Municipal Solid Waste Generation across Socioeconomic Strata

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ABSTRACT: Characterizing municipal solid waste (MSW) at the source of generation is a difficult task in large urban areas of developing countries. In order to understand this problem and devise comprehensive strategies for characterizing waste streams in Kathmandu Metropolitan City (KMC), Nepal, this paper utilizes two- and three-stage cluster sampling of strata. A pilot study of 200 households formed the basis for a field study that was conducted using 336 households. The pilot study provided 161.2 g capita^{-1} day^{-1} of average household solid waste generation in KMC, composition of organic wastes was at 63%, recyclables were in decline, construction debris was on the rise, and hazardous wastes was at 0.4%. The field study found that household solid waste generation was at 497.3 g capita^{-1} day^{-1} and MSW at 0.66 kg capita^{-1} day^{-1}. Organic wastes was the greatest component, while recyclables were on the rise along with hazardous wastes. The positive relationship between income and waste generation were held by all of the six strata in the pilot study and the first three strata in the field study; however the last stratum was an exception in the field study. The stratified generation of waste stream could be a better measure for future reformation of waste management practices in the KMC.

INTRODUCTION

This paper uses data from two large-scale household solid waste studies from Kathmandu Metropolitan City (KMC), the capital of Nepal, conducted in the winter of 2005 and summer of 2007. A pilot study of household solid waste was conducted for two weeks using 200 KMC households from December 14-31, 2005. Based upon the results of this study, a field study was carried out from June-August 2007 using 336 KMC households. Along with the sampling of household solid waste, wastes from restaurants, hotels and institutions (schools) and street litter were measured for a day during the field study between July 6 and 16, 2007. In combining the numbers from these sources, daily municipal solid waste (MSW) generation in KMC was estimated. Additionally, the studies included household surveys, site visits of solid waste management (SWM) infrastructure, interviews, focus group interviews, and collection of government records and reports. The scope of this paper is largely limited within the sampling of waste to understand composition and quantity of waste generation in KMC.

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METHODS

We employed a two-stage stratified cluster sampling design during the pilot study and a three-stage stratified cluster design in the field study. To identify households in the pilot study, all 35 wards of KMC were given equal consideration that together make up six city sectors (East, City Center, City Core North, City Core South, West, and North). These city sectors served as initial six strata for sampling. For the pilot study, a group of two student scientists led by their mentors first identified the sector of KMC that they were assigned and randomly selected a *tole*. (*Tole* is a Nepalese word for cluster of houses.) Upon locating a central point in that *tole*, they then randomly selected a direction and started analyzing waste in the first household positioned in that direction. From that point, sampling continued systematically every 50 m until ten households were sampled. Among the two scientists involved per ten households, one of them gathered, segregated, and weighed the waste. The second scientist recorded the weight in wet basis. Each team was asked to measure a type of waste among the ten categories identified (organic wastes -- food and yard wastes, plastics, paper and paper products, metals, glass, rubber and leather, textiles, dirt and construction debris, hazardous wastes, and other wastes). In this way, the first ten teams evaluated ten waste types in 100 KMC households and the second group of ten teams duplicated the effort in another 100 households.

The results of the pilot study indicated that a sample size of 273 households would be required for a field study. With 84% response rate in the pilot study survey, it would require 325 households in the field study. In the end, 336 households were chosen for the field study. During the field study, first, 20 KMC wards were randomly selected, followed by random selection of two *toles* (clusters) per ward except in the two largest KMC wards (6 and 16), where three clusters each were identified. From that point the first household positioned in randomly chosen direction was included in the study and the next household was the seventh household from across the street. This pattern of choosing households continued until eight households were chosen per cluster. The original six city sectors that served as initial strata were further refined and four new strata were then created based upon household income levels and socioeconomic status of the wards. See Dangi et al. (2008) and Dangi (2009) for details. Scheaffer et al. (2006) suggested that stratified random sampling works best for fewer than six strata where inter stratum means vary widely and intra-stratum variation is small.

