinely purchased by the local recycling depot and itinerant buyers (such as drinking water bottles), and those that were not (such as plastic bags). Other categories of potentially recyclable materials (such as metals and paper) did not contain the same diversity, and were not present in sufficient quantities to warrant further separation.

*Waste hoarding*

Hoarding, in this instance, refers to the practice of saving waste for collection by the study team. For example, if residents were informed on Friday that waste collection was beginning on Monday, they may have saved their waste over the weekend to present it to the study team on Monday. Another problem with the same effect as hoarding can occur if residents include neighbours' wastes with their own, especially at the last opportunity for collection. To exclude instances of waste hoarding on the first and last days of study participation, the mean daily weight of waste was adjusted by excluding those instances where the weight was more than two standard deviations away from the overall mean. Overall, we excluded five cases of first-day hoarding and two days of last-day hoarding from the results.

The occurrence of first-day hoarding is supported by the first-day unadjusted waste total of 124.2 kg (versus the mean of 92.5 kg for the other six days of study). The five outliers removed because of suspicion of hoarding behaviours accounted for 43.3 kg of the first-day waste total. This hoarding could be due to residents saving their waste from the previous days (as some were approached to participate several days before the study actually began), or it could be due to residents picking up excess waste lying around their house that they usually leave there. In support of this latter statement, we observed that much of the plastics and paper collected on the first day was coated with dirt. Additionally, when we weighed the first day's collection, we found that there was a disproportionately high amount of dirt: 25.6% by weight versus the study average of 14.0%.

Last-day hoarding may have occurred because some residents felt that the end of the waste study was their "last chance" to have waste collected at their door. However, many people did not realize that the study had ended when it did, possibly because eight plastic bags were handed out in case residents needed an extra bag over the seven-day study period. On the day after the study ended, we observed that many of the study households had put out bags of waste to be collected. This lack of awareness of the study's end may have helped to reduce last-day hoarding.

Those sample points more than two standard deviations away from the mean that occurred during the observation period, but not on the first or last day, were assumed to be fluctuations that could be expected to occur regularly and were not excluded from the mean weight calculation. In some cases, resident comments on the morning collection route substantiated that these fluctuations were not due to hoarding, but to normal variations in waste generation. For example, a resident on the West Road with a large amount of waste mentioned that she had hosted a gathering the previous night. An alternative possible explanation for unusually high waste quantities during the week is that neighbours not included among the sampled households observed the collection activities and decided to add their waste to that of the sampled households. We had no way of determining whether this was happening, but suspect that, if it did, it was not a serious problem because the collected waste samples (excluding those from the first and last days) exceeded two standard deviations from the mean only four times (representing 1% of all samples).

*Participation in the study*

One household on the East River refused to participate in the study from the first day of collection. The head of this household repeatedly stated that the family did not have any waste to be collected since it had "no waste." Our research assistants spoke with these householders, and reported that they were not amenable to the idea of a CBWM system. This household was not included in the analysis, and so the effective sample size was n = 49. Another household on the West Road only participated on the first day, and cited illness and lack of daily collection as the reasons for non-participation. The value for its one day of participation was included in the study, but no values were included for the days of non-participation. Fifteen other households also had one or two days of non-participation, either because they forgot, because dogs ate their trash, or because they had "no waste." Values for these days were not included in the analysis. Of these fifteen households, hoarding behaviour was observed in only one case on the day after an incident of non-participation.

Unlike Bolaane and Ali (2004), we did not find that participants wanted to be compensated for setting out their waste. They were happy to do it without compensation because many in the study area felt that waste was a problem in the community (75% according to the survey results), while others probably saw the study as a way to clean up their properties.

