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Characterization, quantification and management of household solid waste: A case study in China

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ABSTRACT

This study was undertaken to evaluate the characteristics of household solid waste (HSW) generation and to identify opportunities and benefits for waste recycling in a typical developed city of Suzhou in East China. A four-stage systematic tracking survey of 240 households was conducted for one week in each season starting from the summer of 2011 to the spring of 2012. And the driving forces behind HSW generation were analyzed using a multiple linear regression model. Results show that Suzhou's HSW generation rate was 280.5 g/cap/day, and the annual generation of HSW reached 568 thousand tons, among which, 89.3% were compostable and recyclable waste. Education level of the household daily manager has a major impact on HSW generation rate. And other factors, such as local customs and culture, consumption patterns and residential lifestyles could also influence HSW generation. It could achieve annual economic benefit of 15.9 million RMB, reduce 32.6 million tons of CO_2 equivalent emissions, and supply nearly 3500 job opportunities in Suzhou if source separation practice well. Implications of our results for HSW management in Suzhou and other Chinese cities were also discussed.

1. Introduction

As a major segment of municipal solid waste (MSW), household solid waste (HSW) is an inevitable part of daily life activities (Hering, 2012). Rapid economic growth and living standard improvement in recent decades have led to changes in the phenomenon of "mass production, mass consumption, and mass disposal" (Gu and Fujiwara, 2009; Weng and Fujiwara, 2011). Concurrently, people are discarding growing quantities of HSW, and its compositions are becoming more complex than ever before as consumer products made of plastic and diversified hazardous materials are widely used (Gu et al., 2014; Vergara and Tchobanoglous, 2012). Therefore, effective managements of HSW are urgently required to solve the problems caused by huge HSW generation and complex HSW stream (Chen et al., 2010; Wei et al., 2000; Zhang et al., 2010) and to protect public health and environment in current China (Giusti, 2009). Assessing the generation characteristics of HSW is an initial and important step toward effective MSW management, e.g. estimating the material recovery potential, identifying sources of different components, and improving waste management strategy (Gidarakos et al., 2006; Medina, 2000; Qu et al., 2009; Thanh et al., 2010).

HSW has been studied in many countries. For example, Dennison et al. (1996a,b) carried out a survey of HSW quantity and composition in the City of Dublin, Ireland, and found that the relative compositions of the HSW stream were different compared with two previous studies undertaken in the city in late 1970s. Philippe and Culot (2009) studied the HSW characteristics in Cape Haitian city, Republic of Haiti, and found that HSW generation rate (per capita HSW generation during a period of time, *e.g.* g/cap/day) was 210.0 g/cap/day and the compostable materials (reported as "COM" in this paper, which includes food waste, grass and wood and animal excrements, excluding hard bones/shells) accounted for 65.5% of HSW generation. Thanh et al. (2010) conducted a two-stage survey of 100 households during the dry and rainy seasons in the city of Can Tho, southern Vietnam. The HSW generation rate was found to be 285.3 g/cap/day, of which the COM and recyclable resources (reported as "REM" in this paper, which includes the total physical categories of paper, plastic, metal, glass and textiles) accounted for 80.0% and 11.7%, respectively. Ogwueleka (2013) described the HSW generated from 74 households on a daily basis

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for seven days in Abuja, and found that the HSW generation rate was 634.0 g/cap/day, which were dominated by COM (63.60%), followed by paper (9.70%) and plastic (8.70%).

The correlations between HSW generation and relevant socio-economic factors were also analyzed. Qdais et al. (1997) performed a linear regression analysis and found that the HSW generation was dependent on the household income level and the high-income residents generated 35% more HSW than the average level in the city of Abu Dhabi. Ojeda-Benítez et al. (2008) found that the HSW generation rates varied depending on the household types. The HSW generation rate of a nuclear family was 1100 g/cap/day, which fell between the levels of an extended family at 782 g/cap/day and a single-parent family at 1350 g/cap/day in the city of Mexicali, Calexico. Qu et al. (2009) analyzed the relationship between HSW generation rate and socio-economic factors, which indicated that household size and income both had negative effects on the HSW generation rate in Beijing, China.

It seems that the generation rates, compositions, and driving forces of HSW usually vary from region to region. It urges local authorities to perform their own HSW surveys to evaluate their unique problems, the causes of those problems, and to explore the best way to mitigate or solve them. In China, solid wastes are officially classified and recorded as industrial solid waste, hazardous waste, and MSW. Industrial solid waste and hazardous waste have been defined separately according to the disposal practices and enforced regulations. The sources of MSW generally include residential households (generating HSW), markets, commercial locations, public areas, streets, and temples and religious institutions (Jiang et al., 2009). In recent years, HSW was reported as much as nearly 80% among the quantity of MSW generation in most Chinese cities (Cao and Lin, 2010; He et al., 2008; Wei et al., 2000). However, limited attentions have been paid to HSW, and few strategies or regulations about HSW managements have been well implemented in China.

