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Evaluating the ability of artificial neural network and PCA-M5P models in predicting leachate COD load in landfills

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ABSTRACT

Waste burial in uncontrolled landfills can cause serious environmental damages and unpleasant consequences. Leachates produced in landfills have the potential to contaminate soil and groundwater resources. Leachate management is one of the major issues with respect to landfills environmental impacts. Improper design of landfills can lead to leachate spread in the environment, and hence, engineered landfills are required to have leachate monitoring programs. The high cost of such programs may be greatly reduced and cost efficiency of the program may be optimized if one can predict leachate contamination level and foresee management and treatment strategies. The aim of this study is to develop two expert systems consisting of Artificial Neural Network (ANN) and Principal Component Analysis-M5P (PCA-M5P) models to predict Chemical Oxygen Demand (COD) load in leachates produced in lab-scale landfills. Measured data from three landfill lysimeters, including rainfall depth, number of days after waste deposition, thickness of top and bottom Compacted Clay Liners (CCLs), and thickness of top cover over the lysimeter, were utilized to develop, train, validate, and test the expert systems and predict the leachate COD load. Statistical analysis of the prediction results showed that both models possess good prediction ability with a slight superiority for ANN over PCA-M5P. Based on test datasets, the mean absolute percentage error for ANN and PCA-M5P models were 4% and 12%, respectively, and the correlation coefficient for both models was greater than 0.98. Developed models may be used as a rough estimate for leachate COD load prediction in primary landfill designs, where the effect of a top and/or bottom liner is disputed.

1. Introduction

Waste burial is the least expensive method for disposal of waste materials all across the world (Wallace et al., 2015). Despite implementation of waste reduction plans, recycling, and material processing, waste burial is yet the major element of integrated solid waste management hierarchy (Tchobanoglous et al., 1993). Considered as big biological reactors, landfills always have the potential for contaminating groundwater, soil, and air (Amiri and Sabour, 2014). Only a small quantity of leachate is enough to cause pollution in a considerable number of groundwater resources, since it usually possesses high COD levels, high heavy metal concentrations, and variable pH levels (Wallace et al., 2015). Due to the fact that pollution of underground resources in proximity of landfills is a great environmental challenge, it is required that landfills have monitoring programs for leachate, ground, and surface waters (Kylefors, 2003). However, it is known that there are significant limitations with respect to these programs, such as their high costs and application complexities. If one can predict leachate contamination level and foresee management and treatment strategies, the high cost of such programs may be greatly reduced and cost efficiency of the program may be optimized.

Generally speaking, quantity and quality of landfill leachate are primary concerns in any management and treatment strategy. A number of factors affect leachate quantity and quality. These factors include regional hydrology, climate, landfill age, and conditions under which the leachate is produced (e.g. the type of structure and design, type and thickness of covers), in addition to waste type, compound, moisture content, particle size, and density (Amiri and Sabour, 2014; Gibbons et al., 2014; Tränkler et al., 2005). Due to the high number and complexity of such factors, prediction of leachate contaminant load is not an easy task.

Many researchers have focused on landfills and analyzed their leachate quantitative and qualitative parameters. Tatsi and Zouboulis (2002) carried out a field research on the quality and

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quantity of leachates produced from municipal solid wastes in Greece under Mediterranean climate conditions. In their study, they sampled experimental data, and measured pollution parameters in a sanitary landfill leachate during different stages of landfill stability. Their findings indicated that leachate composition is so much dependent upon stability degree and weather conditions. All measured parameters including COD, Total Kjeldahl Nitrogen (TKN), Biochemical Oxygen Demand (BOD), and total suspended solid were higher for fresh in comparison to old leachate. However, with respect to pH, it was found that the passage of time results in more acidic leachate, causing old leachate pH being lower than the one for fresh leachate. Furthermore, the concentration of heavy metals in fresh leachate was less than old leachate. Rafizul and Alamgir (2012) measured the effect of Bangladesh tropical climate on leachate characteristics produced in three types of landfill lysimeters under different seasonal conditions. Their lab-scale landfills simulated an open landfill with no clay liner at the top or bottom and a minimal top soil cover, and two sanitary ones with different cover thicknesses. Leachate characteristics and climate effects (simulating rainfall depth from June 2008 to May 2010) were monitored, and their findings revealed that more leachate was produced in the open landfill. It was also found that, compared to the sanitary landfills, leachate from the open one included less TKN, less ammonia nitrogen, and more COD. Tsarpali et al. (2012) studied seasonal changes in toxicity and composition of the leachates produced in a semi-arid region in Greece. They found that seasonal composition of the leachate greatly depends upon rainfall depth. Furthermore, parameters such as conductivity, nitrate (NO_3^-), Total Nitrogen (TN), ammonium (NH_4-N), total dissolved solids, and the ratio of BOD to NH_4-N had high correlations with rainfall depth. Based on these results, they concluded that rainfall depth may be used as a criterion for leachate toxicity prediction.

