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LEACHATE CONTAMINATION POTENTIAL OF UNLINED MUNICIPAL SOLID WASTE LANDFILL SITES BY LEACHATE POLLUTION INDEX

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Abstract: Leachate pollution index (LPI) provides an overall pollution potential of a landfill site. In this paper, the concept of LPI is described in brief and stepwise procedure to calculate the LPI of a landfill is explained using data from municipal landfill sites of Ludhiana City, Punjab (India). These landfill sites do not have any base liner or leachate collection and treatment system. Therefore, all the leachate generated finds its path into the surrounding environment. LPI values indicate the leachate contamination potential of landfill sites in a given geographical area on a comparative scale and used as a hazard identification tool. It is an increasing scale index, where a higher value indicates poor environmental condition based on the Delphi technique. In the present study, leachate samples were collected and analyzed for 5 significant leachate pollutant variables *viz* pH, TDS, BOD_5, COD and Chloride (Cl^-). The LPI values of landfill sites i.e. 20.26, 26.45 and 23.39 indicated that the waste deposited has not yet stabilized. Leachate generated from these landfill sites were contaminated and proper treatment will have to be ensured before discharging the leachate into the surrounding environment. It is concluded that LPI value can be used as a tool to assess the leachate pollution potential from landfill sites particularly at places where there is a high risk of leachate migration and pollution of groundwater.

Keywords: Leachate pollution index, Landfill, Delphi technique, Groundwater.

1. INTRODUCTION

Solid waste management is a difficult task which includes the control of generation, storage, collection, transfer and disposal of solid waste in an environmentally acceptable manner. Municipal solid waste (MSW) disposal is a global concern, most especially in developing countries across the world, as poverty, population growth and high urbanization rates combine with ineffectual and under-funded governments to prevent efficient management of wastes (Cointreau, 1982). Landfills are the primary means of MSW disposal in many countries worldwide because they offer dumping high quantities of MSW at economical costs

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in comparison to other disposal methods such as incineration. Most of the landfills in developing countries including India are not designed with proper leachate collection mechanism. Most of these landfills do not come under sanitary landfill classification because there are no facilities for collection and treatment of leachate and there is no infrastructure to collect landfill gas. Landfill leachate produced form MSW landfill sites is generally heavily contaminated and consist of complex wastewater that is very difficult to deal with. Leachate is characterized by high concentration of organic matter, ammonia nitrogen, heavy metals, and chlorinated organic and inorganic salts (Renou et al., 2008). The characteristics of leachate are highly variable depending on the waste composition, amount of precipitation, site hydrology, waste compaction, cover design, sampling procedures, and interaction of leachate with the environment, landfill design and operation (Kulikowska and Klimiuk, 2008). The management of leachate is among the most important factors to be considered in planning, designing, operation, and long-term management of an MSW landfill. Leachate can contaminate groundwater where landfills are not provided with liners and surface water if it is not collected and treated prior to its discharge. A strong need has been felt to take appropriate remedial measures to avoid contamination of the underlying soils and groundwater aquifers from the leachate generated from the landfills. The state regulatory authorities in most of the countries around the world have framed regulations to safe guard against the contamination of groundwater sources from the leachate generated from the landfills. Although legal provision exists in many countries, there are usually financial constraints, and a lack of technical resources and physical infrastructure to implement it. In India, MSW (Management and Handling) Rules, 2000 were notified by Government of India, but their implementation by most of the municipalities in the country that undertake the work of municipal waste management is very poor. The state regulatory authorities in almost all countries have framed regulations to safeguard the different environmental elements from landfills. Landfill remediation and preventive measures are quite expensive and therefore cannot be taken up at the same time, because of financial constraints.The remediation and preventive measures have to be taken up on a priority basis. Thus a system is required to facilitate the setting of the priorities, to establish which landfills need immediate attention for remediation work. An index for comparison of the pollution potential of landfills in a given geographical area, at a particular time, can be a useful tool. Several environmental indices such as the water quality index (Giljanovic 1999, Nagels et al., 2001, Liou et al., 2004) and air pollution index (Inhaber 1974, USEPA 1994) have been developed and are in use. Kumar and Alappat (2003) developed a technique to evaluate the leachate contamination potential of different landfills on a comparative scale using an index known as LPI. Because identification and quantification of pollutants in landfill leachate is the major limitation for its successful treatment (Trankler et al., 2005), LPI can be used as a mean to determine whether a landfill requires immediate attention in terms of introducing remediation measures. LPI has many applications including ranking of landfill sites, resource allocation for landfill remediation, trend analysis, enforcement of standards and scientific research.

