Iranica Journal of Energy & Environment 3 (3): 270-279, 2012
ISSN 2079-2115
IJEE an Official Peer Reviewed Journal of Babol Noshirvani University of Technology
DOI: 10.5829/idosi.ijee.2012.03.03.1807

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# Analysis of Errors Involved in the Estimation of Leachate Pollution Index Due to Nonavailability of Leachate Parameter

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(Received: July 20, 2012; Accepted: August 23, 2012)

**Abstract:** An important part of maintaining a solid waste landfill is managing the leachate through proper treatment to prevent pollution into the surrounding ground and surface water. Any assessment of potential impact of a landfill on groundwater quality requires consideration of the component of leachate most likely to cause an envionental impact as well as the source of concentration of those components. Leachate pollution index (LPI) is an environmental index used to quantify and compare the leachate contamination potential of solid waste landfill. This index is based on concentration of 18 pollutants in leachate and their corresponding significance. That means, for calculating the LPI of a landfill, concentration of these 18 parameters are to be known. However, sometimes the data for all the 18 pollutants included in the LPI may not be available to calculate the LPI. In this study, the possible errors involved in calculating the LPI due to nonavailability of data are reported by the author. The leachate characteristic data for solid waste landfill at Chittagong in Bangladesh have been used to estimate these errors. Based on this study, it can be concluded that the errors may be high if the data for the pollutants having significantly high or low concentration are not available. However, LPI can be reported with a marginal error if the concentrations of the nonavailable pollutants are not completely biased.

**Key words:** Landfill; Leachate; Sub-index value; Pollutant weight; Error analysis; Lechate pollution index

## INTRODUCTION

Landfill leachate is the liquid that moves through or drains from a solid waste landfill. Leachate is the main medium for the transportation of contaminants from landfill to ground and surface water [1]. Moreover, landfill leachate is formed from the infiltration and passage of water through solid waste which results in a combination of physical, chemical and microbial processes that transfers pollutant from waste materials to the water [2,3].

The most common source of landfill leachate is rainwater that filtering down through the landfill and aiding bacteria in the process of decomposition of solid waste [4]. Modern landfills are often designed to prevent liquid from leaching out and entering the environment. However, if it is not properly managed, the leachate is at risk for mixing with groundwater near the site, which can have terrible effects [5].

Leachate consists of many different organic and inorganic compounds that are typically either dissolved or suspended in the wastewater [6]. The leachate may be virtually harmless or dangerously toxic, depending upon what is in the landfill [7,8]. Typically, landfill leachate has the high concentration of chemical oxygen demand (COD), biochemical oxygen demand ($BOD_5$), nitrogen interms of total kjeldahl nitrogen (TKN) and ammonia nitrogen ($NH_4$-N), phenols, pesticides, chloride, solvents and heavy metals [9]. Moreover, the characteristics of leachate are highly variable depending on the wastes deposited in landfill, composition of wastes, moisture content, the particle size, the degree of compaction, sampling procedures, landfill design and operation, the hydrology of the site, the climate and age of the fill and other site-specific conditions including landfill design and type of liners used, if any [7,10]. As leachate emerges from a landfill site, it is often black or yellow, with a strong acidic smell.

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The potential long term environmental impact of a solid waste landfill on groundwater quality will depend on the leachate charecteristics, mass of contaminant in the facility, the infiltration of fluid through waste, nature of leachate containment system and the site hydrology [11,12]. However, leachate characterstics may be expected to vary over time, increasing from initial values to peak and then subsequently decreasing as the potential contaminants are either flushed out of the system, biodegraded or precipitaded [2,13].

A large number of environmental indices have been developed in last four decades. Various indices are developed to quantify the pollution or quality of water and air. Usually, the indices are formulated based on studies conducted by the indices developers or on the Delphi technique [14]. In an effort to develop a method for comparing the leachate pollution potential of various solid waste landfill sites in a given geographical area, an index known as Leachate Pollution Index (LPI) was formulated using Rand Corporation Delphi Technique [15]. The LPI can be used to report leachate pollution changes in a particular landfill over time. The trend analysis so developed for the landfill can be used to assess the post closure monitoring periods. The leachate trend at a given landfill site can facilitate design of leachate treatment facilities for other landfills in the same region [16]. In contrary, LPI can also be used to compare leachate contamination potential of different landfills in a given geographical area or around the world. To quantify and compare the leachate contamination potential of municipal landfills 18 leachate characterstics to be known.The other potential applications of LPI include ranking of landfill sites based on leachate contamination potential, resource allocations for landfill remediation, enforcement of leachate standards, scientific research and public information [15].

The intention of this study was to calculate the error invloved in estimation of LPI due to nonoavailability of data. In this study, it is analyzed the possible error associated with estimation of LPI. To these attempts, leachate samples were collected twice in a month from a selected solid waste disposal site at Chittagong in Bangladesh. The present study was carried out to estimate the possible error may be involved in LPI due to nonavalability of leachate data. Moreover, for easy to estimate and compare the leachate contamination potential level due to nonavalability of leachate parameters of different solid waste disposal site either it is open or sanitary condition in a given geographical area would be a useful tool in this regard.