Similarly, wastes from three restaurants, hotels and schools and litter from four 100-m stretches of KMC streets were analyzed using simple random sampling methods. The waste generation results across the strata were examined using analysis of variance (ANOVA) and SAS 9.1 statistical package.

DISCUSSION OF RESULTS

Pilot Study

The pilot study provided that KMC on average generates 161.2 g capita^{-1} day^{-1} of household solid waste as shown in Fig. 1. The waste generation numbers ranged from 19 to 1866 g capita^{-1} day^{-1} (Dangi et al. 2008). The lowest amount corresponded to a single room rented by four individuals and the highest was from an affluent family that included a bungalow with servants' quarters.

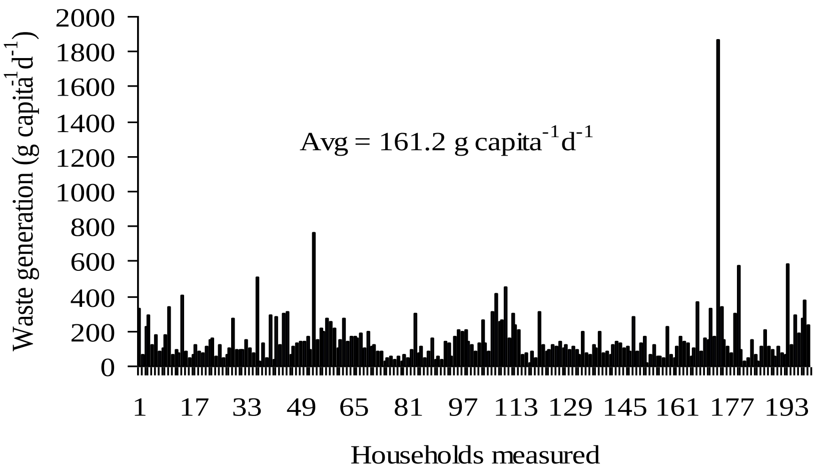

Fig. 1. Average daily household solid waste generation rate in KMC (adopted from (Dangi et al. 2008)).

To further understand waste generation among strata, the study sought to establish socioeconomic distribution across KMC. The survey outcomes provided that North belonged to a higher-income category, City Center was crowded with higher middle-income residents, East and City Core North together made for lower middle-income households, and City Core South and West combined included low-income residents (Fig. 2). Households earning less than Nepalese Rupee (NR) 7000 per month were classified as low-income households and NR 7000-15000, 15000-22000, and above NR 22000 of income per month were categorized as lower middle-, higher middle-, and higher-income households, respectively.

