Evaluating the Pollution Potential of Municipal Solid Waste Leachate Using the Leachate Pollution Index Framework

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Abstract
Landfill leachate produced from an open MSW dumping area can affect groundwater pollution. The impact of open dumping of solid waste on the water quality of adjacent dumping areas was evaluated. To appraise the leachate pollution index (LPI), the quantification of leachate to know the potential contamination using the LPI had to be developed near the MSW dumping yard caused by the dumping site. The municipal solid waste dumping site, situated near Hubali city, lies at a latitude of 15°19‘28.22N and a longitude of 75°6‘34.61E, covering an area of 22 acres. LPI helps simplify the complex leachate pollution data and makes it easier for the general public and researchers to understand the same. This LPI is made more effective by dividing it into three sub-indices. This study demonstrates the applicability of the LPI as a comprehensive environmental assessment tool for evaluating the pollution potential of an unlined municipal solid waste dumpsite. The results of the leachate pollution index indicated pollution load as per LPI organic, LPI inorganic, and LPI heavy metals are 1.125, 4.4766, and 1.7616, respectively. The overall LPI is found to be 7.3677, which can be reduced by taking some control measures to safeguard the surrounding ecological system of the dumping site. Hence, this tool is recommended to be adopted collectively for leachate quality appraisal. The overall LPI of the selected leachate samples in and around the dumping site was found to be 7.368. The LPI of black liquid indicated that the slightly near to the leachate disposal standards to inland surface water as per Municipal Solid Waste (Management and Handling Rules, 2000, Government of India is 7.378. The study provides site-specific evidence from a major municipal dumpsite in India and highlights the usefulness of LPI for landfill monitoring, risk assessment, and sustainable waste management planning.

Keywords: Leachate Pollution Index (LPI); Municipal Solid Waste; Dumpsite Assessment; Environmental Monitoring; Groundwater Pollution; Leachate Characterization; Waste Management.

Introduction
Municipal solid waste management systems are one of the basic environmental concerns around the world. [1]. The surprising thing is that the increase in population also enhanced the quantity of municipal solid waste [2]. The chief challenge in solid waste disposal and management [3, 4] These types of activities, also in metropolitan cities, have succeeded in the management of solid waste disposal and collection using novel technological and high-powered vehicles for the collection and disposal of solid waste [5, 6]. In most of India, open dumping of solid waste is practiced. This type of practice threatens the ecological system. The dumping of waste on open land creates a lot of problems because of changes in the weather and the generation of black-coloured liquid waste called Leachate [7, 8]. The discharged leachate contains highly organic and inorganic pollutants in the form of compounds in dissolved form, along with heavy metals. [9,10,11]. These leachates percolated into the ground, where the solid waste dumped site then contaminated the groundwater and surface water considerably [12, 13, 14]. Another major issue related to leachate percolation is the spread of pathogens to ground water table and surface water sources; hence, this is a major threat to living organisms [15]. The intensity of causes due to leachate is determined by hazard changes with toxic conditions of pollutants, the location of the water table, and ground water layer. [16,17]. This contamination due to black liquid is also causing changes in the geotechnical properties of the soils found at the dumping site [18, 19, 20]. Earlier studies reported the occurrence of trace metals in plat tissues due to translocation of the black liquid [21, 22]. The LPI was developed as an increasing scale index. A higher value indicates that leachate pollution has increased [36]. The LPI has been extensively used around the world to accomplish several goals, including comparing or ranking municipal landfill sites [37, 38]. The leachate pollution index (LPI), a technique to quantify the contamination potential of landfill leachate, was developed in 2003. Since then, numerous factors have challenged the relevance of the LPI, including advancements in technology, the long-term reliability of these indicators, the incidence of emerging contaminants, and the LPI's efficacy [35]. The aim of the current study is to application of LPI technique to apprehend the range of pollution index due to leachate in the MSW dumping area. This paper is also aimed to improve error reduction equations to precisely estimate the LPI limits and reduce the errors that gives from missing leachate variables.

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Materials and Methodology

Site Details

Hubbali-Dharwad, also known as Twin City, is the second-largest city in the state of Karnataka. It is known as the commercial and business hub of North Karnataka. According to the 2011 census, the population of Hubbali-Dharwad city is 9,43,788. Anchatgeri Dump yard is located at a distance of 4km from Hubbali old bus stand. It has a latitude of 15°19'28.22N and a longitude of 75°6'34.61E, covering an area of 22 acres. The average temperature is 34 °C, with an average rainfall of 792.98mm (Figure 1). The plant doesn't have any facilities to treat the leachate generated during the degradation process. Based on the geological structure total four different locations were selected for the present study.