**Laboratory Investigations:** Leachate samples were collected twice in a month from the selected solid waste landfill at Chittagong in Bangladesh. These study periods were covered 1$^{st}$ August and 30$^{th}$ September 2011. In the laboratory, pH was determined by pH meter (HACH, Model No. Sens ion 156), chloride by potentiometric titration method using silver nitrate solution, $BOD_5$ by BOD meter (HACH, HQ-40d), TCB by filter membrane system, Arsenic using sulfamic acid and zinc powder as well as COD by closed reflexive method as per the standard method [17]. In addition, total dissolved solid (TDS) dried at 103-105ºC, ammonia nitrogen ($NH_4$-N) by nesselerization standard method and total kjeldahl nitrogen (TKN) by macro-kjeldahl method as per the standard method [17] were determined in the laboratory. Moreover, Fe, Cu, Zn, Cr, Ni and Pb were analysed using spectrophotometer (HACH; DR/2400) as per the standard method [17].

**Concept of Leachate Pollution Index:** The formulation process and complete description on the development of LPI has been discussed elsewhere [15]. The LPI represents the level of leachate contamination potential of a given solid waste landfill. It is a single number ranging from 5 to 100 (like a grade) that expresses the overall leachate contamination potential of a landfill based on several leachate pollution parameters at a given time. Details of the LPI developed are briefly described here.

LPI Variables and Their Weight: The 18 parameters chosen and their corresponding weights are as follows: chromium (Cr): 0.064; lead (Pb): 0.063; chemical oxygen demand (COD): 0.062; mercury (Hg): 0.062; biochemical oxygen demand ($BOD_5$): 0.061; arsenic (As): 0.061; cyanides (Cn): 0.058; phenolic compounds: 0.057; zinc (Zn): 0.056; pH: 0.055; total kjeldhal nitrogen (TKN):0.053; nickel (Ni): 0.052; total coliform bacteria (TCB): 0.052; ammonia nitrogen ($NH_4$-N): 0.051; total dissolved solids (TDS): 0.050; copper (Cu): 0.050; chlorides ($Cl^-$): 0.048; and total iron (Fe): 0.044. The weight factor indicates the importance of each pollutant variable to the overall leachate pollution. The sum of the weights of all 18 parameters is one.

**Variable Curves:** The averaged sub-index curves for all the pollutant variables have been reported by Kumar and Alappat [14].

**Variable Aggregation:** The weighted sum linear aggregation function was found to be the most suitable one for the calculation of LPI by the Equation (1) [18] and is as follows:

Table 1: Leachate characterstics of solid waste landfill at Chittagong of Banladesh

| SL | Leachate pollutant | Concentration* | Sub-index value ($p_i$) |
|---|---|---|---|
| 1 | Total chromium (Cr) | 1.3 | 8 |
| 2 | Lead (Pb) | 1 | 12 |
| 3 | Chemical oxygen demand (COD) | 9700 | 78 |
| 4 | Mercury (Hg) | 0.007 | 5.5 |
| 5 | Biochemical oxygen demand ($BOD_5$) | 4800 | 52 |
| 6 | Arsenic (As) | 0.01 | 5 |
| 7 | Cyanide (CN) | 0.7 | 11 |
| 8 | Phenol compounds | 3.2 | 10 |
| 9 | Zinc (Zn) | 2.9 | 7 |
| 10 | pH | 8 | 6 |
| 11 | Total kjeldhal nitrogen (TKN) | 718 | 20 |
| 12 | Nickel (Ni) | 0.06 | 7.5 |
| 13 | Total colifom bacteria (TCB) | 6700 | 84 |
| 14 | Ammonia nitrogen ($NH_4$-N) | 487 | 50 |
| 15 | Total dissolved solid (TDS) | 11350 | 23 |
| 16 | Copper (Cu) | 3.5 | 28 |
| 17 | Chlorides (Cl-) | 3250 | 24 |
| 18 | Total Iron (Fe) | 79 | 9 |

*All values in mg/L except pH and total coliform unit (cfu/100ml). * Average of 4 samples taken between 1st August and 30th September 2011.*

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

Where, where LPI is weighted additive leachate pollution index; $w_i$ = the weight for the $i^{th}$ pollutant variable; $p_i$ = the sub-index value of the $i^{th}$ leachate pollutant variable, number of leachate pollutant parameters; n =18 and $\sum w_i$=1.

However, when the data for all the leachate pollutant variables included in LPI are not available, the LPI can be calculated using the data set of the available leachate pollutants by the Equation (2):

$$LPI = \frac{\sum_{i=1}^{n} w_i p_i}{\sum w_i} \quad (2)$$

Where m=number of leachate pollutant for which data are available, when, m<18 and $\sum w_i$<1.

**Errors Involved in Calculating LPI Due to Nonavailability of Data:** To assess the errors involved in calculating LPI due to nonavailability of data, a case study is taken up. Leachate samples were analyzed in the laboratory shown in Table 1.

