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Household hazardous waste quantification, characterization and management in China's cities: A case study of Suzhou

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ABSTRACT

A four-stage systematic tracking survey of 240 households was conducted from the summer of 2011 to the spring of 2012 in a Chinese city of Suzhou to determine the characteristics of household hazardous waste (HHW) generated by the city. Factor analysis and a regression model were used to study the major driving forces of HHW generation. The results indicate that the rate of HHW generation was 6.16 (0.16–31.74, 95% CI) g/person/day, which accounted for 2.23% of the household solid waste stream. The major waste categories contributing to total HHW were home cleaning products (21.33%), medicines (17.67%) and personal care products (15.19%). Packaging and containers (one-way) and products (single-use) accounted for over 80% of total HHW generation, implying a considerable potential to mitigate HHW generation by changing the packaging design and materials used by manufacturing enterprises. Strong correlations were observed between HHW generation (g/person/day) and the driving forces group of "household structure" and "consumer preferences" (among which the educational level of the household financial manager has the greatest impact). Furthermore, the HHW generation stream in Suzhou suggested the influence of another set of variables, such as local customs and culture, consumption patterns, and urban residential life-style. This study emphasizes that HHW should be categorized at its source (residential households) as an important step toward controlling the HHW hazards of Chinese cities.

1. Introduction

Household hazardous waste (HHW) is a heterogeneous waste category that is usually defined as "flammable, corrosive, reactive, caustic, and toxic" (Kummer, 1999). HHW is an important part of the household solid waste (HSW) stream and is closely associated with residential daily life. HHW can not only include such products as batteries, pharmaceuticals, discarded light bulbs and mercury thermometers but also used motor oil, pesticides and solvent and paint residues in used bottles and cans (also known as "packaging and containers", PC). Rapid global urbanization and increases in living standards in recent decades have led to changes in the HHW generation characteristics due to increases in buying power and easier access to products that are convenient but not always safe. In other words, people are exposed to a greater amount of diversified hazardous materials and/or potentially hazardous materials, such as phthalates (Bauer and Herrmann, 1997), antibacterial agents (Perencevich et al., 2001) and monosodium glutamate (Ohguro et al., 2002).

If not well-managed, unpredictable negative outcomes of HHW can occur at its source (residential households), waste collection points, during transportation, and after deposit in landfills and/or incineration sites, with the potential to cause permanent damage to the environment and public health. In fact, the environmental and public health impact of HHW at different stages has been investigated. (1) Delivery stages: a gallon of waste oil poured on the ground can contaminate over one million gallons of drinking water. More seriously, hazardous materials spills can also affect sewer systems (causing explosions in pipes) and even the overall water management system (Region 4 DOD, 2000; UCLA, 2008). (2) Collection and transportation stages: inappropriate HHW classification management, such as improper disposal of aerosol cans, can lead to serious accidents (fires and explosions) that are destructive to transfer station equipment and hazardous to employees (Slack et al., 2004; Palmquist and Hanæus, 2005; Delgado et al., 2007; Otoniel et al., 2008). (3) Final treatment stages: mixing HSW compost with HHW would likely cause it to

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exceed the legally permissible heavy metal limits, which would affect the sales of the final compost (McDougall et al., 2001; Asari et al., 2008). Additionally, the process of deriving biogas from waste without sorting would decrease biogas production compared to the process with sorting (Aprilia et al., 2013). HHW also increases in toxicity if municipal solid waste (MSW) landfill leachate comes into contact with hazardous pollutants, which has been widely reviewed as a primary cause of ground water contamination (Bauer and Herrmann, 1997; Slack et al., 2004, 2005; Komilis et al., 2011). For instance, dioxanes, such as 1,4-dioxane, and dioxolans originating from alkyd resin production wastes and discarded paint and similar products can potentially cause fatalities. High concentrations, as observed in MSW leachate from Japanese and Swedish landfills, can cause severe public health damage (Yasuhara et al., 1997; Paxus, 2000). HHW has also had a harmful effect on air quality, with the burning of batteries leading to the release of mercury, lead, cadmium and nickel into the atmosphere, as reported by Christensen et al. (2001), Slack et al. (2005) and Zhu et al. (2009). In sum, materials hazardous to the environmental and public health have continued to be hot topics throughout the world (Orloff and Falk, 2003; Duan et al., 2008), and the question of how to control HHW has become a key environmental protection issue. Therefore, HHW must be studied to provide credible information for waste managers and planners.