Methodology

Leachate quality also encourages floral species and growth in the dumping site [23, 24–25]. This type of change in the land may be reversible; the reclamation value may decrease, and the overall pollution concentration in dump site leachate is calculated using the Leachate Pollution Index (LPI) as proposed by Kumar and Alappat [26]. LPI is the mathematical tool to be used to appraise the contamination condition of different locations on a comparison level using an index called LPI. LPI is used for ranking dumping sites, allocating resources for dumping remediation, trend appraisal, scientific research, and public information. LPI is a single number ranging from 5 to 100 that can be used to measure and compare the leachate contamination in a selected geographical location. In this paper, the concept of LPI is explained briefly, and various possible techniques are reviewed and used to calculate the LPI using various appropriate functions developed by the Delphi technique [9]. The index is a mathematical tool to calculate the chemical and biological values of the landfill site black liquid (Table 1).

Table 1 Significance and weights of polluted concentration considered in LPI [26]

Sl. No.	Parameters	Significance	Parameters weight (wi)
1	Chromium	4.057	0.097
2	Lead	4.019	0.096
3	COD	3.963	0.095
4	BOD3	3.902	0.093
5	Zinc	3.585	0.086
6	pH	3.509	0.084
7	Total Kjeldahal Nitrogen	3.367	0.080
8	Ammonia Nitrogen	3.250	0.078
9	Total Dissolved Solids	3.196	0.076
10	Copper	3.078	0.074
11	Iron	2.830	0.068
12	Chlorides	3.078	0.074
		41.834	1.0000

The brief description of the LPI is given below

$$LPI = \sum_{i1}^{n} W_i P_i \quad (1)$$

Where wi and Pi are the weight and sub index values of the ith leachate pollutant parameter, correspondingly and is the total number of parameters. If the number of total parameters is equal to 12 then the total weight of the parameters is equal to 1 and the LPI can be determined adopting equation (1), if the parameters are <12 the for determining using equation (2) is estimated by the total value of weights of the parameters and the LPI is determined using

$$LPI = \frac{\sum_{i=1}^{m} W_i P_i}{\sum_{i=1}^{m} W_i} \quad (2)$$ Where m < n

In the current study, total four different leachate sampling locations were selected by adopting standard operating procedure. The LPI values were calculated for leachate samples at dumping site using some aggregation functions. In this paper, four different indices (Table 2) applied to study the LPI in four different leachate samples in MSW dumping sites (Figure 1). These locations were selected based on geological structure of the study area. Landfill leachate is characterized by trace metals high organic and inorganic pollutant concentrations [40].

Table 2 Aggregation functions adopted by different publishers for LPI

Aggregation Function	Expression	Reference
Unweighted Additive Form (UA)	$LPI_{UA} = \frac{1}{n}\sum_{i1}^{n} p_i$	[15,19,26]
Weighted Linear Additive Form (WA)	$LPI_{WA} = \sum_{i1}^{n} w_i p_i$	[14,16,19,29,30,32]
Root sum Power function (r=2)	$LPI_2 = [\sum_{i=1}^{n} p_i^2]^{1/2}$	[27,28]

Root sum Power function (r=4)	$LPI_4 = [\sum_{i=1}^{n} p_i^4]^{1/4}$	[27,28]
Root sum Power function (r=10)	$LPI_{10} = [\sum_{i=1}^{n} p_i^{10}]^{1/10}$	[27,28]
Root sum Power function	$LPI_{rm} = [\sum_{i=1}^{n} p_i^2]^{1/2}$	[11,32]
LPI2.5 (Ambiguity and Eclipsity)	$LPI_{2.5} = \sum_{i=1}^{n} (p_i^{2.5})^{0.4}$	[32,33]
Weighted Ambiguity and Eclipsity	$LPI_{w2.5} = \sum_{i=1}^{n} w_i p_i{}^{2.5}$	[32]
Multiplicative Additive Form	$LPI_{MA} = \prod_{i=1}^{n} p_i^{wi}$	[17,32,33]

One of them is arithmetic index, originally proposed by Horton [30] for use in explaining water quality and also by Brown [29] by selecting variables and their weightages. This index is also reported by Kumar and Allapat [26] for assessing LPI. Another one is the multiplicative additive index, as reported by Brown [28] and Gupta [27], who have reported the same index to appraise the quality of coastal water. The properties of the leachate parameters in the waste samples from the dumping site are appraised. This black liquid is generated at a landfill site. The calculated data will be compared with five indices and correlated among the indices. Finally, the sensitivity appraisal is conducted to determine the most suitable technique.