**Methodology Adopted:** The leachate characteristics studied in this study were insufficient to calculate the actual LPI value; therefore concentrations of some of the leachate characteristics were presumed and have been accepted as the true concentrations for the present study. The concentrations of mercury, cyanide and phenol have been assumed for the solid waste landfill at Rajbandh, Khulna, Bangladesh based on concentration of these parameters reported in literature. Leachate samples were collected twice in a month from the selected solid waste landfill at Chittagong in Bangladesh. Chittagong is a commerce and industry hub and a port city, in southeastern Bangladesh. It has a population of over 5.5 million produces 200 MT of solid waste per day on agerage. The garbage treatment plant is situated in Ananda Bazar, Halishahar having an area 12 acre and the dumping was started since 2004. There is no base and cap liner and it is acted as an open dump landfill [19].

To estimate the possible errors involved in calculating LPI, due to the nonavailability of leachate data, two approaches have been made as:

- Ignoring pollutant data based on weight factor
- Ignoring pollutant data based on sub-index.

The sub-index values of all the pollutant parameters in lechate based on their concentrations are reported in Table 1. The subindex values have been derived from the subindex curves for all the parameters reported by Kumar and Alappat [15]. The LPI value based on these sub-index values has been calculated using Equation (1) and

Table 2: Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with low weight factors ignored)

| Pollutant | Pollutant weight, $w_i$ | Pollutant concentration, $c_i$ | Subindex value, $p_i$ | Derived LPI with considered leachate parameters ($w_i p_i$) 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr | 0.064 | 1.3 | 8 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 |
| Pb | 0.063 | 1 | 12 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 |
| COD | 0.062 | 9700 | 78 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 |
| Hg | 0.062 | 0.007 | 5.5 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 |
| $BOD_5$ | 0.061 | 4800 | 52 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 |
| As | 0.061 | 0.01 | 5 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 |
| CN | 0.058 | 0.7 | 11 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 |
| Phenol | 0.057 | 3.2 | 10 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 |
| Zn | 0.056 | 2.9 | 7 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | - |
| pH | 0.055 | 8 | 6 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | | - |
| TKN | 0.053 | 718 | 20 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | - | | - |
| Ni | 0.052 | 0.06 | 7.5 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | - | - | | - |
| TCB | 0.052 | 6700 | 84 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | - | - | - | | - |
| $NH_4$-N | 0.051 | 487 | 50 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | - | - | - | - | | - |
| TDS | 0.05 | 11350 | 23 | 1.15 | 1.15 | 1.15 | 1.15 | - | - | - | - | - | | - |
| Cu | 0.05 | 3.5 | 28 | 1.4 | 1.4 | 1.4 | - | - | - | - | - | - | | - |
| Chloride | 0.048 | 3250 | 24 | 1.152 | 1.152 | - | - | - | - | - | - | - | | - |
| Iron | 0.045 | 79 | 9 | 0.405 | - | - | - | - | - | - | - | - | | - |
| Summation | 1.000 | | | 24.327 | 23.922 | 22.770 | 21.370 | 20.220 | 17.670 | 13.302 | 12.912 | 11.852 | 11.522 | 11.130 |
| Total weight | | | | 1.000 | 0.955 | 0.907 | 0.857 | 0.807 | 0.756 | 0.704 | 0.652 | 0.599 | 0.544 | 0.488 |
| Derived LPI | | | | 24.327 | 25.049 | 25.105 | 24.936 | 25.056 | 23.373 | 18.895 | 19.804 | 19.786 | 21.180 | 22.807 |
| Percent error | | | | 0.000 | 2.969 | 3.197 | 2.503 | 2.996 | 3.922 | 22.330 | 18.594 | 18.665 | 12.936 | 6.247 |

*Note: Cr=chromium, Pb=lead, COD=chemical oxygen demand, Hg= mercury, $BOD_5$= biological oxygen demand, As=arsenic, CN=cyanide, Zn=zinc, TKN=total kjeldahl nitrogen, Ni=nickel, TCB= total colifom bacteria, $NH_4$-N=ammonia nitrogen, TDS=total dissolved solid, Cu=copper and Fe=iron. All values in mg/L, except pH and TCB ((cfu/100ml)).*

provided in the fifth column, Table 2. The LPI calculated based on these 18 parameters is considered to be the true LPI value of the landfill.

Errors Introduced by Ignoring Pollutant Data Based on Weight Factor: In this approach, two options are discussed. In the first option, the data of the pollutants having low weight factors is ignored and in the second option, the data of the pollutants with high weight factors are assumed to be not available.

**Removing Pollutants with Low Weight Factors:**

- In the first step, the concentration of Fe having the lowest weight, is presumed to be unknown. Hence, by deleting the subindex value of Fe, the LPI value is derived by using Eq. (2). The derived LPI value is reported in the sixth column, Table 2.
- In the next step, the concentration of Cl-having second lowest weight, is also presumed to be unknown in addition to the concentration of Fe. Again using Eq. (2), the LPI of the data set with 16 parameters is calculated and reported in the seventh column, Table 2.
- In a similar fashion, it is presumed that concentrations of Cu, TDS, $NH_4$-N, TCB, Ni, TKN, pH and Zn are also not known one by one in addition to the earlier unknown concentrations of the parameters. The derived LPI values considering concentration of 15, 14, 13, 12, 11, 10, 9 and 8 parameters are calculated and reported in columns 8, 9,10, 11, 2, 13, 14 and 15 of Table 2, respectively.