Nevertheless, there are limited studies on landfill leachate modeling. Samin et al. (2012) predicted leachate generation (mm/day) in Minamiashigara, Japan, for a period of 15 days, using an ANN model. Inputs to their model were rainfall, temperature, humidity, duration of solar radiation, and landfill characteristics. Their results showed that leachate generation may be predicted with a good correlation coefficient of 0.92. Camba et al. (2014) developed a mathematical model for predicting average leachate generation through the application of a water balance. Their study focused on Iberian zones; an oceanic region, in the Europe, with large leachate productions. Their validation results showed that application of their model may be extended to other regions with similar climate conditions. Shoeybi et al. (2012) predicted removal efficiency of organic and nitrogen compounds in leachate circulation process on old wastes using an ANN model. Inputs to their model were BOD, COD, NH_3-N, NH_4-N, pH, and time. The data were gathered from a landfill simulation reactor in a laboratory scale. They were able to predict removal efficiency of organic and nitrogen compounds with a good correlation coefficient of 0.97. Ozkaya et al. (2006) monitored four parameters of sulfate, chloride, COD and BOD in leachates produced in two large-scale test cells at Odayeri Sanitary Landfill, Istanbul, Turkey. The difference in test cells was the existence of leachate recirculation system in one and not in the other. They presented two mathematical models for predicting the four parameter concentrations in leachates from both test cells. Their results indicated a good fitness between the measured and simulated data with correlation coefficients ranging from 0.84 to 0.92. Kylefors (2003) applied multivariate data analysis to evaluate the possibility of predicting certain organic substance contents like volatile and semi-volatile compounds, Phthalates, Chlorophenols, Phenoxy acids, Dioxins and furans in a leachate. Their results indicated that prediction was possible, given the specific leachate under consideration.

Previous studies mainly focused on investigating the effect of different parameters on qualitative and quantitative features of the leachate and prediction of leachate characteristics by regression methods. Despite suitable formulas and equations presented, it should be noted that in the cases where many effective parameters are involved with high rates of complexity, measuring and considering all parameters may not be feasible. In such cases, results of intelligent systems may prove much more precise and practical than the empirical formulas (Nourani et al., 2012). For this reason, in recent years and along with the increase of data processing speed in computers, the use of expert simulation models such as soft computing tools for complicated physical phenomena modeling has been greatly improved. Often, expert simulation models are accepted as a substitute for traditional empirical methods.

Neural networks and M5P have been repeatedly used in complicated physical phenomena modeling and simulations especially when the systems are nonlinear with a relatively large number of affecting parameters. M5P model, first introduced by Quinlan (1992) and often preferred over ANN, is capable of producing a set of specific and simple rules in the process of training. It has been considered in diverse engineering applications such as developing rules for reservoir optimal operation (Nikoo et al., 2013), prediction of scour depth (Balouchi et al., 2015), prediction of pile groups scour (Etemad-Shahidi and Ghaemi, 2011), and prediction of wave run-up on rubble-mound structures (Bonakdar and Etemad-Shahidi, 2011).

One concern in predicting leachate COD load using M5P is how to account for diverse interactions between various dependent input variables. A common approach to avoid this problem is to utilize Principal Component Analysis (PCA) as an accepted method in environmental pattern recognition which has received increasing attentions. This multivariate statistical technique transforms the original dependent variables into new independent variables which are linear combinations of the original ones (Noori et al., 2010a,b, 2009). These new uncorrelated variables maintain a great part of the information, inherited in original variables.

Considering the emergence of expert models, this study aims at evaluating the efficiency of two soft computing models, namely ANN and PCA-M5P models, in predicting leachate COD load (mg/kg solid waste) from an open landfill lysimeter with no clay liner at the top or bottom and a minimal top soil cover, and two sanitary ones with different cover thicknesses. Readily available input data such as number of days after waste deposition, thickness of the top and bottom CCLs, thickness of the top soil covering lysimeter, as well as rainfall depth were utilized. Then, ability of ANN and PCA-M5P models in predicting leachate COD load from the lysimeters were investigated and compared. Finally, using PCA-M5P model, a few rules are proposed to predict leachate COD load under different weather conditions, and landfill characteristics.

2. Methodology

2.1. Overview

Fig. 1 shows the methodology flowchart utilized in this research to predict the leachate COD load. As seen, prediction of the leachate COD load is performed in a three-step process. At the first step, parameters presumed affect the COD load were collected and existence of any correlation between each parameter and the leachate COD load was surveyed using statistical tests. At the second step, a multilayer perceptron ANN and a PCA-M5P model were developed. The models were trained and validated, using measured data. At this stage, PCA-M5P suggested rules and the most proper ANN structure were determined for prediction of the leachate COD load.