In this paper, the concept of LPI is described in brief and stepwise procedure to calculate the LPI of a landfill is explained using data from municipal landfill sites of Ludhiana City, Punjab (India) for 5 significant leachate pollutant variables viz pH, TDS, BOD_5, COD and Chloride (Cl^-). These landfill sites do not have any base liner or leachate collection and treatment system. Therefore, all the leachate generated finds its path into the surrounding environment.

1.1 Concept of LPI

In an effort to develop a method for comparing the leachate pollution potential of various landfill sites in a given geographical area, an index known as LPI were formulated using Rand Corporation Delphi Technique. The formulation process and complete description on the development of the Leachate Pollution Index, has been discussed elsewhere (Kumar and Alappat, 2003). The LPI represents the level of leachate contamination potential of a given 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. It is an increasing scale index, wherein a higher value indicates a poor environmental condition. 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. The LPI can also be used to compare leachate contamination potential of different landfills in a given geographical area or around the world. 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 (Kumar and Alappat, 2003). The important results of the LPI developed are briefed here:

1.1.1 Variable Selection

Eighteen leachate pollutant variables were selected for inclusion in LPI. They are pH, Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Ammonia Nitrogen, Total Iron, Copper, Nickel, Zinc, Lead, Chromium, Mercury, Arsenic, Phenolic Compounds, Chlorides, Cyanide and Total Coliform Bacteria.

1.1.2 Variable Weights

The weights for these eighteen parameters were calculated based on the significance levels of the individual pollutants. The weight factor indicates the importance of each pollutant variable to the overall leachate pollution. For example, the weight factor for chromium is 0.064, and so it is most important variable than the other pollutant variables, while total iron with a weight factor of 0.045 is least important variable as compared to other pollutant variables included in LPI (Kumar and Alappat, 2003). The weights for other pollutant variables are TDS: 0.050; BOD_5: 0.061; COD: 0.062; TKN: 0.053; Ammonia Nitrogen: 0.051; Copper: 0.050; Nickel: 0.052; Zinc: 0.056; Lead: 0.063; Mercury: 0.062; Arsenic: 0.061; Phenolic Compounds: 0.057; Chlorides: 0.049; Cyanides: 0.058 and Total Coliform Bacteria: 0.052. The sum of the weights of all the eighteen parameters is one.

1.1.3 Variable Curves

The averaged sub index curves for each parameter were drawn to establish a relation between the leachate pollution and strength or concentration of the parameter. The sub-index curves for all the pollutant variables are reported in Kumar and Alappat (2003). The averaged sub index curves are the curves that represent the relation between leachate pollution and the strength or concentration of the parameter.

1.1.4 Variable Aggregation

The weighted sum linear aggregation function was used to sum up the behaviour of all the leachate pollutant variables. The various possible aggregation functions were evaluated by Kumar and Alappat (2004) to select the best possible aggregation function. The Leachate Pollution Index can be calculated using the equation:

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

where LPI = the weighted additive leachate pollution index,

w_i = the weight for the ith pollutant variable,

p_i = the sub index value of the ith leachate pollutant variable,

n = number of leachate pollutant variables used in calculating LPI

$$\sum_{i=1}^{n} w_i = 1$$

However, when the data for all the leachate pollutant variables included in LPI is not available, the LPI can be calculated using the data set of the available leachate pollutants. In that case, the LPI can be calculated by the equation:

$$LPI = \frac{\sum_{i=1}^{m} w_i p_i}{\sum w_i} \qquad \text{….. (2)}$$

where m is the number of leachate pollutant parameters for which data is available, but in that case, $m < 18$ and $\Sigma w\ i < 1$.

1.2 Procedure to calculate LPI

The stepwise procedure to calculate LPI is given below.

Step 1 Testing of Leachate Pollutants

Analytical laboratory tests were performed on leachate samples collected from the landfill sites to find out the concentration of the leachate pollutants.

Step 2 Calculating Sub-index Values

To calculate the LPI, one first computes the ‘p' value or sub-index value of the parameters from the sub-index curves based on the concentration of the leachate pollutants obtained during the tests. The ‘p’ values are obtained by locating the concentration of the leachate pollutant on the horizontal axis of the sub index curve for that pollutant and noting the leachate pollution sub-index value where it intersects the curve.

