ARTICLE IN PRESS

Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Development of model for prediction of Leachate Pollution Index (LPI) in absence of leachate parameters

Anjali G. Lothe, Alok Sinha *

Department of Environmental Science and Engineering, Indian School of Mines, Dhanbad 826004, India

A R T I C L E I N F O

Article history:
Received 5 April 2016
Revised 15 July 2016
Accepted 18 July 2016
Available online xxxx

Keywords:
Landfill
Leachate
Leachate pollution index (LPI)
Sub-index values
Pollutant weight
Error analysis
Modelling

A B S T R A C T

Leachate pollution index (LPI) is an environmental index which quantifies the pollution potential of leachate generated in landfill site. Calculation of Leachate pollution index (LPI) is based on concentration of 18 parameters present in leachate. However, in case of non-availability of all 18 parameters evaluation of actual values of LPI becomes difficult. In this study, a model has been developed to predict the actual values of LPI in case of partial availability of parameters. This model generates eleven equations that helps in determination of upper and lower limit of LPI. The geometric mean of these two values results in LPI value. Application of this model to three landfill site results in LPI value with an error of ±20% for $\sum_i^n w_i \geqslant 0.6$.

1. Introduction

Leachate is the liquid generated during acid phase of landfill stabilization. During this phase pH of leachate generated decreases hence mobilises many heavy metals. Composition of leachate depends on many factors like characteristic of waste, landfill design and operation, other site specific characteristics and composition of waste (Rafizul et al., 2012). Poor management of the landfill sites is major concern for underground as well as surface water pollution in many underdeveloped and developing nations (Kumar et al., 2002; Pande et al., 2015). Due to improper installation of liners and leachate collection systems, leachate percolates into the ground water or nearby surface water bodies, degrading the water quality (Kumar and Alappat, 2003a, 2004). To regulate the pollution potential of leachate almost all countries have developed set of rules, but remedial measures are to be installed in phases which is a difficult process and are cost inefficient (Sharma et al., 2008; Kumar and Alappat, 2005a). Hence, to prevent unnecessary wastage of power and money, identification of vulnerable sites which would require immediate attention has become essential (Kumar and Alappat, 2005a). Development of Leachate Pollution Index (LPI) by Kumar and Alappat (2003b) made quantification of landfill pollution potential possible. It can be used as a comparative scale to measure which landfill is more hazardous and requires immediate remedial action.

The Leachate Potential Index (LPI) is a mathematical method of calculating a single value from various physic-chemical and biological parameters of landfill leachate (Kumar and Alappat, 2004). LPI is an increasing scale index i.e. higher LPI value signifies that the landfill site has high pollution causing potential. It was developed using DELPHI technique, detailed procedures of which been discussed in Kumar and Alappat (2003a, 2005a). Total number of eighteen parameters is required for LPI calculation. The 18 leachate pollution parameters considered for calculating LPI are chromium, lead, chemical oxygen demand (COD), mercury, biochemical oxygen demand (BOD_5), arsenic, cyanide, phenolic compounds, zinc, pH, Total Kjeldahl Nitrogen (TKN), nickel, total Coliform bacteria, ammonical nitrogen, total dissolved solids (TDS), copper, chlorides, and total iron (Kumar and Alappat, 2003a, 2003b). Each of these parameters has weights (w_i) determined on the basis of significance value assigned to each variable through Delphi technique (Kumar and Alappat, 2005a). The weights assigned to different parameters are shown in Table 1.

For each parameters average "sub-index curves" were drawn by the experts where the concentration of each parameters were plotted against the levels of leachate pollution (0–100). Hence for a given concentration the sub-index scores (p_i) can be obtained from these curves. Value of p_i varied from 0 to 100 and concentration of

* Corresponding author.
E-mail address: aloksinha11@yahoo.com (A. Sinha).

http://dx.doi.org/10.1016/j.wasman.2016.07.026
0956-053X/

Please cite this article in press as: Lothe, A.G., Sinha, A. Development of model for prediction of Leachate Pollution Index (LPI) in absence of leachate parameters. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.07.026

Table 1
Weights of the pollutant parameters included in leachate pollution index (LPI) (Kumar and Alappat, 2003a, 2003b; Kumar and Alappat, 2005a, 2005b; Sharma et al., 2008).

Sr. No.	Pollutant	Significance	Pollutant weight
1	pH	3.509	0.055
2	Total dissolved solids	3.196	0.050
3	BOD_5	3.902	0.061
4	COD	3.963	0.062
5	TKN	3.367	0.053
6	Ammonia nitrogen	3.250	0.051
7	Total iron	2.830	0.045
8	Copper	3.170	0.050
9	Nickel	3.321	0.052
10	Zinc	3.585	0.056
11	Lead	4.019	0.063
12	Total chromium	4.057	0.064
13	Mercury	3.923	0.062
14	Arsenic	3.885	0.061
15	Phenolic compounds	3.627	0.057
16	Chlorides	3.078	0.048
17	Cyanide	3.694	0.058
18	Total coliform bacteria	3.289	0.052
	Total	63.165	0.999

