Waste Management 41 (2015) 3–11

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Estimating municipal solid waste generation by different activities and various resident groups in five provinces of China

Hui-zhen Fu, Zhen-shan Li *, Rong-hua Wang

Department of Environmental Engineering, Peking University, The Key Laboratory of Water and Sediment Sciences, Ministry of Education, Beijing 100871, China

ARTICLE INFO

Article history:
Received 19 November 2014
Accepted 17 March 2015
Available online 8 April 2015

Keywords:
Estimate
Waste generation
Activity
Resident group

ABSTRACT

The quantities and composition of municipal solid waste (MSW) are important factors in the planning and management of MSW. Daily human activities were classified into three groups: maintenance activities (meeting the basic needs of food, housing and personal care, MA); subsistence activities (providing the financial support requirements, SA); and leisure activities (social and recreational pursuits, LA). A model, based on the interrelationships of expenditure on consumer goods, time distribution, daily activities, residents groups, and waste generation, was employed to estimate MSW generation by different activities and resident groups in five provinces (Zhejiang, Guangdong, Hebei, Henan and Sichuan) of China. These five provinces were chosen for this study and the distribution patterns of MSW generated by different activities and resident groups were revealed. The results show that waste generation in SA and LA fluctuated slightly from 2003 to 2008. For general waste generation in the five provinces, MA accounts for more than 70% of total MSW, SA approximately 10%, and LA between 10% and 16% by urban residents in 2008. Females produced more daily MSW than males in MA. Males produced more daily MSW than females in SA and LA. The wastes produced at weekends in MA and LA were far greater than on weekdays, but less than on weekdays for SA wastes. Furthermore, one of the model parameters (the waste generation per unit of consumer expenditure) is inversely proportional to per-capita disposable income of urban residents. A significant correlation between gross domestic product (GDP) and waste generation by SA was observed with a high coefficient of determination.

1. Introduction

Solid waste research has attracted increasing attentions in recent decades, while solid waste management was one of the hot issues based on the statistical analysis of author keywords (Fu et al., 2010). The prediction of municipal solid waste (MSW) generation plays an important role in solid waste management (Dyson and Chang, 2005). The amount and composition of waste generation provides the basic information needed for the planning, operation and optimization of waste management systems (Beigl et al., 2008). Modeling is a tool used for the planning and management of municipal waste (Benítez et al., 2008). Conventional prediction models include correlation analysis models (Dennison et al., 1996a,b), multiple regression analysis models (Hockett et al., 1995), Single regression analysis models (Thøgersen, 1996), group comparison (Parfitt et al., 2001), system dynamics (Dyson and Chang, 2005), time series analysis (Leao et al., 2001), gray fuzzy dynamic models (Chang and Lin, 1997; Chen and Chang, 2000), and input–output analysis models (Gay et al., 1993; Patel et al., 1998; Joosten et al., 2000).

Estimation models play an important role in predicting the MSW amount and composition, but most of these models are incapable of describing the waste generation if the waste is generated by different activities and is from different resident groups. Modeling the waste generation distribution is a useful method to anticipate the design of waste management strategies as a function of consumption and demographic development, and to plan for future management needs (Purcell and Magette, 2009). Researchers examined waste generation from many different angles, especially in recent years. They explored rapid methods for estimating the rate of solid waste generation (Ibiebele, 1986), identified the waste spatial distribution (Purcell and Magette, 2009; Yenice et al., 2011), waste composition distribution (Moriwaki et al., 2009), and time-related waste distribution (Boldrin and Christensen, 2010), to aid more targeted waste planning and policy decisions.

* Corresponding author at: No. 5, Yi Heyuan Road, Haidian District, Department of Environmental Engineering, Peking University, Beijing 100871, China. Tel.: +86 10 6275 3962; fax: +86 10 6275 6526.

E-mail address: lizhenshan@pku.edu.cn (Z.-s. Li).

http://dx.doi.org/10.1016/j.wasman.2015.03.029
0956-053X/

As a whole, when compared with existing predictions or estimates for MSW generation, the estimation of MSW distribution by different activities and resident groups at a city level, in this paper presents a novel and reliable view for the analysis of MSW generation. Moreover, it is difficult to obtain the amount of waste generated by different activities and resident groups by field surveys, because it is hard to measure waste generation by different resident groups in different time. Recently, a new model based on the relationship of consumption and waste was recently proposed to describe the MSW generation in different activities and by different resident groups (Li et al., 2011). This study employed this model to present waste generation by different resident groups in different time for a wider area of five provinces in China. Five provinces which have top economic development levels and different geographical positions were chosen to study the differences in waste generation for each activity of male and female residents on weekday and weekend. This will help the development of waste management policies and understand MSW generation patterns beyond the current prediction techniques. Furthermore, a high correlation coefficient was observed between the parameters of the newly developed model and economic related indicator.