Step 3 Aggregation of Sub-index Values

The ‘p’ values obtained were multiplied with the respective weights assigned to each parameter. The equation (1) is used to calculate LPI if the concentrations of all the eighteen variables included in LPI are known. Otherwise, equation (2) is used when data for some of the pollutants is not available.It has been observed that LPI values can be calculated with marginal error using equation (2), when the data for some of the pollutants is not available (Kumar and Alappat, 2005). In the present study, out of 18, 5 significant parameters were covered, so equation (2) is used.

2 MATERIALS AND METHODS

2.1 Landfill Site

Ludhiana is the largest city in Punjab, both in terms of area and population. It lies between latitude $30^0$55' N and longitude $75^0$54' E. The Municipal Corporation limit of city is spread over an area of 141sq.km. The population of the city within the Municipal Corporation area is estimated at 34,87,882 in 2011 (Ludhiana District Census Report, 2011). The climate of Ludhiana is semi arid with maximum mean temperature reaching upto 42.8^0C and minimum mean temperature is as below as 11.8^0C. Total rainfall during the year is 600-700 cm; 70% of total rainfall occurs from July to September. The altitude varies from 230 m to 273 m from mean sea level (Vision 2021, Ludhiana City Development Plan, 2001). Leachate sample for the present study is collected from three designated MSW landfill sites available at Ludhiana City, Punjab, India (Table 1). No cover of any description is placed over the spread waste to inhabit the ingress of surface water or to minimize litter blow and odours or to reduce the presence of vermin and insects. Rag pickers regularly set fire to waste to separate non-combustible materials for recovery. Since, there are no specific arrangements to prevent flow of water into and out of landfill site, the diffusion of contaminants released during degradation of landfill wastes, may proceed uninhibited. None of these three landfill sites are lined and waste is directly dumped (without segregation) into the site. No proper compaction is done to compress the waste into the site.

Table 1: MSW landfill sites of Ludhiana City, Punjab (India)

Landfill sites	Land area (acres)	Average depth (in ft.)	Future life (years)	Distance from city centre
Jainpur	10	Filled	Nil	10 km
Jamalpur	25	8 to 10	25	11 km
Noorpur Belt	21	12 to 15	25	14 km

2.2 Leachate sampling and analysis

To determine the quality of leachate, integrated samples were collected from different landfill locations. Leachate sample for the study was collected from all the three landfill sites of Ludhiana City i.e. first landfill site is on Hambran Road at Jainpur Village having 10 acres of low lying land area which is oldest of other two and is now completely filled, second landfill site is on Tajpur Road at Jamalpur Village having 25 acres of low lying land area and third landfill site is at Noorpur Belt on an low lying land area of about 21 acres. These sites are non-engineered low lying open dumps. They have neither any bottom liner nor any leachate collection and treatment system. Therefore, all the leachate generated finds its paths into the surrounding environment. These landfill sites were not equipped with leachate collectors. Leachate samples were collected from the base of solid waste heaps where the leachate was drained out by gravity. Leachate samples were collected in January end, 2012. Various leachate pollutant variables *viz* pH, TDS, BOD_5, COD and Chloride (Cl^-) were analyzed to determine pollution potential of leachate discharge from municipal solid waste landfill sites to estimate its pollution potential.

2.3 Analytical work

Analytical methods were according to "Standard methods for examination of water and wastewater" specified by American Public Health Association (APHA, 2005). The pH was measured by electronic pH meter (4500-H^+.B of Standard Methods). TDS was determined by filtered sample through Whatman filter paper-44 and estimated by gravimetry (2540.C: Standard Methods). COD was determined by refluxion of sample followed by titration with Ferrous Ammonium Sulphate (FAS) was adopted (5220.C: Standard Methods). BOD_5 - Winkler's method was used for estimating initial and final DO in the sample and BOD_5 was determined (5210-B of Standard methods). Argentometric volumetric titration method in the presence of Potassium chromate provides reliable results of chloride (4500-Cl^-.B of Standard Methods).

3. RESULTS AND DISCUSSION

Leachate samples of MSW landfill sites were collected and analyzed for 5 significant leachate pollutant variables *viz* pH, TDS, BOD_5, COD and Chloride (Cl^-) to estimate its pollution potential. The concentration of the studied leachate pollutant variables of all the three landfill sites exceeded the permissible limits. The comparative results of leachate parameters of Jainpur landfill site, Jamalpur landfill site and Noorpur Belt landfill site of Ludhiana City, Punjab and standards for the disposal of leachate to inland surface water, public sewers and land disposal as per Municipal Solid Waste (Management and Handling) Rules, 2000, Government of India were shown in Table 2.

