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Assessment of Municipal Solid Waste Landfill Leachate Treatment Efficiency by Leachate Pollution Index

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Abstract: Leachate pollution index (LPI) value can be used as a tool to assess the leachate pollution potential of 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 as deem fit. In this paper, leachate treatment efficiency was evaluated on the basis of LPI value of leachate before and after treatment by passing through permeable reactive barrier (multibarrier) in a laboratory scale study. Permeable reactive barrier (multibarrier) consisted of low cost locally available waste materials, which is an innovative in-situ remediation technology to treat landfill leachate contamination. Leachate sample of Jamalpur landfill site of Ludhiana City, Punjab (India) was 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 all the studied leachate pollutant variables exceeded the permissible limits. Jamalpur landfill site has neither any base liner nor leachate collection and treatment system. Therefore, all the leachate generated finds its path into the surrounding environment. LPI is an increasing scale index, where a higher value indicates poor environmental condition based on the Delphi technique; which is an opinion research technique to extract information from a group of panel lists. The formulation process involved selecting variables, deriving weights for the selected pollutant variables, formulating their sub indices curves and finally aggregating the pollutant variables to arrive at the LPI. The LPI value of the standards given under Municipal Solid Waste (Management and Handling) Rules, 2000, Government of India for the disposal of leachate to inland surface water is 7.378. In the present study, LPI value of leachate before and after treatment is 26.45 and 7.03, thus LPI value after treatment is under permissible limits.

Keywords: Leachate pollution index, Landfill, Permeable reactive barrier, Delphi technique, Subindices curves.

I. Introduction

India currently is facing a municipal solid waste dilemma, for which all elements of the society are responsible. The community sensitization and public awareness is low. There is no system of segregation of organic, inorganic and recyclable wastes at household level. There is an adequate legal framework existing in the country to address municipal solid waste management (MSWM). What is lacking is its implementation. In spite of a stringent legislation in place, open dumping is the most wide spread form of waste disposal. The possible reasons for poor implementation could be a combination of social, technical, institutional and financial issues. Public awareness, political will and public participation are essential for the successful implementation of the legal provisions and to have an integrated approach towards sustainable management of municipal solid wastes in the country. During the last decade of the 19th century, as well as during the five initial years of 20th century, millions of people died due to Bubonic Plague in India, which had linkages to poor management of solid waste. 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. The disposal of solid waste currently relies principally on landfills. Landfill of MSW is the simplest, cheapest and most cost effective method of disposing of waste in both developed and developing nations of the world [1,2,3,4,5]. In India, most landfills are usually open dumps/unlined landfills. Only a fraction can be regarded as engineered landfills, indicating that they were designed and constructed according to engineering specifications. Landfills are considered one of the major threats to groundwater [6,7]. The scale of this threat depends on the concentration and toxicity of contaminants in leachate, type and permeability of geological strata, depth of water table and the direction of groundwater flow [8]. Modern Sanitary landfills have been reported to leak leachate and pollute groundwater [9]. MSW management encompasses planning, engineering, organization, administration, financial and legal aspects of activities associated with generation, storage, collection, transport, processing and disposal in an environmentally compatible manner adopting principles of economy, aesthetics and energy conservation [10]. The management of MSW is going through a critical phase, due to the unavailability of suitable facilities to treat and dispose of the larger amounts of MSW generated daily in metropolitan cities. The MSW amount is expected to increase significantly in the near future as India strives to attain an industrialized nation status by the year 2020 [11,12,13]. The management of MSW requires proper infrastructure, maintenance and upgrade for all activities. This becomes increasingly expensive and complex due to the continuous and unplanned growth of urban centres. The difficulties in providing the desired level of public service in the urban centres are often attributed to the poor financial status of the managing municipal corporations [14,15]. Wastes placed in landfills are subject to either groundwater underflow or infiltration from precipitation and as water percolates through the waste, it picks up a variety of inorganic and organic compounds, flowing out of the wastes to accumulate at the bottom of the landfill. The resulting contaminated water is termed leachate and can percolate through the soil [14]. Municipal landfill leachate is highly concentrated complex effluents which contain dissolved organic matters; inorganic compounds; heavy metals and xenobiotic substances [16,17,18,19]. 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 [20]. The state regulatory authorities, in almost all the countries of the world, have framed regulations to safeguard against the contamination of groundwater sources from the leachate generated from the landfills. The processes for leachate collection and treatment are complex and the costs are usually quite high [21]. Therefore the remedial and preventive measures cannot be undertaken at all the existing closed and the active landfill sites in one go because of the financial constraints. The remedial and preventive measures need to be taken up in a phased manner. The overall pollution potential of landfill leachate can be calculated in terms of Leachate pollution index (LPI) as proposed by Kumar and Alappat [22]. Because identification and quantification of pollutants in landfill leachate is the major limitation for its successful treatment [23], LPI can be used as a mean to determine whether a landfill requires immediate attention in terms of introducing remediation measures. Kumar and Alappat [22] developed a technique to evaluate the leachate contamination potential of different landfills on a comparative scale using an index known as LPI. LPI has many applications including ranking of landfill sites, resource allocation for landfill remediation, trend analysis, and enforcement of standards, scientific research and public information. 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 was formulated using Rand Corporation Delphi Technique. The formulation process and complete description on the development of the LPI, has been discussed elsewhere [22]. 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 application 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 [22].