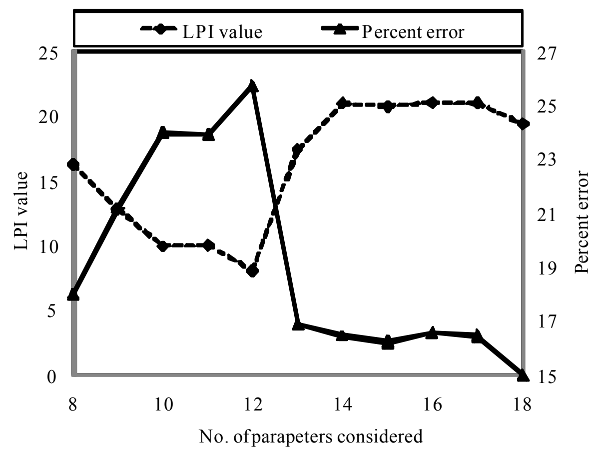


Fig. 1: Variation of LPI and percent error when low weight parameters are ignored

- The percentage error introduced calculating LPI, w.r.t LPI when data are available for all 18 leachate pollutants, is also reported in the last row of respective columns of Table 2.
- The variation in LPI values with respect to the number of parameters considered in calculating LPI is provided in Figure 1. It also gives the percentage error introduced in calculating LPI values with respect to the number of parameters considered.

**Removing Pollutants with High Weight Factors:** A similar procedure was followed here starting with the parameterhaving the highest weight factor.

Table 3: Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with high weight factors ignored)

| Pollutant | Pollutant weight, $w_i$ | Pollutant concentration, $c_i$ | Subindex value, $p_i$ | Derived LPI with considered leachate parameters ($w_i p_i$) 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr | 0.064 | 1.3 | 8 | 0.512 | - | - | - | - | - | - | - | - | - | - |
| Pb | 0.063 | 1 | 12 | 0.756 | 0.756 | - | - | - | - | - | - | - | - | - |
| COD | 0.062 | 9700 | 78 | 4.836 | 4.836 | 4.836 | - | - | - | - | - | - | - | - |
| Hg | 0.062 | 0.007 | 5.5 | 0.341 | 0.341 | 0.341 | 0.341 | - | - | - | - | - | - | - |
| $BOD_5$ | 0.061 | 4800 | 52 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | - | - | - | - | - | - |
| As | 0.061 | 0.01 | 5 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | - | - | - | - | - |
| CN | 0.058 | 0.7 | 11 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | - | - | - | - |
| Phenol | 0.057 | 3.2 | 10 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | - | - | - |
| Zn | 0.056 | 2.9 | 7 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | - | - |
| pH | 0.055 | 8 | 6 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | - |
| TKN | 0.053 | 718 | 20 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 |
| Ni | 0.052 | 0.06 | 7.5 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
| TCB | 0.052 | 6700 | 84 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 |
| $NH_4$-N | 0.051 | 487 | 50 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 |
| TDS | 0.05 | 11350 | 23 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| Cu | 0.05 | 3.5 | 28 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| Chloride | 0.048 | 3250 | 24 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 |
| Iron | 0.045 | 79 | 9 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 |
| Summation | 1.000 | | | 24.327 | 23.815 | 23.059 | 18.223 | 17.882 | 14.710 | 14.405 | 13.767 | 13.197 | 12.805 | 12.475 |
| Total weight | | | | 1.000 | 0.936 | 0.873 | 0.811 | 0.749 | 0.688 | 0.627 | 0.569 | 0.512 | 0.456 | 0.401 |
| Derived LPI | | | | 24.327 | 25.443 | 26.414 | 22.470 | 23.874 | 21.381 | 22.974 | 24.195 | 25.775 | 28.081 | 31.110 |
| Percent error | | | | 0.000 | 4.589 | 8.577 | 7.634 | 1.860 | 12.111 | 5.560 | 0.542 | 5.954 | 15.432 | 27.881 |

*Note: Cr=chromium, Pb=lead, COD=chemical oxygen demand, Hg= mercury, $BOD_5$= biological oxygen demand, As=arsenic, CN=cyanide, Zn=zinc, TKN=total kjeldahl nitrogen, Ni=nickel, TCB= total colifom bacteria, $NH_4$-N=ammonia nitrogen, TDS=total dissolved solid, Cu=copper and Fe=iron. All values in mg/L, except pH and TCB ((cfu/100ml)).*

- In the first step, the concentration of Cr has the highest weight factor, is presumed to be unknown. The LPI, ignoring the subindex value of Cr, is calculated and reported in column 6, Table 3.
- Then, step by step it is presumed that concentrations Pb, COD, Hg, $BOD_5$, As, CN, phenol, Zn and pH are not known in addition to the earlier presumed unknown parameters. The LPI so calculated are reported in Table 3.
- The percentage error in calculating LPI values, with respect to the LPI value when data for all 18 parameter are considered, is also reported in the last row of respective columns of Table 3.
- Figure 2 shows the variation in LPI values with respect to the number of pollutants considered in calculating LPI. It also gives the percentage error introduced in calculating LPI values with respect to the number of parameters considered.

