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Forecasting of municipal solid waste quantity in a developing country using multivariate grey models

Rotchana Intharathirat [a], P. Abdul Salam [a,*], S. Kumar [a], Akarapong Untong [b]

[a] Energy Field of Study, School of Environment, Resources and Development, Asian Institute of Technology, P.O. Box 4, KlongLuang, Pathumthani 12120, Thailand
[b] School of Tourism Development, Maejo University, Chiangmai, Thailand

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ABSTRACT

In order to plan, manage and use municipal solid waste (MSW) in a sustainable way, accurate forecasting of MSW generation and composition plays a key role. It is difficult to carry out the reliable estimates using the existing models due to the limited data available in the developing countries. This study aims to forecast MSW collected in Thailand with prediction interval in long term period by using the optimized multivariate grey model which is the mathematical approach. For multivariate models, the representative factors of residential and commercial sectors affecting waste collected are identified, classified and quantified based on statistics and mathematics of grey system theory. Results show that GMC (1, 5), the grey model with convolution integral, is the most accurate with the least error of 1.16% MAPE. MSW collected would increase 1.40% per year from 43,435–44,994 tonnes per day in 2013 to 55,177–56,735 tonnes per day in 2030. This model also illustrates that population density is the most important factor affecting MSW collected, followed by urbanization, proportion employment and household size, respectively. These mean that the representative factors of commercial sector may affect more MSW collected than that of residential sector. Results can help decision makers to develop the measures and policies of waste management in long term period.

1. Introduction

To plan, manage and use municipal solid waste (MSW) in a sustainable way, accurate forecasting of MSW generation and composition plays a key role (Batinic et al., 2011; Beigl et al., 2008; Cherian and Jacob, 2012; Kumar et al., 2011). However, due to lack of sufficient reliable historical data of MSW characteristics, particularly in developing countries, it is difficult to develop accurate forecasting models (Rimaityte et al., 2011). Failure of accurate forecasting and assessment may lead to several problems in the environment and waste management systems, such as increased environmental impacts and over-or under-estimated capacity of MSW treatment facilities as well as irrelevant policies. In the context of MSW management, it is also necessary to understand how influencing factors (e.g. socio-economic and demographic factors) affect MSW generation.

Beigl et al. (2008) reviewed 45 methods, used for forecasting MSW quantities, which could be categorised into seven groups, such as correlation analysis, group comparison, single regression analysis, multiple regression analysis, time-series analysis, input–output analysis, and system dynamics. Among these methods, regression analysis is widely used to forecast MSW generation due to its mature theory and simple algorithms (Xu et al., 2013). However, regression analysis neither can learn from new data nor can adapt to new situations, and its precision is poor when inaccurate data are used (Ordonez-Ponce et al., 2004; Thanh et al., 2010). Regression analysis does not also consider all factors affecting waste generation (Noori et al., 2009b).

Several literature have shown better results using time-series analysis which appears to be the most appropriate forecasting method considering seasonal impacts (Chung, 2010; Rimaityte et al., 2011). However, this requires a large number of data to provide accurate forecasting in short term period (Beigl et al., 2008; Xu et al., 2013). In waste management perspective, time-series analysis leads to lack of power of generalization and intellectual values, while factor analysis can explain the changes of MSW characteristics associated with influencing variables (Beigl et al., 2008; Chung, 2010).

Recently, Artificial Neural Network (ANN) has been shown to provide more accurate results compared to regression analysis and traditional time series analysis because of the ANN's ability

* Corresponding author. Tel.: +66 2 524 5420; fax: +66 2 524 5439.
E-mail addresses: rotchana.in@gmail.com (R. Intharathirat), salam@ait.ac.th (P. Abdul Salam), kumar@ait.ac.th (S. Kumar), akarapong_un@hotmail.com (A. Untong).

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to learn and construct a complex nonlinear system through a set of input/output examples (Ali Abdoli et al., 2012; Batinic et al., 2011; Jalili Ghazi Zade and Noori, 2008; Kumar et al., 2011; Noori et al., 2009a; Ordonez-Ponce et al., 2004; Patel and Meka, 2013; Roy et al., 2013; Shahabi et al., 2012). However, it needs a large number of historical data and has some disadvantages, such as over-fitting training, difficulty in the determination of network architecture, local minimum, and poor generalizing performance remain unsolved and limit the application of ANN approach into practice (Abbasi et al., 2014).

To overcome the lack of data for modeling and the complexity of the forecasting model, Grey model (GM) has been implemented successfully to forecast for long-term periods with higher accuracy than conventional time series analyses and ANN (Pai et al., 2008; Srivastava and Nema, 2006; Xu et al., 2013). It is usually represented as GM (m, n) for dealing with m, the order of the differential equation and using n variables (Hsu and Wang, 2009).

Grey system theory which consists of grey relational analysis (GRA), grey generating space, grey forecasting, grey decision making, grey control, grey mathematics and grey theory was initially pioneered by Deng (1989) in 1982. For grey forecasting, GM (1, 1), an univariate model, conforms to the grey exponential law (Tien, 2012) and is the most widely used in MSW forecasting and other applications, with higher accuracy (Chen and Chang, 2000; Guo, 2009; Liu and Yu, 2007; Srivastava and Nema, 2006; Untong, 2012; Xiang and Daoliang, 2007; Xu et al., 2013; Ying et al., 2011). In addition, GM (1, 1)-α, i.e., applying GM (1, 1) with adaptive levels of α, has also been used in a tourism field (Huang, 2012), however, it has not been applied in MSW management.