*Possible sources of error*

Since we used hand scales (see Figure 6) to weigh the wastes collected from each household and to weigh the components of the sorted waste, measurement error is a factor in this research. For example, the total weight of the sorted component parts of the collected waste was compared to the initial sums of the weights of waste collected from each household. It was found that there was a slight difference in these totals each day, ranging between a 0.2% net gain and a 2.7% net loss in weight. On average, we observed a 0.8% loss in weight between the initial collection weights and the separated component weights each day. This compares with a 6.6% loss in weight observed by Chung and

Poon (2001) in the waste characterization process in Guangzhou, China. This source of error could also be due to dehydration of the samples during the sorting process, which would explain the overall net loss observed on most days.

Figure 6. Hand scale used to weigh waste samples

A Solid Waste Management Program Officer for the Community Sanitation and Recycling Organization in Phnom Penh commented that his organization has observed less waste (in weight and in volume) during the dry season in Cambodia (May-June to October-November), when our study was conducted, than in the wet season. This observation suggests that a comprehensive waste characterization study would need to be conducted over multiple seasons (Bo Sokhan, 2004). Unfortunately, we had neither the time nor the resources to sample during the wet season. Mohee (2002) and Buenrostro et al. (2001) have observed seasonal changes in the city-wide waste generation rates in Mauritius and Mexico respectively, as have Chung and Poon in China (2001). Other authors have conducted studies at multiple times throughout the year to control for this type of fluctuation (Shimura et al., 2001). Based on their results and expert input from Cambodian colleagues, we would expect a sample in the wet season to find larger quantities of waste, higher moisture content (Chung and Poon, 2001), and greater amounts of organic materials.

## Results

*An overview of the demographics of the study area*

According to the household survey, the average family size in the study area is 6.7 persons. The average number of children under the age of six is 0.8 per household; the average number of children from age six to seventeen is 1.9. Males head 76% of households, and females head 24%. Most of the households headed by women are those where the household head is relatively older (56% of female heads of households are over fifty years old, compared to 30% of male heads of households), implying that these women may be widows. The average age of the household head is 45.7 years.

The most common occupations in the study area include seller, service provider, government staff, farmer, and animal raiser. We found that the average monthly household income in the study area was $434 USD, and average monthly expenditures were $224 USD. However, the validity of these amounts is questionable, since this income figure is very high for this region. The unreliability of the income data in this case may be due to a reluctance of respondents to answer survey questions (in the case of income), and to provide accurate data (with respect to both income and expenditures). Additionally, we discovered that some respondents who run home businesses were confusing their individual income with the gross revenue of their business. To give context to the income values reported in the survey, Cambodia's gross national income (GNI) per capita in 2003 was $300 USD, or $25 USD per month (World Bank, 2005). With an average 6.5 people per household, the average monthly per capita income reported in the study area is $68.77 USD, implying that the values reported in the survey are high. The median monthly household income in the survey area was found to be $225 USD; this value is much lower than the mean, supporting the conclusion that the reported income data was inflated. The implications of these inflated income values for our analyses are discussed below.

*Waste generation*

The mean daily weight of the waste collected from all forty-nine houses in the waste characterization study was 97.0 kg (this was calculated by averaging the daily totals of waste collected over the seven day observation period). The mean daily volume was $0.6m^3$ (similarly calculated by averaging the daily volume of waste) and the mean waste density was 156 $kg/m^3$ (calculated by dividing the weight of the waste by its volume for each day, and then averaging these daily densities).

On average, the per capita waste generation was 0.34 kg per day (calculated by first averaging the daily weight of waste for each household, then dividing this by the number of residents in each household, as reported in the household survey, and then averaging the daily per capita waste generation figures across the 49 households). Following is a histogram showing the frequency of waste per capita data points for individual households. Almost half of the households in the study produce between 0.10 and 0.30 kg of waste per capita per day (see Figure 7).