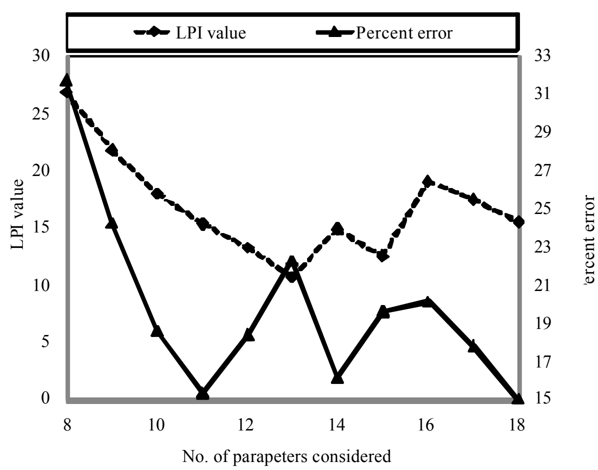


Fig. 2: Variation of LPI and percent error when high weight parameters are ignored

Errors Introduced by Ignoring Pollutant Data Based on Sub-indexValue: In this approach, three scenarios were considered as reveals:

- Firstly, it was presumed that data for one parameter having the highest sub-index value are not available and then LPI calculated. Next it is presumed that the data for two parameters having the highest sub-index values are not available and so on for three, four, fifth to tenth parameters. From Table 2, column 4, it is observed that the pollutants having the highest sub-index values are TCB, COD, $BOD_5$ and $NH_4$-N with subindex values of 84, 78, 52 and 50, respectively. To start with, it is presumed that data for TCB are not available. Based on this assumption, the LPI value is

Table 4: Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with highest sub-index values ignored)

| | | | | Derived LPI with considered leachate parameters ($w_i p_i$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pollutant | Pollutant weight, $w_i$ | Pollutant concentration, $c_i$ | Subindex value, $p_i$ | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| Cr | 0.064 | 1.3 | 8 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 |
| Pb | 0.063 | 1 | 12 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | N.C | N.C |
| COD | 0.062 | 9700 | 78 | 4.836 | 4.836 | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C |
| Hg | 0.062 | 0.007 | 5.5 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 |
| $BOD_5$ | 0.061 | 4800 | 52 | 3.172 | 3.172 | 3.172 | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C |
| As | 0.061 | 0.01 | 5 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 | 0.305 |
| CN | 0.058 | 0.7 | 11 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | N.C |
| Phenol | 0.057 | 3.2 | 10 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 |
| Zn | 0.056 | 2.9 | 7 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 | 0.392 |
| pH | 0.055 | 8 | 6 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| TKN | 0.053 | 718 | 20 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | N.C | N.C | N.C |
| Ni | 0.052 | 0.06 | 7.5 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
| TCB | 0.052 | 6700 | 84 | 4.368 | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C |
| $NH_4$-N | 0.051 | 487 | 50 | 2.55 | 2.55 | 2.55 | 2.55 | N.C | N.C | N.C | N.C | N.C | N.C | N.C |
| TDS | 0.05 | 11350 | 23 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | N.C | N.C | N.C | N.C |
| Cu | 0.05 | 3.5 | 28 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | N.C | N.C | N.C | N.C | N.C | N.C |
| Chlorides | 0.048 | 3250 | 24 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | N.C | N.C | N.C | N.C | N.C |
| Total Iron | 0.045 | 79 | 9 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 |
| Summation | 1.000 | | | 24.327 | 19.959 | 15.123 | 11.951 | 9.401 | 8.001 | 6.849 | 5.699 | 4.639 | 3.883 | 3.245 |
| Total weight | | | | 1.000 | 0.948 | 0.897 | 0.835 | 0.774 | 0.724 | 0.676 | 0.628 | 0.575 | 0.512 | 0.454 |
| Derived LPI | | | | 24.327 | 21.054 | 16.860 | 14.313 | 12.146 | 11.051 | 10.132 | 9.075 | 8.068 | 7.584 | 7.148 |
| Percent error | | | | 0.000 | 13.455 | 30.696 | 41.166 | 50.072 | 54.573 | 58.352 | 62.696 | 68.825 | 70.619 | 70.619 |

*Note: Cr=chromium, Pb=lead, COD=chemical oxygen demand, Hg= mercury, $BOD_5$= biological oxygen demand, As=arsenic, CN=cyanide, Zn=zinc, TKN=total kjeldahl nitrogen, Ni=nickel, TCB= total colifom bacteria, $NH_4$-N=ammonia nitrogen, TDS=total dissolved solid, Cu=copper and Fe=iron. All values in mg/L, except pH and TCB ((cfu/100ml)).*
*N.C= parameter not considered*

calculated using Eq. (2) and reported in column 6, Table 4. In the next step, it is presumed that data for COD are also not available in addition to TCB. The LPI value based on this assumption is calculated using Eq. (2) and reported in column 7, Table 4. Similarly, it is presumed that data for three and then four pollutants are not available and the corresponding LPI values are calculated and reported in columns 8 and 9 of Table 4. Moreover, in the similar fashion, it is presumed that data for fifth to fourteen pollutants are not available and the corresponding LPI values are calculated and reported in columns 9 to 19 in Table 4. The percentage error introduced in calculating these fourteen LPI values is also calculated and reported in the last row of respective columns in Table 4 and the results are shown in Figure 3.