3.1 Calculating LPI

The procedure explained above has been used to calculate the LPI for the MSW landfill sites. Sub-index curves of 5 studied leachate pollutant variables *viz* pH, TDS, BOD_5, COD and Chloride (Cl^-) were shown in Fig.1 (a-e). The LPI value of Jainpur landfill site, Jamalpur landfill site and Noorpur Belt landfill site of Ludhiana City, Punjab (India) and also the LPI of leachate disposal standards given under Municipal Solid Waste (Management and Handling) Rules, 2000 notified by Government of India was calculated using the above procedure and reported in Table 3, 4 and 5.

Table 2: Comparative leachate pollutant variables of landfill sites of Ludhiana City, Punjab (India) and leachate disposal standards

Leachate Pollutant Variables*	Jainpur landfilling site	Jamalpur landfilling site	Noorpur Belt landfilling site	Standards (Mode of Disposal)**		
				Inland surface water	Public sewers	Land disposal
pH	9.3	9.8	9.5	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
TDS	5348	6563	5693	2100	2100	2100
BOD_5	329	495	406	30	350	100
COD	1335	2535	2018	250	-	-
Chloride	1448	1836	1653	1000	1000	600

* All values in mg/l except pH

** Municipal Solid Wastes (Management and Handling) Rules, 2000, Govt. of India

4 CONCLUSIONS

- LPI value can be used as a tool to assess the leachate pollution potential from landfill sites particularly at places where there is a high risk of leachate migration and pollution of groundwater and thus can help to take necessary decisions.
- In the present study, the LPI values of 20.26, 26.45 and 23.39 for the of landfill sites indicated that the waste deposited has not yet stabilized.
- High value of LPI of these landfill sites indicated that leachate generated from these landfill sites were contaminated and proper treatment will have to be ensured before discharging the leachate. These landfill sites do not have any base liner or leachate collection and treatment system. Leachate should be properly treated and these sites should be monitored on a continuous basis.
- It should be noted here that the LPI values indicate the leachate contamination potential of landfill sites in a given geographical area on a comparative scale and is at best a hazard identification tool as other factors like dose response effect, volume of leachate generated, type of liner provided in case of a lined landfill, exposure period, depth of water aquifer, type of soil strata and population affected also need careful consideration. A planning index,

specifically for decision-making, may be further generated, as the one used by United States Environmental Protection Agency for planning waste treatment projects (Truett, 1975).

4.1 Comparison with Standards

- The LPI value of the standards for the disposal of leachate to inland surface water shall not exceed 7.378 which is the permissible limit for the disposal of leachate to inland surface water as per the standards given under Municipal Solid Waste (Management and Handling) Rules, 2000 notified by Government of India.
- The comparison of the LPI values of landfill sites i.e. 20.26, 26.45 and 23.39 with the standards set for the disposal of leachate indicated that the leachate generated from the landfill is highly contaminated and will have to be treated before discharge so that the LPI value reaches below 7.378.

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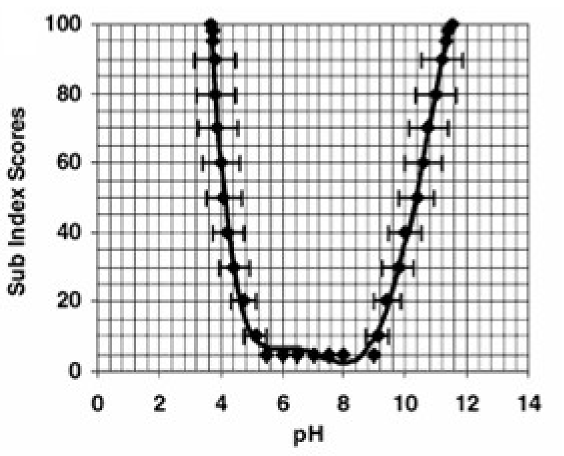
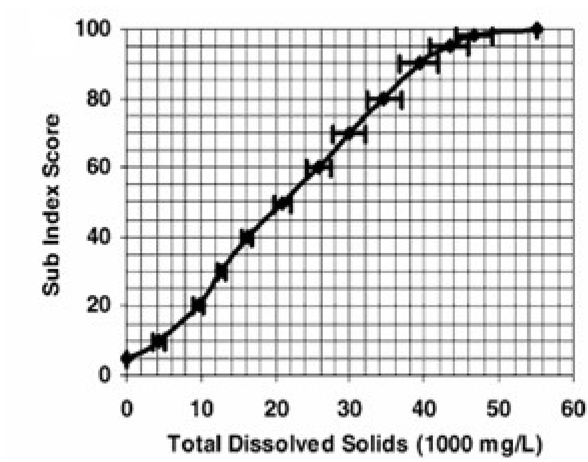