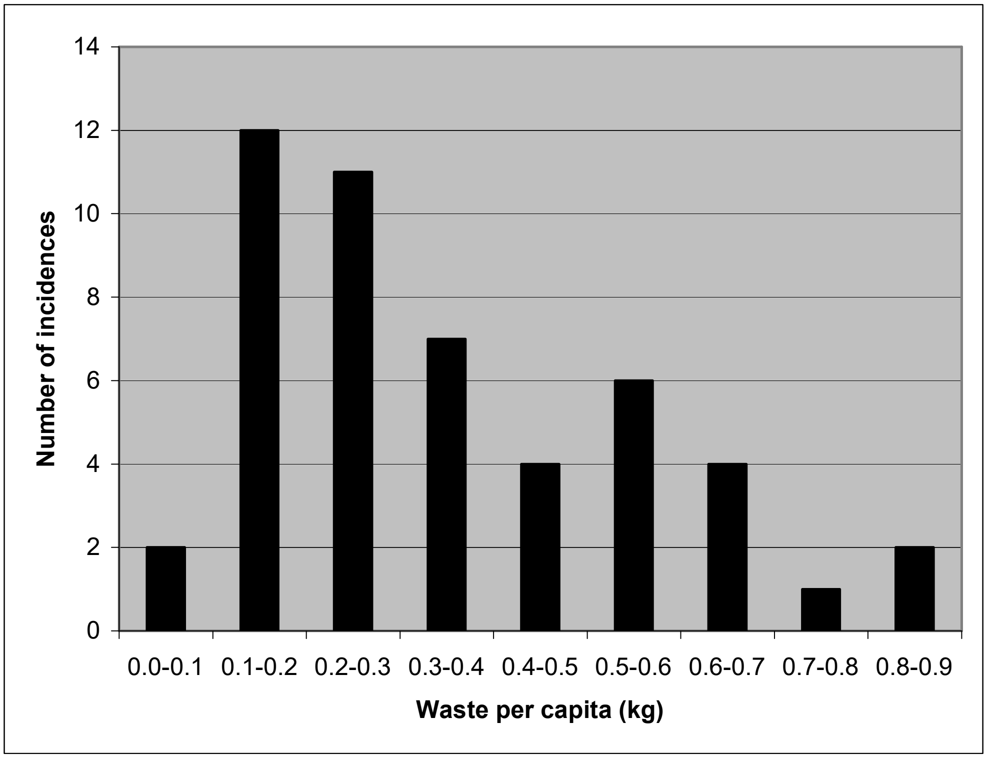


Figure 7. Histogram of daily waste per capita results

To give context to these waste generation figures, a study in the centre of the Town of Siem Reap found that residents produce an average of 0.50 kg of waste each day (ECSPESC and Ministry of Environment, 1997). Waste generation may be lower in the study area because of lower average incomes, higher rates of composting or animal rearing (using food scraps as a source of feed), and less waste from home businesses. Waste generation rates per capita per day vary across the world, and even across the developing world. The study area's waste generation per capita figures are at the lower end of those found in a number of other urban waste generation studies, such as 0.33kg in Gabarone, Botswana (Bolaane and Ali, 2004); 0.51kg in Guadalajara, Mexico (Bernache-Pérez et al., 2001); 0.63kg in Morelia, Mexico (Buenrostro et al., 2001); and 1.76kg in Abu Dhabi City, U.A.E. (Abu Qdais et al., 1997).

All of the above studies used door-to-door collection methods for assessing waste generation per capita, and are studies of residential waste generation. Theses studies do not discuss commercial wastes (with the exception of Buenrostro et al., 2001, who also conducted a separate non-residential waste generation study), and do not discuss whether commercial wastes from home businesses we also present in the residential waste stream. None of these studies speak to the existence of home businesses within the residential sample. We found that many homes in the study area served as a base for a business, whether it was a restaurant, a pharmacy, or the site for preparing goods that were later sold in another location. The presence of home businesses in our sample no doubt affected our waste per capita values. One of the primary aims of our research was to assess the capacity that would be required for a CBWM system that would collect all of the waste produced in the study area. Therefore, those home businesses that were randomly selected for the sub-sample were considered to be representative of the constituents of the study area, and so their inclusion in the study enhanced the accuracy of our waste estimates.