Fig 1. Four different Leachate sampling locations near MSW dumping site in Hubli

Result and Discussion

The study area and leachate sampling locations and the LPI in and around the dumpsite for the two different periods were given in the (Table 3) using standard LPI indices. Primarily selection of Aggregation Functions is the most suitable aggregation function for appraising of LPI can be mainly determined and estimated on the basis of some criteria accordingly, all the LPI values are showing LPI(UA), LPI(WA), Root sum Power (r=2, r=4, r=10), LPI(RM), Unweighted multiplicative, Multiplicative Aggregation, Ambiguity and Eclipsity (Table 4). Also, the computed LPI values exceed the maximum values individual properties sub-index values.

Table 3 gives the calculations of sub-LPI and overall LPI for two periods in four locations of leachate sampling. The Analytical values of black liquid samples components of organic contents an average of COD: 488.25; SD: 2.2 and BOD: 36.5; SD:1.9), inorganic content an average of pH:9.5; SD:0.3, TKN:107.67, SD:1.6, Amm. Nitrogen: 51.97, SD: 3.0, TDS:1162.3, SD:31.1and Chlorides:359.8, SD:7.5. The average value of trace metals and SD value is 0.4 (Table 3).

Table 3 Characteristics of leachate, sub-LPI and Aggregation LPI Dump site

Sl. No.	Parameters	LS-1	LS-2	LS-3	LS-4	Average	Sub-Index pi	Aggregation wipi
Organic								
1	COD	486	487	489	491	488.25	7	0.66312
2	BOD3	38	36	34	38	36.5	5	0.46637
								1.1295
Inorganic								
3	pH	9.2	9.4	9.6	9.8	9.5	5	0.41940
4	Total Kjeldahal Nitrogen	106.0	108.5	109.4	106.8	107.675	7	0.56339
5	Ammonia Nitrogen	56.0	52.0	51.0	48.9	51.975	6	0.46613
6	Total Dissolved Solids	1152.0	1195.0	1178.2	1124.0	1162.3	30	2.29192
7	Chlorides	350.2	361.2	368.4	359.4	359.8	10	0.73577
								4.4766
Heavy Metals								
8	Copper	1.20	1.19	1.16	1.13	1.17	5	0.36788
9	Chromium	0.12	0.16	0.20	0.11	0.1475	5	0.48489
10	Lead	0.10	0.11	0.10	0.10	0.1025	5	0.48035
11	Zinc	4.2	4.6	5.0	4.9	4.675	5	0.42848
12	Iron	0.0730	0.0730	0.0730	0.0730	0.073	-	-
						Sub LPI		**1.7616**
						Aggregate LPI		**7.3677**

Table 4 LPI values for black liquid properties of dumpsite using different Aggregation forms

Sl. No.	Parameters	LPI (UA)	LPI (WA)	Root sum Power			LPI (RM)	Multiplicative		Ambiguity and Eclipsity
				R=2	R=4	R=10		Unweighted	Aggregation,	
Organic										
1	COD	7	0.66312	24.5	600.30	28247524.90	4.74	0.583	1.202	7.0
2	BOD3	5	0.46637	12.5	156.30	976562.50	3.62	0.417	1.169	5.0
In Organic										
3	pH	5	0.41940	12.5	156.30	976562.50	3.62	0.417	1.169	5.0
4	Total Kjeldahal Nitrogen	7	0.56339	24.5	600.30	28247524.90	4.74	0.583	1.170	7.0
5	Ammonia Nitrogen	6	0.46613	18.0	324.00	6046617.60	4.19	0.500	1.149	6.0
6	Total Dissolved Solids	30	2.29192	450.0	202500.00	5904900000000.0	15.19	2.500	1.297	30.0
7	Chlorides	10	0.73577	50.0	2500.00	10000000000.0	6.31	0.833	1.185	10.0
Heavy Metals										
8	Copper	5	0.36788	12.5	156.30	976562.50	3.62	0.417	1.169	5.0
9	Chromium	5	0.48489	12.5	156.30	976562.50	3.62	0.417	1.169	5.0
10	Lead	5	0.48035	12.5	156.30	976562.50	3.62	0.417	1.169	5.0
11	Zinc	5	0.42848	12.5	156.30	976562.50	3.62	0.417	1.169	5.0
12	Iron	-	-	-	-	-	-	-	-	-
	Total	90	7.368	642.0	207462.00	59050068401042.40	57.93	7.50	12.919	90.0
	LPI Values	**7.5**	**7.368**	**642.0**	**2.0E+5**	**5.9E+13**	**57.93**	**7.50**	**12.91**	**7.5**