Nevertheless, forecasting of MSW generation by univariate model is not satisfactory because solid waste is heterogeneous and can be affected by numerous factors (Ali Abdoli et al., 2012; Chen, 2010). Therefore, GM (1, n), a multivariate model, which was also pioneered by Deng (Deng, 1988 cited from Tien, 2012) has been implemented for MSW forecasting (Wang et al., 2012; Zhang, 2013) and other applications (Hsu and Wang, 2009; Pai et al., 2008, 2007). For the multivariate grey model, GRA was used to investigate the relationship between MSW generation and other factors affecting amount of waste (Liu and Yu, 2007; Wang et al., 2012). However, in view of provision of supplementary information, the prediction accuracy of GM (1, n) should be higher than that of GM (1, 1). The solution of the whitening differential equation of GM (1, n) can be mostly inaccurate and may thereby producing significant practical forecasting errors (Tien, 2012). According to Tien (2012), the GM (1, n), as $n \geqslant 2$, can only be used for relational analysis of the system's factors but cannot be used for prediction.

Grey model with convolution integral GMC (1, n) was proposed by Tien (2005) to derive a more accurate trend by adding a grey control parameter u, like GM (1, 1) besides the same terms of the GM (1, n) model. Thus, the GMC (1, n) can degenerate to be GM (1, 1) for the special case $n = 1$ and becomes the linear differential equation (Tien, 2005). GMC (1, n) model has been applied in only few studies such as internet access population forecast (Wu and Chen, 2005) and the indirect measurement of tensile strength forecast (Tien, 2012). However, its application of MSW management has not been found.

A few literature identified and quantified the influencing factors affecting MSW quantities in residential and commercial sectors using regression analysis and geographical information system (GIS) approaches (Buenrostro et al., 2001; Lebersorger and Beigl, 2011; Purcell and Magette, 2009). Several studies forecasted MSW quantity in Thailand using regression and time-series analyses associated with few influencing factors, such as population, GDP and expenditure (DEDE, 2009; Luanratana, 2003; Mongkoldhumrongkul and Thanarak, 2012; TGO, 2010; Vanapruk, 2012). These results might be inaccurate due to insufficient number of data. Also, a study investigated the factors affecting MSW generation by comparing standardize coefficient at a city level (Sukholthaman and Chanvarasuth, 2013). However, the model providing explanatory factors affecting residential and commercial wastes has not been found.

This study attempts to identify, quantify and select suitable factors affecting the MSW collected. For policy and planning of waste management, these factors represent the influence of residential and commercial sectors. Especially, the study aims to develop the alternative models (i.e. GM (1, 1), GM (1, 1)-α, GM (1, n) and GMC (1, n)) and select the most accurate to forecast MSW collected with the uncertainty forecasting, prediction interval (PI) approach.

The information related to Thailand and the data collection used in this study is given in Section 2. The methodology and the literature review of the hypothesis of influencing factors and MSW forecasting models are described in Section 3. The results are illustrated and discussed in Section 4. Finally, Section 5 concludes the key findings and provides recommendations for further research.

2. Background of study area and data

Thailand located in Southeast Asia has total area of approximately 513,000 km^2 and has population of 64.6 million in 2012. As one of the rapidly increasing income and urbanization country, MSW generation in Thailand increased by 3.34% during the four years, i.e., from 23.93 million tonnes (Mt) in 2008 to 24.73 Mt in 2012 (PCD, 2013). The highest amount of MSW generation was 25.35 Mt in 2011 due to the huge flood. In 2012, about 13.62 Mt or 55% of MSW generated was disposed through open dumping or burning sites and left within the township (PCD, 2013). In early 2014, a fire broke out at several dump sites and caused two hundred residents to move away due to the release of poisonous gases (Fredrickson, 2014). Hence a critical problem facing Thailand is also a serious issue of managing the huge amount of MSW generated associated with environmental impacts. Ineffective policies is another vital problem of MSW management. In the Tenth National Economic and Social Development Plan (NESDP: 2007–2011), Thailand could not achieve both targets as part of MSW management strategies i.e., 30% of waste generation recovered by 3R and waste-to-energy (WTE) (about 26% of such was achieved) and 40% of waste generation disposed properly (approximately 38% of such could be obtained) (Vanapruk, 2012).

As waste generation cannot be measured directly in developing countries, the amount waste reported in a country level is normally obtained from municipalities measuring from the estimation of vehicles capacity and/or weight at the dump sites. The quantities of MSW was reported by the Pollution Control Department (PCD) in the country level, as called MSW collected in this study, including the amount of residential and commercial wastes (PCD, 2001-2013, 2011). The time series of the amount of MSW collected and influencing factors were accessed from PCD, the National Statistical Office (NSO) (NSO, 2013), the Bank of Thailand (BOT) (BOT, 2014), the Bureau of Registration Administration (BORA) (BORA, 2014) and the Bureau of Epidemiology (BOE) (BOE, 2014). These time series data during 2000–2012, totally 13 data, were used to develop models. Ten data, i.e. during 2000–2009, were used in building the alternative models, while the remaining data; i.e., three data during 2010–2012, were used for verification by the calculation of the error measure (mean absolute percentage error: MAPE).

3. Methodology

As shown in Fig. 1, the study could be distinguished as having four main steps for forecasting the MSW collected, i.e. (i) identifying and selecting the influencing factors, (ii) developing