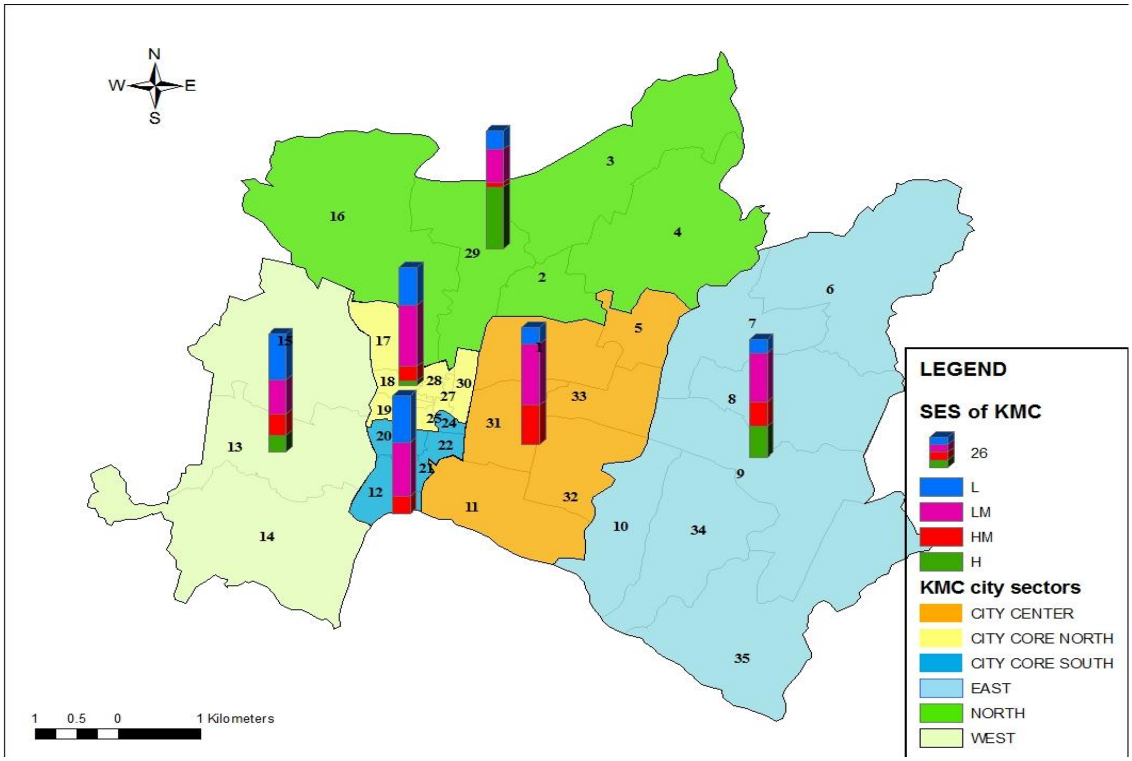

Fig. 2. Socioeconomic stratification (SES) in KMC, where L = low-income, LM = lower middle-income, HM = higher middle-income, and H = higher-income (adopted from Dangi (2009)).

The household solid waste generation was highest in North (226 g capita^{-1} day^{-1}) and lowest in City Core South (107 g capita^{-1} day^{-1}). Others in between included 197, 154, 137, and 120 g capita^{-1} day^{-1}, in that order for City Center, City Core North, East, and West (Dangi et al. 2008). The positive relationship found between income and waste generation in the literature (Abu Qdais et al. 1997, Vesilind et al. 2002) was held true by the pilot study.

The waste characterization included 63% for organic wastes, 19% for construction debris, 5% each for plastics and paper and paper products, 2% each for glass, textile and other wastes, 1% for metal, and 0.4% for hazardous wastes (Fig. 3). The percentages for organic wastes and construction debris are similar to those from earlier studies of KMC as described by Dangi et al. (2006). The lower percentages of recyclable items are credited to orderly scavenging that takes place at the source of generation in KMC and rigorous sampling that took place for two weeks could have helped to stabilize the numbers. Presence of hazardous wastes indicates rising prevalence of such wastes in KMC waste streams that often get mixed with MSW.