Permeable reactive barrier (multibarrier) is a continuous, permeable treatment zone designed to intercept and remediate a contaminant. The treatment zone may be created directly using reactive materials such as iron or indirectly using materials designed to stimulate secondary processes, such as by adding carbon substrate and nutrients to enhance microbial activity. In this way, contaminant treatment may occur through physical, chemical and biological processes. The phenomena, which help in remediation within PRB, are adsorption/sorption, precipitation, oxidation/reduction and biodegradation. Recently, many researchers have introduced the permeable reactive barrier (PRB) system as an alternative technology to control leachate [24,25,26,27].

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In this paper, efficiency of method adopted for leachate treatment was expressed in terms of leachate pollution index (LPI). LPI value of a landfill was determined using data from municipal landfill site of Ludhiana City, Punjab (India) for 5 significant leachate pollutant variables *viz* pH, TDS, BOD_5, COD and Chloride (Cl^-). Jamalpur landfill site has neither any base liner nor leachate collection and treatment system. Therefore, all the leachate generated finds its path into the surrounding environment. Leachate treatment efficiency was evaluated in terms of LPI value of leachate before and after treatment by passing through permeable reactive barrier (multibarrier). Permeable reactive barrier (multibarrier) consisted of low cost locally available waste materials, which is an innovative in-situ remediation technology to treat landfill leachate contamination.

II. 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 [28]. 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 [29]. Leachate sample for the present study was collected from Jamalpur landfill site of Ludhiana City (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. No proper compaction is done to compress the waste into the site.

Table 1. Jamalpur landfill site of Ludhiana City, Punjab (India)

Jamalpur Landfill site	Land area (acres)	Average depth (in ft.)	Future life (years)	Distance from city centre
	25	8 to 10	25	11 km

2.2 Leachate sampling

Leachate sample was collected from landfill site on Tajpur Road at Jamalpur Village having 25 acres of low lying land area. This site is non-engineered low lying open dump. It has neither any bottom liner nor any leachate collection and treatment system. Therefore, all the leachate generated finds its paths into the surrounding environment. The landfill site is not equipped with any leachate collectors. To determine the quality of leachate, integrated samples were collected from different landfill locations. 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 MSW landfill site to estimate its pollution potential.

2.3 Leachate treatment method

LPI value of a landfill was determined using data from municipal landfill site of Ludhiana City, Punjab (India) for 5 significant leachate pollutant variables *viz* pH, TDS, BOD_5, COD and Chloride (Cl^-). Leachate treatment efficiency was evaluated as LPI value of leachate before and after treatment by passing through permeable reactive barrier (multibarrier). Permeable reactive barrier (multibarrier) consisted of low cost locally available waste materials, which is an innovative in-situ remediation technology to treat landfill leachate contamination. Detail description about the treatment method adopted is out of scope of this paper.