*Relationship of waste generation to income and location*

We tested for a relationship between waste generation and household income and a proxy for income, namely location of the home relative to the river. We felt that this information might prove useful for generalizing the results of the waste generation study to other similar communities in Siem Reap. Additionally, an understanding of the economic nature of waste production in the study area could assist in designing and targeting education programs.

It seems intuitive that those residents with more income will consume more goods, and therefore produce more waste. However, most previous research (as discussed below) has found that income is not related to waste generation, although several of these studies did not test for a statistical relationship. It is also difficult to compare these studies because of differences in the way that they measure income. Some use continuous income data, some use categorical income data, and some use proxy variables for income, such as housing rental rate and expenditures. However, the use of different measurement approaches is not terribly surprising given that the difficulty of soliciting accurate income data from households is well known. Many people consider their income to be a private matter while others are reluctant to divulge income data for fear that they might have to pay more taxes. The problem of income solicitation can be even more challenging in developing countries, where many people work in the informal sector with fluctuating incomes and have difficulty estimating annual incomes (Adedibu, 1988).

Adedibu (1988) used multiple regression analysis to examine the relationship between waste generation and 25 explanatory variables, including income of the head of household, in 324 households in Ilorin, Nigeria. Neither the contribution of income nor the regression model itself were found to be statistically significant. Based on a sample of 300 households in Guadalajara, Mexico, Bernache-Pérez et al. (2001) found that there was no relationship between per capita waste generation and family income, although they did not provide any details on the type of test used in the analysis or indicate whether income was measured as a continuous or categorical variable.

In contrast to Adedibu and Bernache-Perez et al., two other researchers have found positive relationships between income (or income proxies) and waste generation. In a study of 840 samples of waste generated by 40 households in Abu Dhabi City, United Arab Emirates, Abu Qdais et al. (1997) found a strong positive correlation between household waste generation rates and self-reported annual property rental rates ($R^2$ = 0.69, significance not reported). Bolaane and Ali (2004) conducted a waste generation study on 47 households in Gabarone, Botswana and found that waste generation for low and medium income households was the same, but lower for the high income group. They did not test whether this difference was statistically significant.

We tested for the presence of an income relationship in the study area by using both income and expenditure data from the household survey and comparing them to the adjusted average weight of household waste and the per capita weight of household waste, using linear regression analysis. None of the relationships were found to be statistically significant (see Table 1).

Table 1. Regression model results for household waste generation by income and by expenditures (n=49)[1]

| Independent Variables | Dependent Variables | | | |
|---|---|---|---|---|
| | Average waste per household per day | | Ln (average waste per capita per day) | |
| | $R^2$ | t-test probability | $R^2$ | t-test probability |
| Ln (Household expenditures) | .027 | .268 | .002 | .741 |
| Total household income | .012 | .463 | .026 | .279 |

a) Household expenditures and average waste per capita were transformed into their natural logs in order to eliminate a problem of heteroscedasticity in the residuals and to ensure that the variable distributions were approximately normal. None of the standardized residuals in the regressions exceeded 2.5 and visual inspection of the residual scatterplots revealed no obvious outliers.

We suspected that a possible reason for the lack of significant relationships was the inaccuracy of the income and expenditure data. One concern was that some households with home businesses might have reported gross income rather than net income. Other concerns included those described in the above noted studies, such as lack of truthfulness and poor recall. In an attempt to reduce the effect of these possible inaccuracies, we collapsed the income and expenditure data into three categories (high, medium, low) that each contained about 1/3 of the data points. We then ran an analysis of variance (ANOVA) test for a difference in the mean waste generation levels by income and expenditure category, but again found no significant relationships (see Table 2).