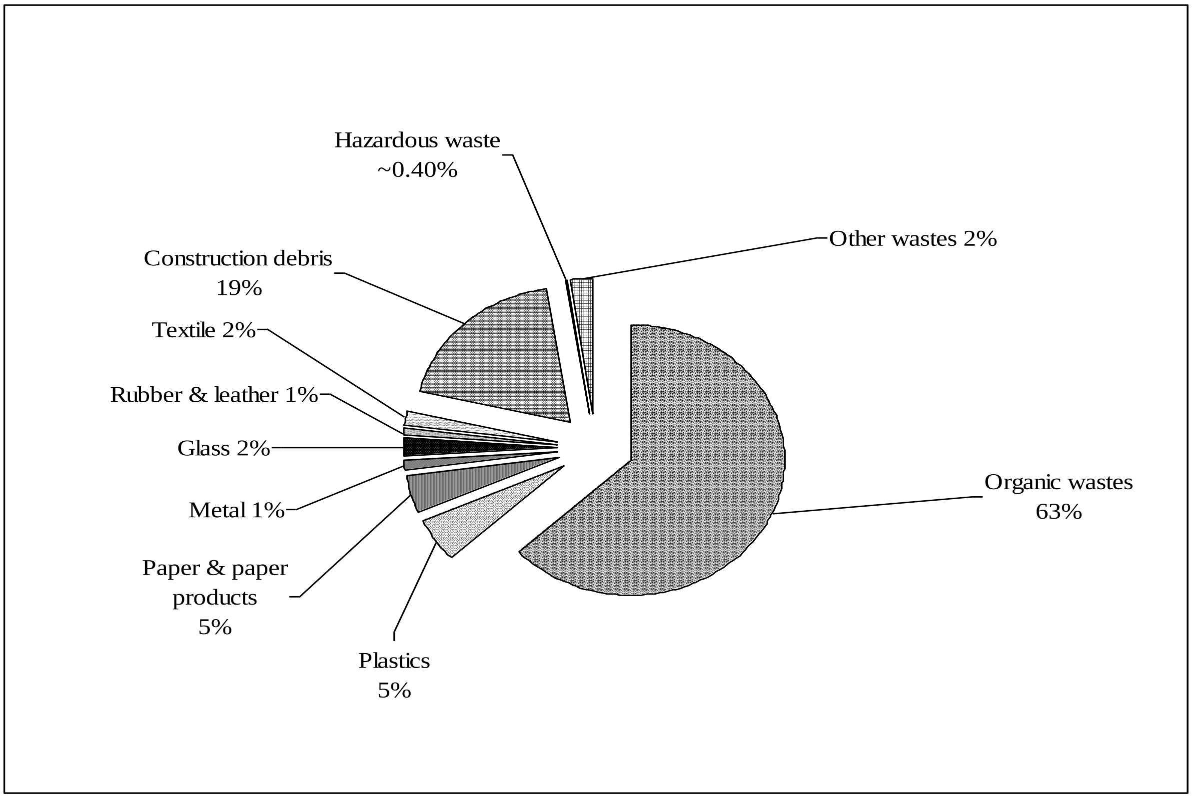

Fig. 3. Household waste characterization in KMC (adopted from Dangi et al. (2008)).

Field Study

The data from the pilot study, mean waste generation rates, standard deviations, number of households examined, and total households from each sector, were entered into a programmed Excel workbook, which yielded that a sample size of 273 would be required for the field study. The original six strata were further refined and renamed as strata I, II, III, and IV to represent higher-, higher middle-, lower middle-, and low-income households, correspondingly. The mean waste generation from 336 households was 497.3 g capita^{-1} day^{-1} and the earlier relationship between income and waste generation was held between strata I through III; however, the waste generation was the highest for stratum IV at 1584 g capita^{-1} day^{-1}. See Fig. 4. Stratum IV with a household of new construction and exceptionally high waste generation (97758.2 g capita^{-1} day^{-1}) contributed to an overall increase in the average waste generation rate of this stratum. The mean household waste generation of this stratum without this particular household came at 210 g capita^{-1} day^{-1} and for KMC, it was 204.3 g capita^{-1} day^{-1}. While these means are closer to the pilot study results, rare events that generate much debris should not be ignored. We retained that data, which yielded an estimate of 497.3 g capita^{-1} day^{-1} as an average waste generation from households.