2.4 Analytical work

Analytical methods were according to Standard methods for examination of water and wastewater specified by American Public Health Association [30]. 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

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(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 result of chloride (4500-Cl^-.B of Standard Methods).

2.5 Calculating LPI

2.5.1 Variable selection

Eighteen leachate parameters were selected for inclusion in LPI [27]. 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.

2.5.2 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 [27]. The weights for other pollutant variables are Total Dissolved Solids: 0.050; Biochemical Oxygen Demand: 0.061; Chemical Oxygen Demand: 0.062; Total Kjeldhal Nitrogen: 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.

2.5.3 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 were reported by Kumar and Alappat [27]. The averaged sub index curves are the curves that represent the relation between leachate pollution and the strength or concentration of the parameter.

2.5.4 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 [31] to select the best possible aggregation function. The Leachate Pollution Index can be calculated using the equation:

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

Where LPI = the 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,
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:

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

Where *m* is the number of leachate pollutant variables for which data is available, but in that case, $m < 18$ and $\Sigma w_i < 1$.

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2.6 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 sample collected from the landfill site to find out the concentration of the leachate pollutant variables.

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 [32]. In the present study, out of 18, 5 significant parameters were covered, so equation (2) is used.

III. RESULT AND DISCUSSION

Leachate sample of Jamalpur landfill site was 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 all the studied leachate pollutant variables exceeded the permissible limits. Leachate treatment efficiency was evaluated on the basis of LPI value of leachate before and after treatment by passing through permeable reactive barrier (multibarrier) in a laboratory study. The procedure explained above has been used to calculate the LPI for the MSW landfill site. 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 leachate of Jamalpur landfill site before and after treatment and also the LPI of leachate disposal standards to inland surface water as per Municipal Solid Waste (Management and Handling) Rules, 2000, Government of India [33] were calculated using the above procedure and reported in Table 2.

3.1 Comparison with standards

The LPI value of 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 LPI value of Jamalpur landfill site before treatment was 26.45 indicated that the waste deposited is contaminated. Whereas the LPI value of leachate after treatment by passing through permeable reactive barrier (multibarrier) was 7.03, which is under permissible limits.

IV. CONCLUSION

- High value of LPI of Jamalpur landfill site indicated that leachate generated is contaminated. Jamalpur landfill site has neither any base liner nor leachate collection and treatment system. Therefore, all the leachate generated finds its path into the surrounding environment.
- Leachate treatment efficiency was evaluated as LPI value of leachate before and after treatment by passing through permeable reactive barrier (multibarrier). Permeable reactive barrier (multibarrier) consisted of low cost locally available waste materials, which is an innovative in-situ remediation technology to treat landfill leachate contamination.
- LPI value of leachate before and after treatment was 26.45 and 7.03, thus LPI value after treatment is under permissible limits.
- It should be noted that the LPI value indicate the leachate contamination potential of landfill sites in a given geographical area on a comparative scale and is a hazard identification tool.