In recent decades, some researchers (Stanek et al., 1987; Reinhart, 1993; Chaaban, 2001; Gendebien et al., 2002; Yasuda and Tanaka, 2006; Delgado et al., 2007; Voulvoulis et al., 2007; Otoniel et al., 2008; Aprilia et al., 2013) have studied the characteristics of HHW stream in various regions around the world. Yasuda and Tanaka (2006) found that the rate of HHW generation was 5.48 g/person/day in Japan, accounting for 0.25–0.43% of Japan's total HSW generation. Voulvoulis et al. (2007) collected 1 ton of HHW from 500 UK households and estimated the rate of HHW generation to be 7000 tons per month. Otoniel et al. (2008) found that approximately 1.60% of the HSW stream in Morelia, Mexico is HHW, with an HHW generation rate of 7.10 tons per day. Thanh et al. (2010) reported a rate of HHW generation of 0.53 g/person/day, accounting for approximately 0.20% of the HSW stream in Mekong Delta City, Vietnam. Researchers have also analyzed the relationships between HHW generation and parameters of income (Gaxiola, 2003), consumption patterns (Otoniel et al., 2008), geographical location (Delgado et al., 2007; Otoniel et al., 2008), dwelling type (Yasuda and Tanaka, 2006) and waste management policies (Slack et al., 2009; Aprilia et al., 2013; Lu et al., 2013). However, no such study of HHW has been conducted in China. The available results show that HHW generation, composition, and driving forces often vary from region to region, indicating that HHW management should be conducted differently in different countries. Therefore, local authorities need to create their own HHW database as quickly as possible.

In China, hazardous wastes are classified into three types: (1) industrial hazardous waste, (2) medical hazardous waste, and (3) HHW. Industrial hazardous waste and medical hazardous waste are separately disposed of and accurately recorded in accordance with Chinese law. Comparatively speaking, HHW is neglected in China, with no governing legal framework. Moreover, although most Chinese cities encourage the separation of HHW, such as batteries, oil paint and light tubes, prior to disposal, these items are generally mixed in HSW and/or MSW during collection and disposal (Tai et al., 2011). China is one of the fastest developing countries with an average of 8% GDP increase in recent years (according to the China Official Statistics, China's 2013 GDP growing by 7.7% over the previous year). There is a huge imbalance existing between economic development and HHW management in China. However, no statistics and/or investigational data are available on a national or city level, indicating a critical need to study China's HHW to enable the proposal and development of an effective HHW management system.

Therefore, we planned and implemented a case study to quantify the generation and characteristics of HHW from 240 urban residential households in Suzhou, a typical developed city on China's eastern coast. A tracking survey was conducted for one week in each season from the summer of 2011 to the spring of 2012, followed by modeling and extrapolation of HHW generation. Based on these analyses, we attempted to identify the current state of the HHW generation stream and then to provide suggestions for promoting HHW management in China. This report describes an original systematic tracking survey of HHW analysis in a Chinese city over a four-stage survey period. The results of this study will provide a benchmark for the discussion of China's HHW generation and will also help officials to plan strategies designed to manage China's HHW.

2. Methods

Duan et al. (2008) reported that disagreement were existed between the official volume statistics and investigational data about hazardous waste generation in China. Martin et al. (1995) indicated that one of the most accurate approaches to characterizing waste composition consists of collecting waste at the point of generation and directly sorting it according to the type of material. Therefore, this study applied the field tracking survey method to analyze the generation and characteristics of HHW in a Chinese city, Suzhou.

2.1. HHW survey implementation

2.1.1. Description of the study area

Suzhou is located on the east coast of China and borders Shanghai (Fig. 1). In 2012, the urban area covered 2742.62 km^2 and was home to a residential population of more than 5.45 million (SBSC, 2012). As one of the fastest growing cities (Suzhou's GDP ranked 6^{th} place in China), its annual per capita GDP reached 114,029 RMB in 2012 (residential population), higher than that of both Beijing (87,091 RMB, (BBSC, 2011)) and Shanghai (85,373 RMB, (SBSC, 2011)).

There is only one specialized enterprise in charge of the collection, disposal and integrated utilization of hazardous waste for Suzhou. However, HHW is generally collected, managed and disposed along with HSW, which is landfilled and/or incinerated in the disposed site of Qizishan, Suzhou. HHW and HSW are handled in the same way in most other Chinese cities such as Hangzhou (Zhuang et al., 2008), Nanjing and Guilin (Tai et al., 2011).

Along with rapid urbanization, most Chinese cities have experienced a modular pattern of development, resulting in both well-modernized (new, developed) and relatively undeveloped (old, developing) districts (Zhou, 1999). As shown in Fig. 1, Suzhou has also followed this development pattern. The principal investigators of this study divided the survey area into two districts according to the levels of economic development and urbanization. Northern Suzhou, including Xiangcheng and Gusu, is the city's ancient historical section and is defined as the old district. Other areas of Suzhou, including Suzhou Industrial Park (SIP), Huqiu, Wuzhong and Wujiang, make up the new district. Despite being managed by the same municipal government, generally the two districts have different socioeconomic characteristics, life-styles and consumption patterns, among other differences.

2.1.2. Sampling households

Environmental problems associated with waste generation are among the societal changes in which the household plays an important role. Consumption patterns and life-style influence a