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Research article

Forecasting municipal solid waste generation using prognostic tools and regression analysis

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ABSTRACT

For an adequate planning of waste management systems the accurate forecast of waste generation is an essential step, since various factors can affect waste trends. The application of predictive and prognosis models are useful tools, as reliable support for decision making processes. In this paper some indicators such as: number of residents, population age, urban life expectancy, total municipal solid waste were used as input variables in prognostic models in order to predict the amount of solid waste fractions. We applied Waste Prognostic Tool, regression analysis and time series analysis to forecast municipal solid waste generation and composition by considering the Iasi Romania case study. Regression equations were determined for six solid waste fractions (paper, plastic, metal, glass, biodegradable and other waste). Accuracy Measures were calculated and the results showed that S-curve trend model is the most suitable for municipal solid waste (MSW) prediction.

1. Introduction

Human activities always produce waste, and the generation rates increase with population expansion and economic growth (EEA, 2003; Giusti, 2009). They say that the waste amount could reflect the socio-economic development, industrialization and urbanization (Hogland and Marques, 2007; Pires et al., 2011). In fact, waste generation is a symptom of raw material and energy losses, thus leading to additional costs to society for collection, treatment and disposal (EEA, 2003; Schiopu et al., 2007).

Waste management is becoming an emerging problem for national and local governments, since the manners in which the growing amount of solid waste are managed do influence the human health and the environment and could contribute significantly to resources conservations (Berechet and Fischer, 2015; Costiuc et al., 2015; Ghinea et al., 2012; Giusti, 2009; Ngoc and Schnitzer, 2009). Environmental pressures from generation, collection and processing of waste including emissions to air, soil and water have different impacts on the human health and the environment (Bjelić et al., 2015; Luca and Ioan, 2014; Orlescu and Costescu, 2013; Schiopu et al., 2009; Taboada-González et al., 2011). Effective management of solid waste has become environmentally, economically and socially mandatory due to the escalation of

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environmental problems emerging from solid waste generation (Panaitescu and Bucuroiu, 2014). According to the European Landfill Directive, waste management hierarchy recommends the decrease of waste quantity landfilled and the increasing in weight and preference for waste minimization, recycling and reuse alternatives (Costuleanu et al., 2015; Gaba et al., 2014; Ghinea et al., 2014; Panaitescu and Bucuroiu, 2014).

Modeling approaches and structures are becoming increasingly applied to ensure a further accurately representation of the tangible municipal solid waste (MSW) management systems, especially in situations where lots of waste streams should be coped, from different sources and at various time phases, involving dozens of possible processes devoted to collection and treatment (Ghinea and Gavrilescu, 2010a; Levis et al., 2013). In general, planning and properly operation of solid waste management systems are affected by the evaluation of MSW streams and by more precise predictions of the waste amounts possible to be generated (Abbasi et al., 2013; Ghinea, 2012; Pires et al., 2011; Wang et al., 2012).

Since the prognosis of solid waste quantities represents an increasingly challenge for policy makers and planning, various predictive and prognosis models were proposed and developed in order to ensure sustainable planning, management and valorization of MSW.

Artificial Neural Networks (ANN) were applied as a reliable modeling tool by for the prediction of waste generation during different seasons, over short, medium or long time stages, based on absolute relative error and correlation coefficients (Zade and Noori, 2008). Four statistical indexes were used by Shamshiry et al. (2014): Mean Absolute Error (MAE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE), and correlation coefficient (R^2) for selection of the best forecasting waste generation model, using for prediction 10–20 neurons in the hidden layer for network training with 4 variables. ANN was applied for waste prediction in Serbia considering 4 inputs (economic indicator, average age of population, level of education and municipal sector), 10 neurons in hidden layer and 6 outputs (organic waste, paper, glass, metal, plastic and other waste) (Batinic et al. (2011). Karaca and Özkaya (2006) proposed a method based on the so called backpropagation algorithm (*n*eural *n*etwork-based *lea*chate *p*rediction method; NN-LEAP) for modeling leachate flow-rate in a municipal solid waste (MSW) landfill. ANN was also combined with Multiple Linear Regression for seasonal municipal solid waste generation prediction for 20 cities from Iran (Azadi and Karimi-Jashni, 2015). The results showed that Multiple Linear Regression has poor prediction performance, while ANN has a higher predictive accuracy.