Table 2. ANOVA results for household waste generation by income and by expenditures

| | | Sample size | Average waste per household per day | | Average waste per capita per day | |
|---|---|---|---|---|---|---|
| | | | Mean (kg.) | Prob. of F | Mean (kg.) | Prob. of F |
| Household Income | Low | 13 | 1.78 | .551 | .275 | .256 |
| | Medium | 20 | 2.15 | | .412 | |
| | High | 15 | 1.90 | | .333 | |
| Household expenditures | Low | 19 | 1.88 | .698 | .356 | .941 |
| | Medium | 13 | 1.93 | | .330 | |
| | High | 17 | 2.15 | | .358 | |

Because of the suspected unreliability of the income and household expenditure data, the initial selection of the waste characterization subset was stratified by both household income and household location. In the study area, we anticipated that household location might be related to income. In particular, we expected that those residents who live on either bank of the river (and who therefore have no official land tenure) would tend to be of lower socioeconomic status, and would have distinct patterns of waste production. T-tests conducted on the adjusted mean household weight of waste and the per capita waste generation indicate that there is no statistically significant difference in waste generation based on location of the households on the river or on the road, suggesting that either location was not a very effective proxy for income, or that it was a good proxy but that waste generation is not related to income in the study area.

*Relationship of waste generation to household size*

Several previous studies have shown that there is a relationship between waste generation per capita and household size. As the number of household members increases, waste generation per capita has been found to decrease, probably because of economies of scale in the consumption of goods and packaging. Abu Qdais et al. (1997) found a statistically significant but weak negative relationship between waste generation per capita and household size in Abu Dhabi ($R^2 = 0.11$), while Bolaane and Ali (2004) found a similar weak, negative relationship in Gabarone, Botswana ($R^2 = 0.34$). Our results also show that there is a weak ($R^2 = 0.35$), but significant ($p = 0.000$) negative relationship between per capita waste generation and the number of people in a household.

In his waste characterization study in Ilorin, Nigeria, Adedibu (1988) observed that the number of people living in a household can vary from week to week as relatives move in and out. If this is the case, our waste per capita estimates may not be completely accurate, since the waste characterization study was conducted approximately one month after the household survey was completed. We were able to conduct a rough test of the mobility of household members in the sample area by comparing household size reported in the first survey (conducted before the waste characterization study), to household size reported in the follow-up survey one year later. Of the 273 households that were observed in both surveys, 162 households (59.3%) reported different household sizes in the two time periods. The mean number of household members in the initial survey was 6.56, and the maximum was 17; in the follow-up survey, the mean number of residents was 6.42, and the maximum was 14. We ran a paired t-test analysis of these means, and found that there was no statistically significant difference between them (p=0.319). Although the average household size has not changed significantly, the presence of so many households with differences in household sizes over a one-year period is still a concern. It suggests that mobility is fairly high in the study area and that even one month after the initial survey, at least some households may have lost or gained residents and thus affected our estimates of per capita waste generation.

*Waste composition*

The waste composition results (as reported in Table 3) are based on the aggregate weight of all waste collected from the study households once it had been sorted into its component parts.

Table 3. Waste composition, by weight
(n = 49; percentages represent an average of the results of all seven days of observation)

| *Waste Composition* | *Percentage (by weight)* |
|---|---|
| High nitrogen organics (mostly kitchen wastes) | 31% |
| High carbon organics (mostly yard wastes) | 22% |
| Stones and dirt | 14% |
| Non-recyclable plastic | 13% |
| Wood and coconut | 13% |
| Paper | 3% |
| Metal | 1% |
| Textiles | 1% |
| Recyclable plastic | 1% |
| Glass | 1% |
| Shells and bones | 0.3 % |
| Medical waste (both hazardous and non-hazardous) | 0.3 % |

The composition of waste in the study area is largely organic. Kitchen wastes, yard waste, wood, and coconut shells collectively account for 66% of waste by weight. This amount is similar to that found in residential waste characterization studies in other developing countries. For example, 68% of waste by weight is putrescible in Gabarone, Botswana, (Bolaane and Ali, 2004), 53% is putrescible in Guadalajara, Mexico, (Bernache-Pérez et al., 2001), and 58% is putrescible by weight in Guangzhou, China, (Chung and Poon, 2001). However, we note that the amount of organic matter observed in the waste stream in our study area represents the amount of organic waste available for collection, not the amount generated, since 35% of the households surveyed reported that they currently compost at least some of their waste or feed it to animals.