(a)



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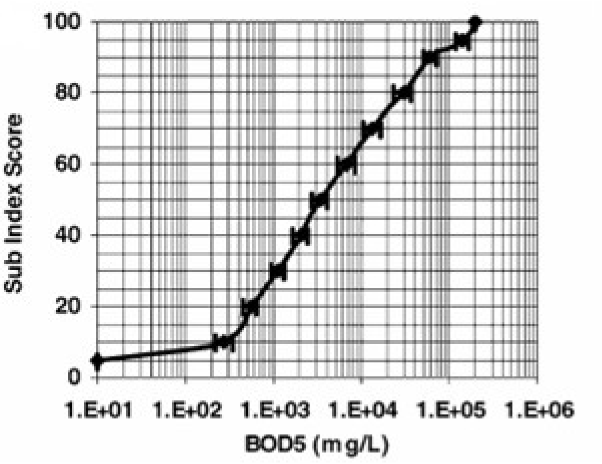

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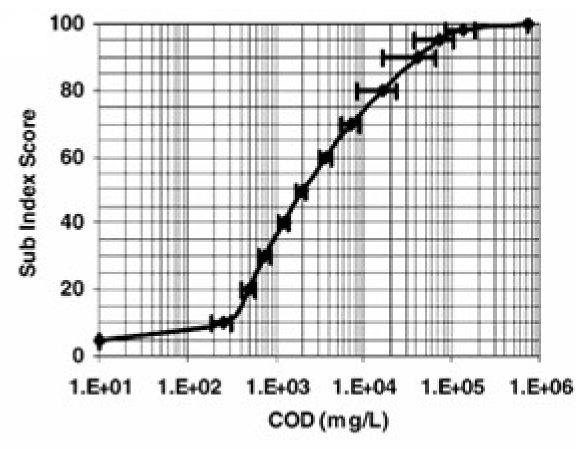

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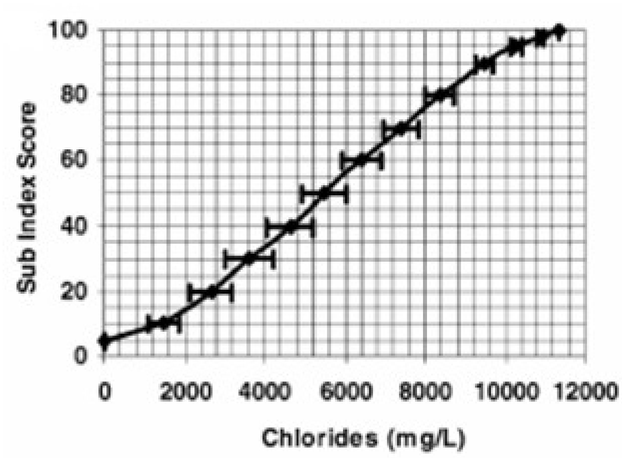

(e)

Fig. 1 (a-e) Sub-index curves of pH, Total Dissolved Solids, BOD_5, COD and Chloride

Table 3: Calculating LPI for Jainpur landfill site, Ludhiana City, Punjab (India)