Various regression analyses were performed in order to estimate how different variables can affect waste generation on long-term, considering urban population, gross domestic product, consumption level of residents as main factors which influences waste production (Grazhdani, 2015; Wei et al., 2013). Autoregressive Integrated Moving Average (ARIMA) time series model was applied by Owusu-Sekyere et al. (2013) to analyse the dynamics of solid waste generation using ARIMA (1, 1, 2); ARIMA (2, 1, 1) and ARIMA (1, 1, 1) models. Apart from these ARIMA models, Mwenda et al. (2014) used also ARIMA (2, 1, 0) and ARIMA (0, 1, 1) for prediction of solid waste amounts. The results of both studies indicated ARIMA (1, 1, 1) as the most appropriate model for the forecast of solid waste generation. Regression modeling was implemented in Waste Prognostic Tool and time series analysis (ARIMA and seasonal exponential smoothing) by Rimaityte et al. (2012) to predict municipal solid waste generation in Kaunas, Lithuania. They demonstrated that time series analysis is very suitable for short-term prediction of the waste generation (weekly variation). In order to describe and forecast the municipal solid waste fractions generation seasonal behavior for four East European cities, Denafas et al. (2014) applied time series analysis as well. A seasonal Auto Regressive and Moving Average (sARIMA) methodology was applied by Navarro-Esbri et al. (2002) for waste prediction. They demonstrated that sARIMA provides good results for daily and monthly data. Abbasi et al. (2013) proposed a new method of municipal solid waste forecasting based on application of support vector regression and data reduction.

Therefore, there is a perpetual need for waste management planning, when reliable data on waste generation, factors which influence waste generation and forecasts of waste quantities based on facts are obviously necessary. In this context, the aim of our paper is to provide and apply modeling tools to help the decision and policy makers and stakeholders in forecasting the amount of municipal solid waste fractions (paper and cardboard, plastic, glass, metals, biodegradable waste and others). In this purpose we have collected data for Iasi city, Romania such as: *the number of inhabitants*, *population aged 15 to 59 years*, *urban life expectancy* and *amounts of municipal solid waste generated* for the following years: 1990, 2000–2014 (16 years in total). The data used are at municipality level and are presented and illustrated in the Section 2 of the paper. The first three categories of data were collected from Iasi County Statistics (INS, 2015), while the amount of municipal solid waste and composition in Iasi were taken from data published by Doba et al. (2008) and Iasi County Council (2009). The age structure was chosen based on other studies which showed and proved that there is a positive relationship between the waste generation and the percentage of the medium age group (Beigl et al., 2005; Lindh, 2003). In fact, all variables were chosen based on other studies which demonstrated that these variables are linked with waste generation and have a greater influence than others (Beigl et al., 2005; Ordonez-Ponce, 2004; Rimaityte et al., 2012). After we studied other research papers and selected the variables, the data collection process was performed. If for the first tool (Waste Prognostic Tool) the variables were already fixed and required by the software, for the other one (Minitab) we have chosen from several variables those that provide results closer to the reality and certainly the same that we used for the first tool.

The estimated amounts of waste are based on the analysis of the relationship between socio-economic conditions and the rate of waste generation (Fig. 1). Data resulted from waste prediction is linked with waste generation, planning and exploitation of waste management system. From Fig. 1 it can be observed that waste prediction is performed based on waste amount and nature of waste (which have impact on environment, resources and human health), and on economic and social conditions. Waste quantities are estimated in order to take actions to prevent waste, improve current waste management systems and use data obtained (after projection) in modeling and simulation. By knowing waste fractions that will be generated and their quantities, we can propose waste treatment/disposal methods which can be included in different waste management systems and then we can evaluate the MSW systems proposed using life cycle assessment methodology for establishing the environmental impacts, cost-benefit methodology for determining the costs and benefits of implementing of these systems or applying multicriteria evaluation methods and others.

2. Municipal solid waste management in Iasi, Romania

Iasi is a city belonging to Iasi County, a part of the Region North East from Romania (Doba et al., 2008). The number of inhabitants has increased according to the INS data (Fig. 2a) (INS, 2015). Fig. 2b illustrates the population aged 15–59 years: the values of this indicator are between 60 and 70% for the time period studied. The urban life expectancy in the city has increased (INS, 2015) (Fig. 2c).