- Then it is presumed that the data for one parameter having the least sub-index value are unknown and then LPI calculated. Subsequently it is presumed that, data for two, three, four and tenth parameters having the lowest sub-index values are not available. From column 4 of Table 2, it is observed that the parameters having the lowest sub-index values are As, Hg, pH and Zn with sub-index values of

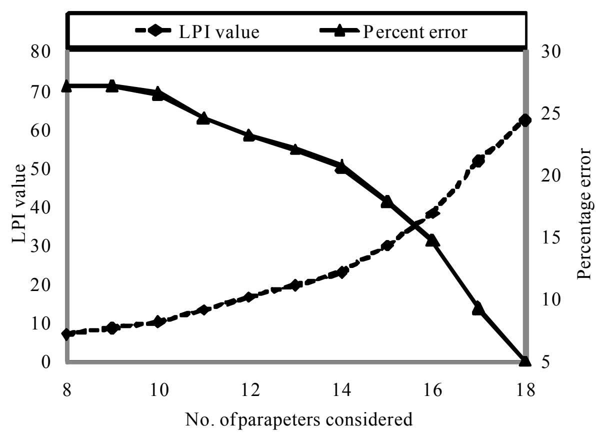


Fig. 3: Variation of LPI and percent error when parameters with highest sub-index values ignored.

5, 5.5, 6 and 7, respectively. The above procedure is repeated for calculating LPI values (reported in Table 5). The percentage error introduced in calculating LPI for each presumption is also calculated and reported in respective columns of Table 5 and the results are shown in Figure 4.

- After that it is presume that data for two parameters, having the highest and lowest sub-index value are unknown simultaneously. The parameter having

Table 5: Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with lowest sub-index values ignored)

| Pollutant | Pollutant weight, $w_i$ | Pollutant concentration, $c_i$ | Subindex value, $p_i$ | Derived LPI with considered leachate parameters ($w_ip_i$) 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr | 0.064 | 1.3 | 8 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | 0.512 | N.C | N.C | N.C | N.C | N.C |
| Pb | 0.063 | 1 | 12 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 | N.C |
| COD | 0.062 | 9700 | 78 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 | 4.836 |
| Hg | 0.062 | 0.007 | 5.5 | 0.341 | 0.341 | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C |
| $BOD_5$ | 0.061 | 4800 | 52 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 | 3.172 |
| As | 0.061 | 0.01 | 5 | 0.305 | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C |
| CN | 0.058 | 0.7 | 11 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 | N.C | N.C |
| Phenol | 0.057 | 3.2 | 10 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | N.C | N.C | N.C |
| Zn | 0.056 | 2.9 | 7 | 0.392 | 0.392 | 0.392 | 0.392 | N.C | N.C | N.C | N.C | N.C | N.C | N.C |
| pH | 0.055 | 8 | 6 | 0.33 | 0.33 | 0.33 | N.C | N.C | N.C | N.C | N.C | N.C | N.C | N.C |
| TKN | 0.053 | 718 | 20 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 |
| Ni | 0.052 | 0.06 | 7.5 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | N.C | N.C | N.C | N.C | N.C | N.C |
| TCB | 0.052 | 6700 | 84 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 | 4.368 |
| $NH_4$-N | 0.051 | 487 | 50 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 | 2.55 |
| TDS | 0.05 | 11350 | 23 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| Cu | 0.05 | 3.5 | 28 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| Chlorides | 0.048 | 3250 | 24 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 |
| Total Iron | 0.045 | 79 | 9 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 | N.C | N.C | N.C | N.C |
| Summation | 1.000 | | | 24.327 | 24.022 | 23.681 | 23.351 | 22.959 | 22.569 | 22.057 | 21.652 | 21.082 | 20.444 | 19.69 |
| Total weight | | | | 1.000 | 0.939 | 0.877 | 0.822 | 0.766 | 0.714 | 0.662 | 0.617 | 0.617 | 0.559 | 0.496 |
| Derived LPI | | | | 24.33 | 25.58 | 27.00 | 28.41 | 29.97 | 31.61 | 33.32 | 35.09 | 34.17 | 36.57 | 39.69 |
| Percent error | | | | 0.00 | 5.16 | 11.00 | 16.77 | 23.21 | 29.93 | 36.96 | 44.25 | 40.46 | 50.34 | 63.17 |

*Note: Cr=chromium, Pb=lead, COD=chemical oxygen demand, Hg= mercury, $BOD_5$= biological oxygen demand, As=arsenic, CN=cyanide, Zn=zinc, TKN=total kjeldahl nitrogen, Ni=nickel, TCB= total colifom bacteria, $NH_4$-N=ammonia nitrogen, TDS=total dissolved solid, Cu=copper and Fe=iron. All values in mg/L, except pH and TCB ((cfu/100ml)).*
*N.C= parameter not considered.*