China is now experiencing rapid economic development and urbanization, which make it confront with the stringent challenges in HSW management. As the basic of an effective HSW management, the demand for reliable HSW generation databases has grown eagerly. However, few studies (Qu et al., 2009) on the HSW generations have been conducted in China based on field survey, which is widely accepted as an accurate approach for establishing waste databases (Chang et al., 2011; Yuan et al., 2006; Tai et al., 2011).

Therefore, we implemented a case study in Suzhou, a typical developed city in East China, to quantify the HSW generation characteristics in several dimensions: physical categories, recycling potential, and the components of packaging waste. A systematic field-tracking survey of 240 households was implemented for one week in each season from the summer of 2011 to the spring of 2012. The HSW generation rates were then analyzed and modeled. The environmental and social-economic benefits of waste composting and recycling were also analyzed. In the end, we recommend strategies for HSW management in Suzhou, which could provide reference for other Chinese cities.

2. Methodology

Collecting waste at generation sites and directly sorting them is one of the most accurate approaches for characterizing waste (Martin et al., 1995; Chang and Davila, 2008), and this kind of survey should be conducted at least one week during each season of a year (Thanh et al., 2010). In this study, we used field-tracking survey method to manually classify and analyze the characteristics of HSW generation. We treated one family as a basic unit, one year as the macro cycle and one week in various seasons as the micro cycle.

2.1. Survey of household solid waste

2.1.1. Study area

Suzhou is located in the east coast of China (Fig. 1), bordering Shanghai and covering an area of 2743 km^2. It is one of the most developed cities in China, whose per capita GDP (based on residential population) reached 114,029 RMB in 2010, which was even higher than that of Beijing (87,091 RMB) (CBSC, 2011) and Shanghai (85,373 RMB) (SBSC, 2011). The residential population exceeded 5.45 million, and each household had an average of 2.8 family members (SBSC, 2011).

According to He et al. (2008), management of HSW has become a severe challenge for Suzhou in recent years. There is only one sanitary landfill, one incineration plant and one composting site for this city, which are all located at Qizishan in Suzhou. And HSW in Suzhou is currently collected, managed and disposed with other MSW. It should be noted that the minor amount of HSW spontaneously recycled by the residential household were usually not reported in the official statistics of China's cities, let alone the amount of recyclable HSW. In 2012, more than 75% of Suzhou's MSW generation was HSW, and nearly 40% and 60% of the HSW were respectively buried in landfill and incinerated. Because of land scarcity, local government has required all the HSW to be incinerated since 2013. However, the actual incineration rate was about 90% according to the evaluation by Suzhou Environmental Sanitation Administration Agency (SESAA).

Most Chinese cities have experienced uneven development patterns, with both highly modernized and relatively laggard districts in a same period (Zhou and Cao, 1999). Suzhou has followed this development pattern and can be divided into two districts. Northern Suzhou, including Xiangcheng and Gusu, is the city's historical epitome and was defined as the old district. Other areas of Suzhou, including Suzhou Industrial Park (SIP), Huqiu, Wuzhong, and Wujiang were considered to be dynamic and defined as the new district. As presented in Fig. 1, we selected two representative communities (Erlangxiang and Linglongwan) in above two districts as the sampling points for this HSW survey on behalf of discrepant socio-economic characteristics, consumption patterns and residential lifestyles.

2.1.2. Household survey

Previous studies (Bandara et al., 2007; Liu et al., 2003; Ojeda-Benítez et al., 2008; Qu et al., 2009; Tadesse et al., 2008; Thanh et al., 2010) reported that an important driving factor propelling HSW generation was household size. In Suzhou, household sizes were broken down and recorded in SBSC (2011) that 15.3% with one person, 31.8% with two people, 31.3% with three people, 10.7% with four people, and 10.6% with more than four people. The 240 target households (half in the old district and half in the new district, respectively) were divided into five types with the same proportions of various sizes of families as mentioned above at each survey stage. Households of each size were randomly selected within the survey communities.

Traditional questionnaire (paper form) was carried out in this study using community assemblies and face-to-face household visit for multiple times during the pre-survey and survey periods. This enabled us to build up household profiles, which include the basic attributes (e.g. age, gender, education) of household daily manager (the household member who manages daily household affairs, such as shopping, dealing with HSW) and head of household (the household member who has the highest authority) (Gu et al., 2014), household size, household income, household type and even household daily consumption expenditures for various commodities and services (Table S1). Details of the questionnaire were described in Table S2 1 and 2. This information allowed us