the pollutants varied up to the maximum concentration reported in the literatures. Determination of LPI includes analysis of concentration of pollutants to determine p_i using the rating curves. Values of p_i and w_i are put in the following formula (Kumar and Alappat, 2005a):

$$\mathrm{LPI} = \sum_{i=1}^{n} p_i w_i \Big/ \sum_{i}^{n} w_i \quad (1)$$

where

LPI = the weighted additive leachate pollution index,
w_i = the weight for the ith pollutant variable,
p_i = the sub index score of the ith leachate pollutant variable,
n = number of leachate pollutant variables used in calculating LPI,
If, n = 18, $\sum_i^n w_i = 1$,
and if n < 18, $\sum_i^n w_i < 1$.

For estimation of correct value of LPI it is required to analyse concentration of all eighteen parameters. Analysis of some of these parameters can be difficult and time consuming process, which leads to unavailability of parameters, hence error in LPI value. In few cases where error is negative, value of LPI is exaggerated and when error comes out to be positive, the LPI value is understated. Kumar and Alappat (2005b) calculated the errors involved in LPI calculations in absence of 18 parameters. They calculated the errors involved in absence of data having low weights, high weights, low sub-index and high sub-index values. They concluded that the errors may be high if the data for the parameters having significantly high or low concentration are not taken into account.

Use of randomized data in calculation of risk assessment has been used widely for providing authentic values of risk (Chen and Liao, 2006; Chen et al., 2012; Yang et al., 2014; Gungormus et al., 2014). However, use of randomized data for evaluation of LPI in absence of desired parameters has not been addressed. This paper aims at estimating the LPI values in absence of parameters through development of general equations by generating random data. These equations would facilitate calculation of the actual values of LPI even in the absence of some parameters. Validation of these equations is also demonstrated by presenting case studies for three landfill sites in India namely Okhla landfill site, Dhapa landfill site and Chittagong landfill site.

2. Methodology adopted

2.1. Data set generation

Two types of data sets were generated. Both of these data sets included assignment of random values to sub-index score of each variable.

Data set type 1: Objective of this data set was to determine relation between $(\sum_{i=1}^n p_i w_i / LPI)$ normalized value (n_i) and % error. To create this data set random sub-index values were selected for all 18 variables. Randbetween() function present in Microsoft Excel was used to define these data sets. Sub-index values vary from 5 to 100, minimum sub-index value of 5 is assigned to each variable in order to obtain non-zero value of LPI (Kumar and Alappat, 2005a). Approximately more than 500 data sets were generated.

Data set type 2: Objective of this data set was to plot boundary values of $\sum_{i=1}^n p_i w_i$ against corresponding % error for different $\sum_i^n w_i$ values. To define these datasets groups of the parameters were formed such that each group had different number of parameters in the group. For instance, if group of parameters was determined to have 17 parameters, according to permutation and combination theory there were $^{18}C_{17}$ i.e. 18 combinations possible. Groups were formed such that it had 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, or minimum 6 numbers of parameters. So, the total 226 combinations were possible hence 226 values for $\sum_i^n w_i$ were obtained. Random sub-index values were generated using same function as described above, for the group of parameters considered, while rest of the parameters were assigned 5 and 100 as sub-index in order to obtain minimum and maximum $\sum_{i=1}^n p_i w_i$ values, respectively. For each $\sum_i^n w_i$ value, 24 sets of data were generated. Table 2 exemplifies the data sets for $\sum_i^n w_i = 0.33$ when only 6 parameters were considered.

As can be seen from the Table 2 for $\sum_i^n w_i = 0.33$ only six parameters including Cr, phenolic compounds, Zn, pH, TKN and Fe are assigned random values and rest of the parameters are assigned with 5 and 100.

2.2. Error analysis study

Imitating the approach of Kumar and Alappat (2005b) and Rafizul et al. (2012) for estimating errors involved in calculation of LPI, in case of non-availability of concentration of pollutants, four cases were considered and pollutants were ignored on the basis of their weights. All these four cases were applied on both type of data sets and calculated values of $\sum_{i=1}^n p_i w_i$, % error and n_i were collected for further estimation.

To produce different cases, all the parameters were sorted according to decreasing weights and four cases were created.

2.2.1. CASE 1: Removing pollutants with higher weights

(1) Table 3 exemplifies the first iteration of case 1 where number of parameters considered for LPI calculation is 6. It was assumed that concentration of chromium is not available and was ignored in first step of calculation of case 1, as reported in column 7 of Table 3.
(2) In the next step parameter with second highest weight was ignored. Similar pattern was followed until minimum 6 parameters were left.
(3) Calculation of LPI was done using Eq. (1). For each case the values of LPI, $\sum_{i=1}^n p_i w_i$, % error and n_i are calculated.
(4) Percentages error was calculated with respect to actual LPI (based on 18 parameters) values and $\sum_{i=1}^n p_i w_i$ was normalized by corresponding LPI for that data set, for calculation of normalized values (n_i).