There is a substantial amount of plastic in the waste stream, although it is probable that the weights for plastics are slightly exaggerated as this total often included dirt and moisture from organics that could not be separated from the plastics. The study found that there are very few recyclables in the waste stream (3% of the waste by weight is made up of paper, 1% is recyclable plastic, and 1% is metal). According to the household survey, 89% of sampled residents already separate recyclable materials from the waste stream to sell (to itinerant buyers or local recycling depots) or to give away (to friends or to the less advantaged, for example). The sale of recyclables is a regular practice, and on average, a household in the study area earns $1.14 USD per month from selling items reclaimed from the waste stream.

The amounts of paper and metal observed in the study area are generally lower than those reported in other residential waste characterization studies (Bolanne and Ali, 2004, Bernache-Pérez et al., 2001). Chung and Poon (2001) observe similarly low amounts of paper (6%) and metal (1%) in the waste stream in Guangzhou, China, and note that householders frequently set aside paper and metal waste for redemption at private recycling depots. Few studies differentiate between recyclable and non-recyclable plastics in the manner that we have, limiting a comparison of recyclable plastics in the waste stream. Chung and Poon (2001) found that recyclable plastic beverage containers only constituted 0.1% of the waste stream by weight, in comparison to the category of all recyclable plastics in our study, which constituted 1% of the waste stream by weight.

Several households in the study area have home businesses and some of the waste from these businesses was found to pose special problems for a CBWM project, both in terms of quality and quantity. For example, a household on the West Road that runs a pharmacy from its residence consistently set out mixed medical waste. This type of waste could pose health hazards to waste collectors. We observed that in many instances, home businesses added substantial amounts of waste to the total amount of waste requiring collection from a household. One home business produced waste that could actually be very beneficial for composting. A carpenter in the study area generates large quantities of wood shavings and, if composting is part of the CBWM program, these shavings are an ideal high-carbon additive for composting piles.

**Discussion**

While the results of the waste characterization study are valuable as a reference point for comparison with other communities in Southeast Asia and the developing world in general, the primary importance of these results is their usefulness for waste management planning. Following is a discussion of how the results can be of use in designing a CBWM system in the study area.

*Design of the collection system*

An extrapolation of the waste generation results from the forty-nine observed households to the entire study area indicates that the total daily generation for the study area would be 1,980 kg (calculated by dividing the average daily weight of waste collected from all of the households by 49, and multiplying this number by 1,000), and the total volume for 1,000 households would be 12.2 $m^3$ per day (calculated by dividing the average daily volume of waste collected from all of the households by 49, and multiplying this number by 1,000). We used these extrapolations to estimate the capacity and number of collection vehicles as well as the frequency of collection that would be required for the CBWM collection system.

Because conventional garbage trucks are too cumbersome for the study area, alternative transportation for waste collectors will be required for CBWM. The successful use of a cart attached to a motorcycle for collecting waste in the waste characterization study illustrated for the local community that this method of collection could be appropriate for the CBWM project as well.

*Source Separation*

Because the composition of waste in the study area is largely organic, there is a potential for including source separation as an element of the collection system in order to manage the organic stream by composting it. Thirty five percent of respondents to the household survey currently make compost from organic wastes; the predominant reason given for composting was improving soil quality. Additionally, 75% raise or feed animals, supposedly using some of their organic households wastes for this purpose. This suggests that there is already a culture of separating organic waste and composting in this area, which may provide the basis for a broader educational program. Although the waste characterization study suggests that composting is an appropriate option for managing the study area's waste, results from the household survey raised questions about the feasibility of source separation. Only 49% of residents indicated willingness to separate organic material from the waste stream. This less than enthusiastic response seems rather strange, given that many households already separate organics for backyard composting or for feeding animals. A chi-squared analysis indicated that those who already make compost are more willing to separate their food wastes, and those who do not compost are more opposed to separating their food wastes ($p = 0.001$). We did not find a significant relationship between animal raising and willingness to separate food wastes. Of those willing to separate their wastes, 32% said they are willing to separate all organic wastes, and 38% are willing to separate some. The rest said they would only separate specific materials Therefore, despite the high percentage of organic material available for composting, it is uncertain whether a source-separation project can proceed with such low rates of willingness to participate. In addition, wood and coconut (13% by weight) do not biodegrade quickly, and so may not be as suitable for composting as other organic materials. Alternatively, the community might want to consider mixed waste composting, although the production of a high quality compost product can be difficult with mixed-waste composting (Hoornweg et al., 1999).