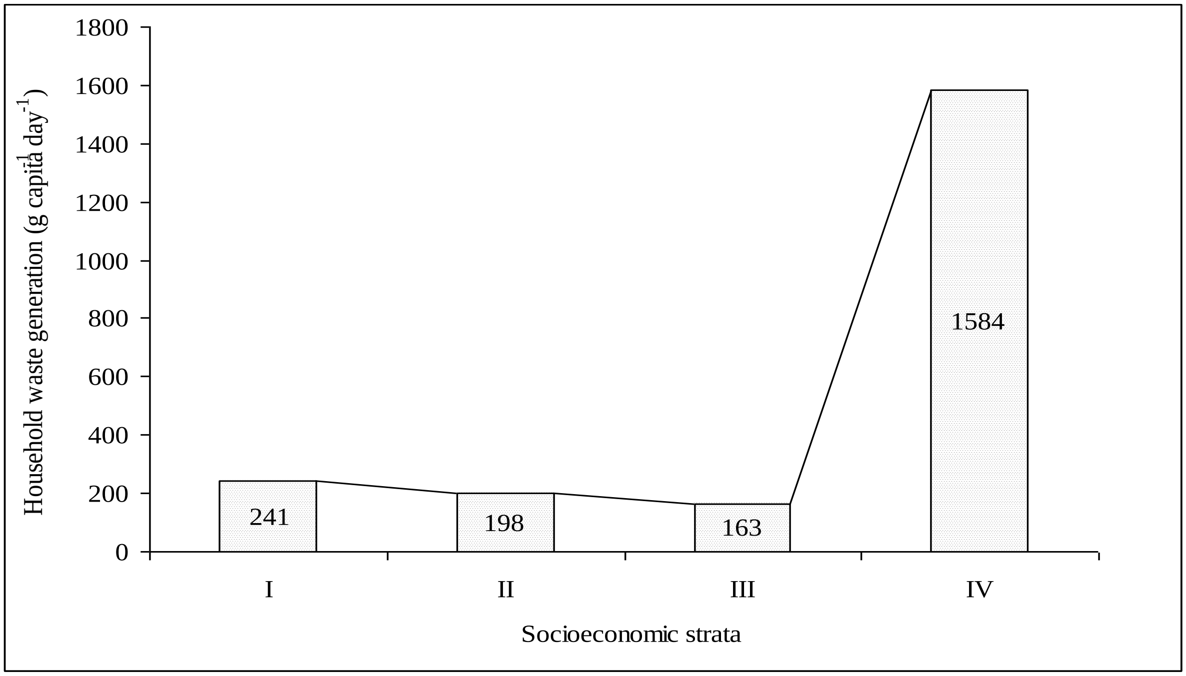

Fig. 4. Household waste generation among KMC strata (adopted from Dangi (2009)).

Wastes from restaurants, hotels, and schools and street litter also were studied. Three of each restaurant, hotel, and school and four 100-m stretches of streets were randomly identified for the study. The average waste generation from these facilities measured 48.5 kg day^{-1} from the restaurants, 113.3 kg day^{-1} from the hotels, and 26.1 kg day^{-1} from schools. The average amount of street litter accumulated was 61115.9 g 100 m^{-1} day^{-1} of street length. Given the total road length of 794.1 km in KMC (SWMRMC et al. 2004), 485.3 metric tons of street litter can accumulate in a day. Because that number was much higher than expected, the researcher contacted KMC sweepers working that day who confirmed that the KMC streets had not been swept for a week during this period. So, an average of 69.3 metric tons day^{-1} of street litter in KMC was obtained by dividing the total street litter by seven. Upon combining these numbers with household waste generation, the study showed 523.8 metric tons day^{-1} or 0.66 kg capita^{-1} day^{-1} of waste generation in KMC.

The waste sampled from households, restaurants, hotels, and institutions and street litter were segregated into ten types to investigate composition. The waste composition from households is included in Fig. 5, where organic wastes was the largest proportion (71%) and rubber and leather was the smallest (0.3%). Plastics (12%), paper and paper products (7.5%) and dirt and construction debris (5%) followed the organic wastes. Glass, hazardous wastes, textiles, other wastes, and metals' composition were greater than rubber and leather. The hazardous wastes stream measured considerably more at 1% than the 0.4% obtained in the pilot study.