2. Model

Waste generation has long been a consequence of human activity (Louis, 2004). It is the result of a production and consumption cycle which starts with the production of consumer goods and continues with the generation, collection, storage, and final disposal of MSW. All manufactured, commercialized and consumed products are finally converted, or at least partially converted, into waste (Benítez et al., 2008).

A new model based on the relationship of consumption and waste was proposed to describe the MSW generation in different activities and by different resident groups (Li et al., 2011). The conceptual model and mathematical model were presented sequentially.

2.1. Conceptual model

The essential reason for MSW generation is the consumption of consumer goods in human beings' daily activities. Consumption requires time, and human activities consume goods (Jara-Diaz, 2003). Consumer goods eventually turn into disposal in part (Benítez et al., 2008). People play an important role as the users who utilized consumer goods and the producers of waste. Therefore, the concrete relationships between residents and MSW generation in a city can be divided into four levels: resident groups, consumer goods, activity and waste composition, as shown in Fig. 1 (Li et al., 2011). Each level fell into groups, and the line relationships turn to complex distributions between adjacent levels. All the people in the city were divided into Rn groups (R1, R2, ..., Ri, ..., Rn). Each group of residents conduct An groups of activities (A1, A2, ..., Ai, ..., An), and in each activity group, Cn groups of consumer goods (C1, C2, ..., Ci, ..., Cn) were consumed and each group of consumer goods finally converted to Wn groups of waste composition (W1, W2, ...,Wi, ..., Wn). Ultimately, the total quantity of MSW is the sum of various waste groups derived from consumer goods in different activities by all people in the city. The important relationships were obviously involved, between resident group and activities, between activities and consumer goods, and between consumer goods and waste composition. Three important parameters were therefore proposed based on these three relationships to describe the waste generation.

2.2. Mathematical model

Initially, two assumptions were proposed (Li et al., 2011):

(1) The research target of the model was the group behavior instead of individual behavior. Residents, consumer goods, and waste were classified into groups. Thus, the gender, age, education, and other personal features of the actors were not included in the model.
(2) The quantity of waste generation was only determined by consumer expenditure. All the consumer goods consumed in one year were finally converted into MSW. The consumer goods of one group share the same rate of conversion. The quantity of waste generation is directly proportional to consumer expenditure and the waste generation per unit consumer expenditure can be considered constant in a short time (i.e. <5 y) at constant prices.

The quantity of waste generation (X) in a city equals the product of waste generation per unit of consumer expenditure (K), consumer expenditure distribution to activities in unit time (C) and time assigned to activities by resident groups (T).

$$X = KCT \tag{1}$$

Eq. (1) is a general equation for waste generation. The concrete mathematical equations for various detailed groups of MSW generation are explained below.

The product of waste generation per unit consumer expenditure in year i (k_i) and consumer expenditure distribution to activity j in unit time (c_j) is the rate of waste generation of each group of activity j in year i (r_{ij}). Each activity j that residents participated in would produce MSW; the production rate of which can be calculated in year i using Eq. (2):

$$R_{ij} = K_i \cdot C_j \tag{2}$$

where:

(1) $K_i = \begin{Bmatrix} k_1 \\ k_2 \\ \dots \\ k_i \end{Bmatrix}$, k_i, waste generation per unit of consumer expenditure in year i.
(2) $C_j = \{c_1 \quad c_2 \quad \dots \quad c_j\}$, c_j, consumer expenditure distribution to activity j in unit time.
(3) $R_{ij} = \begin{Bmatrix} r_{11} & r_{12} & \dots & r_{1j} \\ r_{21} & r_{22} & \dots & r_{2j} \\ \dots & \dots & \dots & \dots \\ r_{i1} & r_{i2} & \dots & r_{ij} \end{Bmatrix}$, r_{ij}, waste generation rate of activity j in year i.

Males and females were the two residents groups analyzed here ($m = 1$, stands for male; $m = 2$, stands for female). Then, waste production by resident group m in activity j in year i can be calculated by time spent on activity j by resident group m (t_{mj}) and the waste generation rate of activity j in year i (r_{ij}) based on Eq. (3):

$$x_{mj} = t_{mj} \cdot r_{ij} \tag{3}$$

where

(1) $T_{mj} = \begin{Bmatrix} t_{11} & t_{12} & \dots & t_{1j} \\ t_{21} & t_{22} & \dots & t_{2j} \end{Bmatrix}$, t_{mj}, time assigned to activity j by resident group m.
(2) $X_{mj} = \begin{Bmatrix} x_{11} & x_{12} & \dots & x_{1j} \\ x_{21} & x_{22} & \dots & x_{2j} \end{Bmatrix}$, x_{mj}, waste generation rate of activity j by resident group m in year i.