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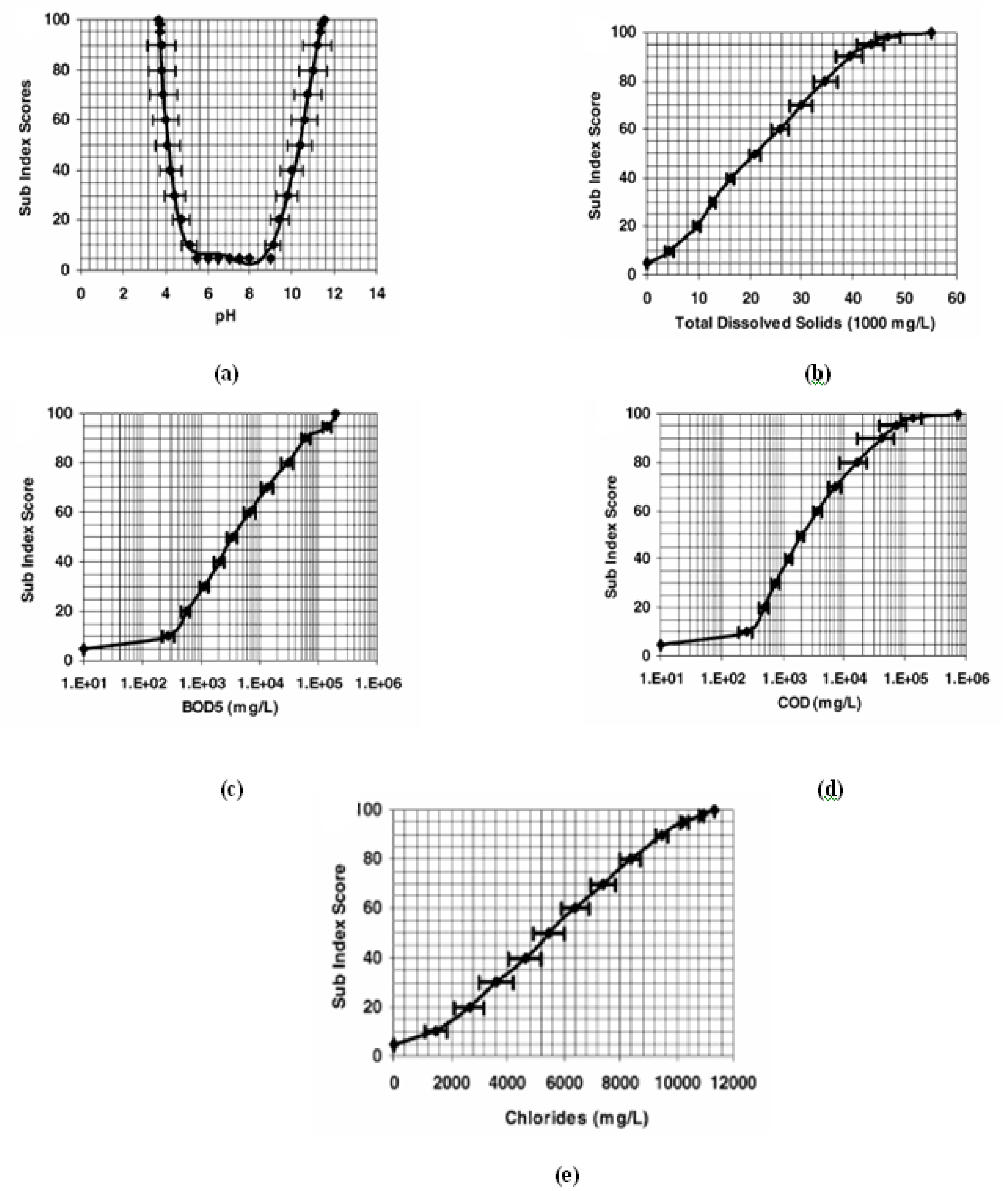

Fig. 1 (a-e) Sub-index curves of pH, Total Dissolved Solids, BOD_5, COD and Chloride

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Table 2

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

		LPI of leachate from landfilling site			LPI of treated leachate			LPI of leachate disposal standards**		
Leachate Pollutant Variable	**Variable Weight wi**	**Pollutant Conc. Ci***	**Pollutant Sub Index Value pi**	**Aggregation wi.pi**	**Pollutant Conc. after treatment Ct***	**Treated Leachate Sub Index Value pt**	**Aggregation Treated Leachate wi.pt**	**Leachate Disposal Standards for Inland surface water Cs***	**Pollutant Sub Index Value ps**	**Aggregation Treated Leachate Standards 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	418	15	0.93	250	10	0.62
Mercury	0.062	-	-	-	-	-	-	0.01	6	0.37
BOD_5	0.061	495	15	0.915	116	6	0.36	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	8.6	4	0.22	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	1539	3	0.15	2100	7	0.35
Copper	0.05	-	-	-	-	-	-	3.0	18	0.90
Chlorides	0.049	1836	14	0.686	653	6	0.29	1000	8	0.39
Total Iron	0.045	-	-	-	-	-	-	No Standard	-	-
Total	0.716			7.327			1.95			6.67
LPI Value				**26.45**			**7.03**			**7.378**

*All values in mg/l except pH
** Municipal Solid Wastes (Management and Handling) Rules, 2000

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