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Forecasting municipal solid waste generation using artificial intelligence modelling approaches

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ABSTRACT

Municipal solid waste (MSW) management is a major concern to local governments to protect human health, the environment and to preserve natural resources. The design and operation of an effective MSW management system requires accurate estimation of future waste generation quantities. The main objective of this study was to develop a model for accurate forecasting of MSW generation that helps waste related organizations to better design and operate effective MSW management systems. Four intelligent system algorithms including support vector machine (SVM), adaptive neuro-fuzzy inference system (ANFIS), artificial neural network (ANN) and *k*-nearest neighbours (kNN) were tested for their ability to predict monthly waste generation in the Logan City Council region in Queensland, Australia. Results showed artificial intelligence models have good prediction performance and could be successfully applied to establish municipal solid waste forecasting models. Using machine learning algorithms can reliably predict monthly MSW generation by training with waste generation time series. In addition, results suggest that ANFIS system produced the most accurate forecasts of the peaks while kNN was successful in predicting the monthly averages of waste quantities. Based on the results, the total annual MSW generated in Logan City will reach 9.4×10^7 kg by 2020 while the peak monthly waste will reach 9.37×10^6 kg.

1. Introduction

Accurate projection of municipal solid waste quantities is important for the successful planning of efficient waste management system. Future estimations of municipal solid waste generation serve as a basis in the development of existing waste management infrastructures as well as their further sustainable development and optimization. Imprecise forecasts may lead to widespread problems, such as inadequate or excessive waste disposal infrastructure (collection, incineration, landfilling or processing) (Buenrostro et al., 2001). Therefore, the demand for reliable data concerning waste generation is implicitly included in the majority of national waste management laws (Antanasijević et al., 2013). However, the process of forecasting MSW generation is often challenging and compound by rapidly changing and uncontrollable parameters (Beigl et al., 2008).

There is a growing body of literature on forecasting municipal solid waste (MSW) generation which includes a high heterogeneity of applied models from purely application-oriented to highly sophisticated academically inclined tools (Chung, 2010). Over the period from 1970 to 2014, more than 80 studies addressing the topic of forecasting of MSW generation have been published. MSW forecasting methods can be broadly classified into five main categories: descriptive statistical methods (Bider and Franklin, 1980; Even et al., 1981; Sha'Ato et al., 2007); regression analysis (Denafas et al., 2014; Franchetti, 2012; Vivekananda and Nema, 2014; Wei et al., 2013); material flow model (Liu et al., 2014; Schiller et al., 2010; Tonjes and Greene, 2012; Zhang et al., 2012); time series analysis (Katsamaki et al., 1998; Navarro-Esbrí et al., 2002; Xu et al., 2013); and artificial intelligence models (Abbasi et al., 2014; Antanasijević et al., 2013; Kumar et al., 2011; Noori et al., 2010). However, all modelling approaches have their own strengths and weaknesses.

Conventional and descriptive statistical methods of forecasting MSW generation usually use population growth and average per-capita waste generation as the main predictor (Abdoli et al., 2012). However, this method is no longer effective due to the dynamic characteristics of MSW generation process (Abbasi et al., 2013). Regression analysis is a widely used modelling technique because of the simplicity of underlying mathematics and well-developed statistical theory. In regression analysis, MSW generations are associated with economic and demographic variables (Abdoli et al., 2011). In order to conform with the theoretical

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assumptions of regression, input variables must meet stringent requirements such as independence, constant variance and normality of errors (Hockett et al., 1995). All of these requirements place limitations on the suitability of regression for predicting MSW generation as a complex real-world problem. The material flow model can fully characterize the dynamic properties in the process of solid waste generation. However, this modelling approach can be used for predicting total waste rather than collected waste (Beigl et al., 2008). Nevertheless, collected waste may still be estimated where recycling and littering rates are known. However, Hockett et al. (1995), after analysing results obtained from input-output models like material flow analysis, highlighted that comparisons of the results with real observed waste data on the highest aggregation levels were questionable due to the presence of different aggregations or because of low consistency within the studies. Hekkert et al. (2000) further suggested that comparison may even prove to be impossible because studies on final consumption are almost completely lacking. In contrast with the previously mentioned methods, time series analysis does not rely on the estimation of social and economic factors; thus it has the advantage of overcoming the lack of social parameters and other predictors. Time series data of waste generation are dynamic in nature, and it is possible to employ non-linear tools in order to discern relationships within the time series.