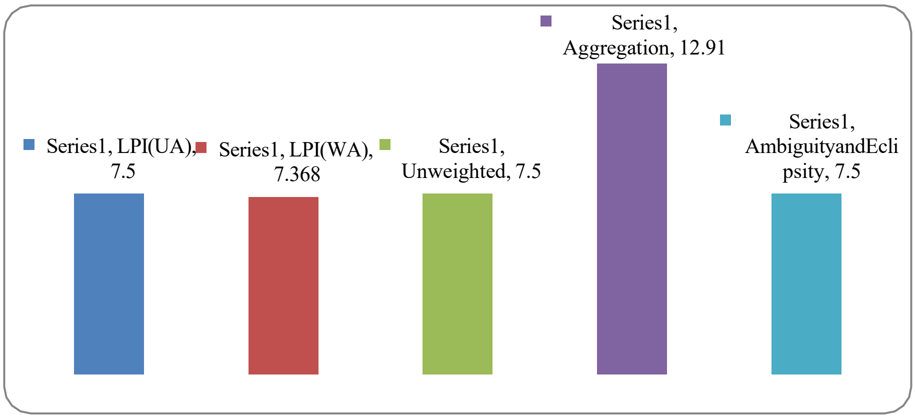

Fig. 2 Graph indicating LPI values of index techniques

Among the nine indices in the current study, unweighted LPI(UA) is simple aggregation form which is an arithmetic average of the unweighted sun-indices. The most popular aggregation form is multivariate LPI(WA) is considered and Unweighted multivariate (LPIum) is adopted for comparison purposes. Ambiguity and eclipsing forms are adopted to overcome the problems. The general forms of these indices are presented in Table 2. The LPI values of leachate samples collected from dumpsites are calculated by adopting the formula given in Table 2. The LPI (RM) and aggregation value are 12.91 and 57.93, respectively (Table 4), whereas the LPI values of others are in the range of 7.63 to 7.5 (Figure 2).

In the study, to measure the intensity and degree of linear significance between two variables, Karl Pearson (1867–1936) developed an equation called the correlation coefficient (r), whose value was calculated. This is also referred to as the product-moment correlation coefficient (Gupta and Kapoor, 2002). The random variables of the LPI are taken to find out the correlation between two of the five. The correlation coefficients between the indices are given in Table 5.

Table 5 Product-moment correlation coefficients

Indices	**LPI(UA)**	**LPI(WA)**	**Unweighted**	**Aggregation**	**Ambiguity & Eclipsity**
LPI(UA)	1.000				
LPI(WA)	0.988	1.000			
Unweighted	0.892	0.903	1.000		
Aggregation	0.888	0.894	0.912	1.000	
Ambiguity & Eclipsity	0.712	0.789	0.812	0.882	1.000

From the correlation coefficients in Table 5, it can be noted that all the five indices show a correlation relationship among each other. LPI (UA) is highly significant with LPI (WA), unweighted, aggregation, and is also closely related to ambiguity and Eclipsity. The order of the indices estimated by the correlation coefficients is in the line LPI (UA) (0.988)> LPI (UW) (0.892)> LPI (Agg) (0.888)> LPI (AE) (0.712). Although all five indices have indicated significant relationships with each other, unweighted [LPI (UW)] was the lowest of the five. One should hence consider any four indices to find the best of the above four indices; the sensitive analysis is considered.

Conclusions

Four samples were collected from a dump site situated near Hubbali. Leachate samples were analyzed for twelve different parameters like inorganic (pH, TDS, TKN, Ammonia Nitrogen, chlorides), Organic (COD, BOD), and Heavy metals (Zinc, Copper, Chromium, Lead, and iron). The average results of the leachate-indicated variables were In organic (9.5, 1162.3mg/L, 107.68 mg/K, 51.97mg/L, 359.8mg/L), Organic (488.25mg/L, 36.5 mg/L), and Heavy metals (4.675mg/L, 1.17mg/L, 0.1475mg/L, 0.1025mg/L, 0.073mg/L) correspondingly.

In the current study, evaluated only five different indices to understand the leachate pollutants in and around the MSW area. The overall LPI of the selected leachate samples in and around the dumping site was found to be 7.368. The LPI of black liquid indicated that the slightly near to the leachate disposal standards to inland surface water as per Municipal Solid Waste (Management and Handling Rules, 2000, Government of India is 7.378. Hence, necessary actions should be taken to limit the leachate pollution in and around the dump site, and also this may contaminate the ground water table.

Aggregation form has shown ambiguity in index values. The product moment correlation coefficients have indicated the least preference to Ambiguity & Eclipsity. The weightages of the variables is necessary in terms of toxicity. Hence, the arithmetic leachate pollution index (LPIA) is the most acceptable option for calculating LPI of an unlined solid waste dumpsite as it indicates better results.

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