		LPI of leachate from landfill site			LPI of leachate disposal standards		
Leachate Pollutant Variables	**Variable Weight wi**	**Pollutant Conc. Ci***	**Pollutant Sub Index Value pi**	**Aggregation wi.pi**	**Leachate Disposal Standards for Inland surface water Cs***	**Pollutant Sub Index Value ps**	**Aggregation wi.ps**
Total Chromium	0.064	-	-	-	2.0	9	0.58
Lead	0.063	-	-	-	0.1	5	0.32
COD	0.062	1335	42	2.604	250	10	0.62
Mercury	0.062	-	-	-	0.01	6	0.37
BOD_5	0.061	329	11	0.671	30	6	0.37
Arsenic	0.061	-	-	-	0.2	5	0.31
Cyanide	0.058	-	-	-	0.2	6	0.35
Phenol	0.057	-	-	-	1.0	5	0.29
Zinc	0.056	-	-	-	5.0	6	0.34
pH	0.055	9.3	20	1.1	5.5 - 9.0	5	0.28
TKN	0.053	-	-	-	100	6	0.32
Nickel	0.052	-	-	-	3.0	10	0.52
TCB	0.052	-	-	-	No Standard	-	-
Amm-N	0.051	-	-	-	50	7	0.36
TDS	0.05	5348	13	0.65	2100	7	0.35
Copper	0.05	-	-	-	3.0	18	0.90
Chlorides	0.049	1448	12	0.588	1000	8	0.39
Total Iron	0.045	-	-	-	No Standard	-	-
Total	0.716			5.613			6.67
LPI Value				**20.26**			**7.378**

*All values in mg/l except pH

Table 4: Calculating LPI for Jamalpur landfill site, Ludhiana City, Punjab (India)

		LPI of leachate from landfill site			LPI of leachate disposal standards		
Leachate Pollutant Variables	**Variable Weight wi**	**Pollutant Conc. Ci***	**Pollutant Sub Index Value pi**	**Aggregation wi.pi**	**Leachate Disposal Standards for Inland surface water Cs***	**Pollutant Sub Index Value ps**	**Aggregation wi.ps**
Total Chromium	0.064	-	-	-	2.0	9	0.58
Lead	0.063	-	-	-	0.1	5	0.32
COD	0.062	2535	53	3.286	250	10	0.62
Mercury	0.062	-	-	-	0.01	6	0.37
BOD_5	0.061	495	15	0.915	30	6	0.37
Arsenic	0.061	-	-	-	0.2	5	0.31
Cyanide	0.058	-	-	-	0.2	6	0.35
Phenol	0.057	-	-	-	1.0	5	0.29
Zinc	0.056	-	-	-	5.0	6	0.34
pH	0.055	9.8	28	1.54	5.5 - 9.0	5	0.28
TKN	0.053	-	-	-	100	6	0.32
Nickel	0.052	-	-	-	3.0	10	0.52
TCB	0.052	-	-	-	No Standard	-	-
Amm-N	0.051	-	-	-	50	7	0.36
TDS	0.05	6563	18	0.9	2100	7	0.35
Copper	0.05	-	-	-	3.0	18	0.90
Chlorides	0.049	1836	14	0.686	1000	8	0.39
Total Iron	0.045	-	-	-	No Standard	-	-
Total	0.716			7.327			6.67
LPI Value				**26.45**			**7.378**

*All values in mg/l except pH

Table 5: Calculating LPI for Noorpur Belt landfill site, Ludhiana City, Punjab (India)

		LPI of leachate from landfill site			LPI of leachate disposal standards		
Leachate Pollutant Variables	**Variable Weight wi**	**Pollutant Conc. Ci***	**Pollutant Sub Index Value pi**	**Aggregation wi.pi**	**Leachate Disposal Standards for Inland surface water Cs***	**Pollutant Sub Index Value ps**	**Aggregation wi.ps**
Total Chromium	0.064	-	-	-	2.0	9	0.58
Lead	0.063	-	-	-	0.1	5	0.32
COD	0.062	2018	50	3.1	250	10	0.62
Mercury	0.062	-	-	-	0.01	6	0.37
BOD_5	0.061	406	13	0.79	30	6	0.37
Arsenic	0.061	-	-	-	0.2	5	0.31
Cyanide	0.058	-	-	-	0.2	6	0.35
Phenol	0.057	-	-	-	1.0	5	0.29
Zinc	0.056	-	-	-	5.0	6	0.34
pH	0.055	9.5	22	1.21	5.5 - 9.0	5	0.28
TKN	0.053	-	-	-	100	6	0.32
Nickel	0.052	-	-	-	3.0	10	0.52
TCB	0.052	-	-	-	No Standard	-	-
Amm-N	0.051	-	-	-	50	7	0.36
TDS	0.05	5693	15	0.75	2100	7	0.35
Copper	0.05	-	-	-	3.0	18	0.90
Chlorides	0.049	1653	13	0.63	1000	8	0.39
Total Iron	0.045	-	-	-	No Standard	-	-
Total	0.716			6.48			6.67
LPI Value				**23.39**			**7.378**

*All values in mg/l except pH