In recent years, artificial intelligence models and machine learning such as support vector machine (SVM), adaptive neuro-fuzzy inference system (ANFIS) and artificial neural network (ANN) have been gaining popularity because of their high flexibility and proven prediction abilities (Abbasi et al., 2013, 2014; Antanasijević et al., 2013). Intelligent models are shown to be capable of predicting MSW generation on long, medium and short term scales (Abbasi et al., 2014; Abdoli et al., 2012; Jalili Ghazi Zade and Noori, 2008). However, there is limited information about monthly prediction of MSW generation as well as optimal algorithm for this purpose. This paper will review the state of the art of the intelligent modelling approaches for MSW generation forecast and then apply them to a real case scenario in order to identify the most suitable algorithm to predict MSW collected by kerbside service on a medium-term scale.

2. Application of artificial intelligence in forecasting MSW generation

Advanced artificial intelligence forecast systems have shown superiority to conventional models in engineering problems as well as in waste management research (Abdoli et al., 2012). Recent research in this topic focused on using artificial intelligence models to deal with the non-linearity of the historical data. In this section, application of the techniques including ANN, ANFIS, SVM and *k*-nearest neighbours (kNN) will be reviewed in the field of MSW generation.

2.1. Artificial neural network

Artificial neural networks are cellular information processing systems designed and developed on the basis of the perceived notion of the human brain and its neural system (Firat et al., 2010). One of the most beneficial and significant features of ANN in forecasting is its learning ability. ANN can construct a complex nonlinear system through a set of input/output examples. Consequently, ANN has been successfully employed in nonlinear system modelling (Firat et al., 2010). Accordingly, the nonlinear structure of MSW generation makes the ANN an ideal candidate for forecasting waste generation. Literature survey returned applications of ANN to forecast MSW generation in short, medium and long-term periods (Abbasi et al., 2013; Abdoli et al., 2012; Noori et al., 2010).

Ordóñez-Ponce et al. (2006) employed multi-layer perceptron neural network to predict long-term generation rate of MSW in Chile. Using a range of variables which covered socio-demographic, economic, geographic and waste-related factors, ANN was able to predict waste generation with great accuracy ($R^2 = 0.819$). Ordóñez-Ponce et al. (2006) concluded that population, percentage of urban population, years of education, number of libraries and number of indigents were the most important factors which affected waste generation in Chile.

The ability of ANN to predict short-term MSW generation was also examined by other researchers (Noori et al., 2009a,b). These studies focused on forecasting MSW generation by analysing time series of waste generation rather than analysing effective factors in waste generation. Results showed that feed-forward ANN with one hidden layer and 16 neurons was the best structure to forecast short-term waste generation rates (Noori et al., 2009a,b). However, ANN accuracy may suffer when faced with large database due to the effect of irrelevant, redundant and noise in the data. Therefore, different input selection methods such as principal component analysis, wavelet transform and gamma test were introduced to deal with accuracy loss (Noori et al., 2009a,c). Although ANN model has good ability to forecast MSW generation, its performance suffers because of its tendency to over-fitting training, local minimum, and poor generalization.

2.2. Adaptive neuro-fuzzy inference systems

Adaptive neuro-fuzzy inference systems (ANFIS) are a well-known data driven modelling technique that combines ANN and fuzzy logic. ANFIS is composed of two parts, antecedent and conclusion, which are connected to each other by fuzzy rules based on the network form. Limited attempts, 3 studies, to predict waste generation using ANFIS were found in the literature. The studies compared the performance of ANN and ANFIS models ability to predict MSW generation (Chen and Chang, 2000; Noori et al., 2009c; Tiwari et al., 2012). Tiwari et al. (2012) suggested that ANFIS is a more reliable model than ANN for forecasting the aggregate impact of economic trend, population changes, and recycling on solid waste generation. Chen and Chang (2000), on the other hand, demonstrated the ability of ANFIS to forecast waste generation with limited input data. Chen and Chang (2000) and later Noori et al. (2009c) applied fuzzy goal regression method to improve the overall prediction accuracy of ANFIS.

2.3. Support vector machine

Support vector machine (SVM), a novel neural network algorithm, was developed by Vapnik and colleagues (Vapnik, 1995). SVMs are a type of maximum margin classifiers which seek to find a maximum margin hyperplane to the best line across data. The hyperplane thus obtained is called the optimal separating hyperplane and the training examples that are closest to the maximum margin hyperplane are called support vectors. While most of conventional neural network models implement the empirical risk minimization principle, SVM implements the structural risk minimization principle. Neural network model seeks to minimize the misclassification error or deviation from correct solution of the training data but the SVM searches to minimize an upper bound of generalization error. Therefore, the solution of SVM may be global optimum while other neural network models may tend to fall into a local optimal solution. Thus, SVM is unlikely to result in overfitting (Kim, 2003).

SVM model was used to forecast weekly MSW generation in Tehran city, Iran by Abbasi et al. (2013). They concluded that