As noted above, only 5% of the waste (by weight) is composed of potentially recyclable materials. The implication of the low recyclable waste content is that few revenues can be expected from recovering recyclables. This is unfortunate for the economics of a CBWM scheme even if it does not include source separation. Many CBWM projects expect collectors to be able to supplement their salaries, which are usually very low, by picking out recyclables from the waste that they collect (Anschütz, 1995; Richardson, 2003).

*Community education*

The toxicity of some commercial waste materials observed in the waste stream presents a danger for collectors (such as some of the pharmaceutical wastes described above). Identification of toxic wastes not suitable for collection will need to be included in awareness-raising programs (for both residents and collectors) prior to project implementation.

Our observations during the study indicate that conceptions of "waste" varied from household to household. Although we asked for everything that people usually burn, bury, throw in the river, or discard on the ground, it was clear that we received different types of waste from different people. For example, some people cleared the leaves from their yard each day and considered this matter to be waste, while others did not give us their yard waste. A few households repeatedly claimed that they had "no waste" for us to collect, again problematizing the consistent definition of "waste." These observations reinforce the need to engage with local residents about their definitions of "waste" in order to effectively design an appropriate waste management system. We have not come across any other studies that investigate local meanings of "waste."

**Conclusions**

This waste characterization study has proven useful for the design and social programming of a CBWM project in Siem Reap. Results from the study have helped determine the number and capacities of collection vehicles that will be needed for the project. Our waste composition results show that there is very little potential for recovery of recyclables from the waste stream. While there is abundant organic waste available for a composting program, about half of the surveyed households are not willing to separate their organic waste at source. This attitude might change if there is an education program to help households understand the benefits of source separation. The waste composition study's finding of toxics in the waste stream suggests that an education program may also be needed to help residents understand what materials should and should not be set out for waste collection.

Our research has also shown that the recommendations for CBWM design can be enhanced if the waste characterization study is conducted in conjunction with a household survey. For example, a survey is useful for calculating waste generation per capita because there are unlikely to be better sources for providing up-to-date data on the number of household members, especially in the developing world where demographic and census data are often unavailable or unreliable. A survey can also collect information on waste management attitudes and behaviours, such as whether residents are willing to source separate their waste. It can provide information about culturally contingent perceptions of waste that may be important in the design of an education campaign prior to launching a CBWM project. Of course, a survey is also essential for answering questions about the overall feasibility of a CBWM system, such as household desire for, and willingness-to-pay for, collection services.

The research results presented in this paper represent only part of the information required to assess the potential for implementing a CBWM project. Other aspects of our study, reported elsewhere (Parizeau, 2005), have focused on the political and financial feasibility of this type of project, such as the cost of labour and equipment, appropriate management arrangements, the size of the collection fee, and the willingness of various stakeholders to participate in the project. Based on these other results, and linking them to the results of the waste characterization study, we have concluded that the project is financially feasible, but will require much political will to move forward. We found that local government authorities were very supportive of a CBWM project; however, the local waste contractor sees CBWM as a threat because it represents lost future customers, and the contractor is therefore reluctant to provide secondary waste collection services at a reasonable price. At the moment, negotiations between the contractor and the local community are on-going. We conclude by noting that, although conducting a waste characterization study, complemented by a household survey, is an important element of planning for CBWM, it is just one of many needed to set the stage for a successful CBWM project.

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