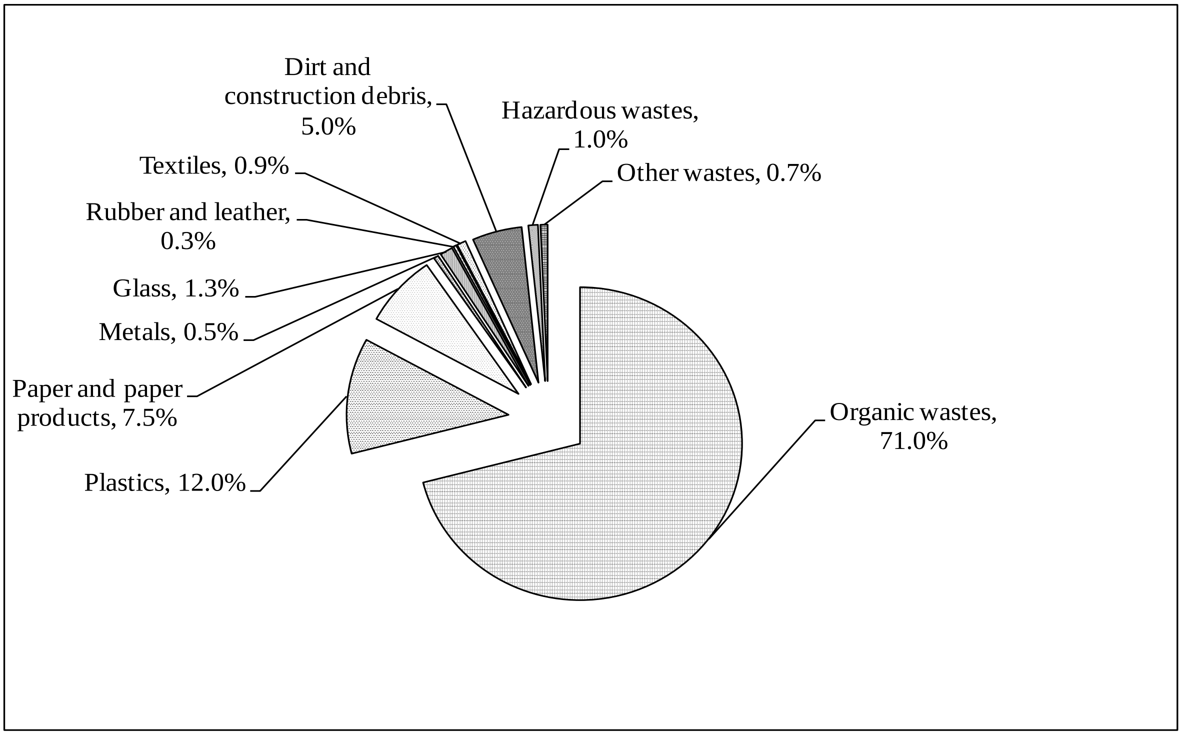

Fig. 5. Composition of household waste in KMC (adopted from Dangi (2009)).

Organic wastes was the greatest waste stream in all five sources of waste investigated with a high of 71% in household waste and a low of 38.6% in school waste with varying levels between those in the remaining waste sources. This is true because nature, type, and level of fresh food and vegetable items handled vary among the five waste sources examined. The 1% of hazardous wastes found in the household waste was replicated in the street waste, supporting the finding of the pilot study that hazardous waste materials is on the rise in KMC.

CONCLUSIONS

The data suggests that wealthier KMC strata generally produce higher waste generation. Dirt and construction debris are significant in the stratum with open spaces and new construction. Waste stream across stratum reflect higher percentages of organic wastes, plastics, paper and paper products, and dirt and construction debris. Hazardous wastes has witnessed significant increases in recent years. The information about waste stream characteristics and quantity of waste generation across the strata can be helpful to implement appropriate waste management techniques. Large quantity of organic wastes can be addressed via composting and the presence of recyclable items provides prospect for stratum wide recovery of waste. Strata that generate elevated amount of dirt and construction debris could be handled differently to encourage reuse of this material as a fill substance in road building or exchange as a construction material. Increased quantity of hazardous wastes in MSW stream indicates that they are often mixed with non-hazardous MSW and require separate handling. The effectiveness of scavenging noticed at the household level during the pilot study is a good measure for its prospective consideration in formal waste management.

In addition, the stratified cluster sampling is a useful tool in understanding waste composition and generation pattern in large urban areas of developing countries. Urban sections that differ in socioeconomic status, demography, distribution and types of households, area, and income levels can be utilized to come up with statistical sample size for a waste characterization study.

The sampling and measurements indicated that KMC generates 497.3 g capita^{-1} day^{-1} of household solid waste and produces 0.66 kg capita^{-1} day^{-1} of MSW. Overall, the data presented here could be valuable for organizing waste management in KMC and the methods used to derive the data can be useful procedure in examining waste stream characteristics in other developing countries.

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