Table 6: Estimating errors involved in calculating LPI due to nonavailability of data (Parameters with highest and lowest sub-index values ignored simultaneously)

| Pollutant | Pollutant weight, $w_i$ | Pollutant concentration, $c_i$ | Subindex value, $p_i$ | Derived LPI with considered leachate parameters ($w_ip_i$) 18 | 16 | 14 | 12 | 10 |
|---|---|---|---|---|---|---|---|---|
| Cr | 0.064 | 1.3 | 8 | 0.512 | 0.512 | 0.512 | 0.512 | N.C |
| Pb | 0.063 | 1 | 12 | 0.756 | 0.756 | 0.756 | 0.756 | 0.756 |
| COD | 0.062 | 9700 | 78 | 4.836 | 4.836 | N.C | N.C | N.C |
| Hg | 0.062 | 0.007 | 5.5 | 0.341 | 0.341 | N.C | N.C | N.C |
| $BOD_5$ | 0.061 | 4800 | 52 | 3.172 | 3.172 | 3.172 | N.C | N.C |
| As | 0.061 | 0.01 | 5 | 0.305 | N.C | N.C | N.C | N.C |
| CN | 0.058 | 0.7 | 11 | 0.638 | 0.638 | 0.638 | 0.638 | 0.638 |
| Phenol | 0.057 | 3.2 | 10 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 |
| Zn | 0.056 | 2.9 | 7 | 0.392 | 0.392 | 0.392 | 0.392 | N.C |
| pH | 0.055 | 8 | 6 | 0.33 | 0.33 | 0.33 | N.C | N.C |
| TKN | 0.053 | 718 | 20 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 |
| Ni | 0.052 | 0.06 | 7.5 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
| TCB | 0.052 | 6700 | 84 | 4.368 | N.C | N.C | N.C | N.C |
| $NH_4$-N | 0.051 | 487 | 50 | 2.55 | 2.55 | 2.55 | 2.55 | N.C |
| TDS | 0.05 | 11350 | 23 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| Cu | 0.05 | 3.5 | 28 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| Chlorides | 0.048 | 3250 | 24 | 1.152 | 1.152 | 1.152 | 1.152 | 1.152 |
| Total Iron | 0.045 | 79 | 9 | 0.405 | 0.405 | 0.405 | 0.405 | 0.405 |
| Summation | 1.000 | | | 24.327 | 19.654 | 14.477 | 10.975 | 7.521 |
| Total weight | | | | 1.000 | 0.887 | 0.774 | 0.657 | 0.539 |
| Derived LPI | | | | 24.33 | 22.16 | 18.70 | 16.70 | 13.95 |
| Percent error | | | | 0.00 | 8.92 | 23.11 | 31.33 | 42.64 |

*Note: Cr=chromium, Pb=lead, COD=chemical oxygen demand, Hg= mercury, $BOD_5$= biological oxygen demand, As=arsenic, CN=cyanide, Zn=zinc, TKN=total kjeldahl nitrogen, Ni=nickel, TCB= total colifom bacteria, $NH_4$-N=ammonia nitrogen, TDS=total dissolved solid, Cu=copper and Fe=iron. All values in mg/L, except pH and TCB ((cfu/100ml)).*
*N.C= parameter not considered.*

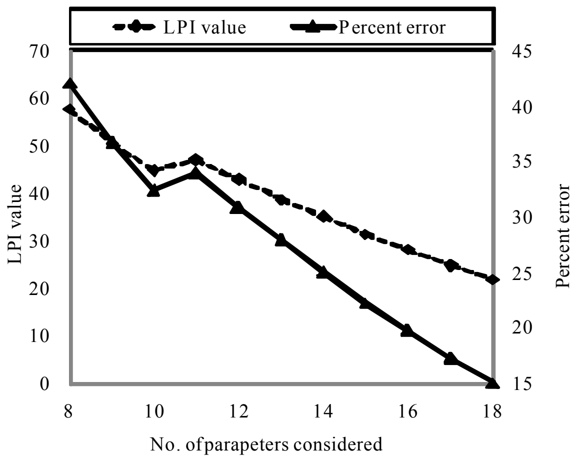


Fig. 4: Variation of LPI and percent error when parameters with lowest sub-index values ignored

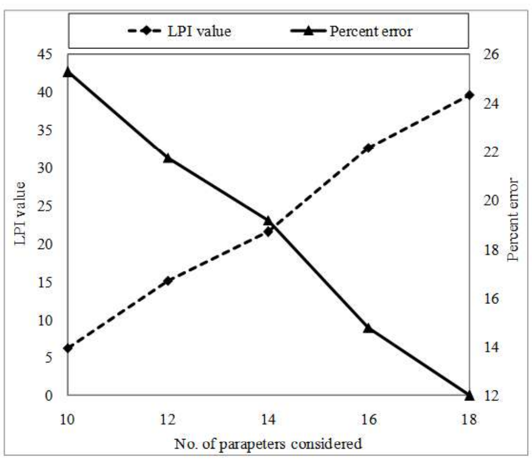


Fig. 5: Variation in LPI due to nonavailability of data parameters with highest and lowest sub-index values ignored simultaneously

the highest sub-index value is TCB and the one having the lowest sub-index value is As. The LPI for this is calculated and reported in column 6, Table 6. Subsequently it is presume that data for four parameters: two parameters with highest sub-index values (TCB and COD) and two parameters with lowest sub-index values (As and Hg) are not available. The LPI for this presumption is calculated and reported in column 7, Table 6. Moreover, it is presume that data for six parameters: three parameters with highest sub index values (TCB, COD and $BOD_5$) and three parameters with lowest sub-index values (As, Hg and pH) are not available. The LPI for this presumption is calculated and reported in column 8, Table 6. Subsequently, it is presume that data for eight parameters: four parameters with highest and four with lowest sub index values are not available. The LPI for this presumption is calculated and reported in column 9, Table 6. The percent error introduced in calculating LPI is reported in the last row of respective columns in Table 6 and the results are shown in Figure 5.

## RESULTS AND DISCUSSIONS

Errors Introduced by Ignoring Pollutant Data Based on Weight Factor: Based on Table 2 and Figure 1, it can be depicted that error introduced in calculating LPI is 2.97 %, when concentration of one parameter, i.e., Fe (pollutant with lowest weight factor) is not considered. It also depicts that error increases to 3.19 % when concentration of two parameters, Fe and $Cl^-$, is unknown. Then the error decreases to 2.50 % when data for three parameters, Fe, Cl-and Cu, is not known. The error introduced in LPI is the highest, i.e., 22.33 %, when data of six parameters is not considered. After this, the error decreases with the increase in the number of missing parameters. The error is just 6.25 % when only eight parameters are considered (that is when data for twelve parameters are not considered).

Similarly from Table 3 and Figure 2, it is observed that the error is 4.59 %, when data for one parameter that is Cr (pollutant with highest weight factor) is not considered in calculating LPI. The error increases to 8.58 % when data for two pollutants, Cr and Pb, are ignored in calculating LPI. The error is highest, i.e., 27.88 %, when data for the twelve pollutants are ignored. But the percent error was observed 0.542 % when seven parameters are not considered in calculating the LPI value. This leads to the conclusion that the error involved in calculating LPI does not vary with the number of parameters considered and the variation is erratic. The erratic behavior in the error introduced in the LPI is due to the fact that the parameters ignored while calculating LPI had significantly different subindex values with respect to the overall LPI.

Errors Introduced by Ignoring Pollutant Data Based on Subindex Value: Table 4 and Figure 3 reveals that error introduced is highest, i.e., 70.62 %, when data for the twelve parameters having the highest subindex values are not considered, followed by 68.83 % when data for the eight parameters having the highest subindex values are not considered. However, it may reduce to 30.69 and 13.45 % when data for the two and one parameters having the highest subindex values, respectively are not considered. Moreover, the errors introduced due to nonconsideration of data of one parameters having the lowest subindex values are 5.16 % and it rises gradually to 63.17 % when data for the fourteen parameters are not considered (Table 5 and Figure 4).

On the other hand, in the third scenario, the error introduced in calculating LPI is significantly low as compared to the other two scenarios. The error introduced is 8.92 and 42.64 % for nonavailability of data for two and eight parameters, respectively (Table 6 and Figure 5).

Here, it is important to note that derived LPI are lower than the true LPI when pollutants with high sub-index values are ignored. On the contrary, the derived LPI are higher than the true LPI when data for the pollutants with low sub-index values are ignored. Hence, the results obtained by ignoring data for the pollutants with high subindex values produce falsified results, leading to a false sense of security, indicating a relatively more polluted environment as less polluted.

But when data for the pollutants with low subindex values are ignored, distended results are obtained and the results will raise an unnecessary alarm by indicating a comparatively less polluted environmental situation to be more contaminated. Based on this discussion, it is possible to conclude that the errors involved in LPI values are high and dangerous when the data for the pollutants having high subindex values are not available as compared to the scenario when data for the parameters having low subindex values are not available. The error involved in LPI values is low when data for the pollutants having highest and lowest subindex values are not considered simultaneously.

## CONCLUSIONS

Result reveals that maximum error (22.33 %) is introduced in calculating LPI when the data for the six low weight parameters are not considered, but the error is as low as 2.50 % when data for five parameters are not considered. Similarly the error involved in calculating LPI is maximum (27.88 %) when data for twelve high weight parameters are ignored, but the error involved is low (0.542 %) when data for seven high weight factors are ignored. Here it can be concluded that the errors introduced in calculating LPI values are not at all related to the number of parameters whose concentrations are not known. From this it can be concluded that LPI is more reliable and accurate as a larger number of parameters are available in its formulation. In contrary, the error introduced in calculating LPI is more sensitive when data for the parameters having high sub-index values are not considered as the derived LPI values are lower than the true LPI value and produce vague results. Finally, it can be concluded that errors introduced in calculating LPI are marginal when the data of the parameters having highest and lowest sub-index values are not considered simultaneously.

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