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Leachate Quality of Municipal Solid Waste Dumpsites at Chennai, India

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Abstract: The paper discusses the characteristics of leachates from municipal solid waste dumps at Chennai, India. Leachate samples from Perungudi and Kodungaiyur dumping grounds were collected and analyzed for pH, electrical conductivity, total dissolved solids, chemical oxygen demand, biochemical oxygen demand, dissolved organic carbon, ammonia nitrogen, chloride, sulphate, phosphate, sodium, potassium, calcium, magnesium, cadmium, chromium, copper, nickel, lead and zinc. Leachates were slightly alkaline. Total dissolved solids varied from 1391 to 8124 mg/L. The maximum chemical and biochemical oxygen demands recorded were 1370 and 58 mg/L, respectively. Heavy metals were in microgram levels. Pollution potential indicating parameter ratios BOD/COD and COD/DOC were < 0.1 and < 2, respectively. Results of the study indicated that the leachate quality of these sites were similar to those of aged or stabilized landfills. A comparison of the quality in the two sites showed that the pollution potential of Perungudi leachates was slightly higher than that of Kodungaiyur.

Key words: Dumpsite, leachate, TDS, BOD, COD, heavy metal.

Introduction

Sanitary land filling is the widely accepted method for municipal solid waste disposal. In developing countries, more than 90% of the landfills are unorganized open dumps leading to a number of environmental problems (Visvanathan et al., 2003). One of the severe problems associated with solid waste dumpsites is the infiltration of leachates and the subsequent contamination of the surrounding land and water. Examples for such events include leachate pollution in private wells around the Llangollon landfill in New Castle county, Delaware (Chian and DeWalle, 1976) and bacterial and chemical contamination of well water near a landfill in Kane county (Walker, 1969). Reports on aquifer and surface water contamination due to landfill leachates are also available (Kelley, 1976; Masters, 1998; Kumar et al., 2002).

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Landfills without protection liners have been reported to cause leachate contamination problems over a period of time (Freeze and Cheery, 1970; Beveli and Baccini, 1989). Merz (1952, 1954) evaluated the leachate quality of incinerator ash dumps and municipal solid waste landfills in USA. Chian and DeWalle (1976) investigated the chemical composition of landfill leachates collected from different parts of the United States. Leaching of soluble contaminants along with the washout of fines and colloids results in highly contaminated leachates containing a host of toxic and carcinogenic chemicals harmful to both humans and the environment (Lee, 1996).

The quantity and quality of leachates produced in landfills depend on several factors (El-Fadel et al., 2002). The quantity is controlled by moisture content, refuse age, segregation, compaction, permeability, particle size, density, settlement, vegetation, cover, side walls, liner materials, gas and heat generation and transport. Quality is controlled by the pretreatment methods, separation of recoverable materials, leachate recirculation and locations of the sites (Johansen and Carlson, 1976; Chian, 1977; Bookter and Ham, 1982; Hamsen, 1983; Kouzeli-Katsiri et al., 1993; Robinson, 1993; Gettinby et al., 1996). Therefore, it is difficult to generalise the chemical composition that a leachate possesses at a time. Several earlier workers (Rees, 1980; Pohland et al., 1983; Halvadakis et al., 1983; Pohland and Harper, 1986; Barlaz, 1988; Ehrig, 1988) have reported a trend of continually decreasing chemical composition. Leachates from Gazipur dumpsite at New Delhi, India, were found to contain high concentrations of organics, total dissolved solids and total solids (Zafar et al., 2002).

In developed countries, proper remedial measures are used to reduce the environmental impacts of dumpsites. Leachate quality data are useful to choose suitable remedial methods. Chennai, one of the four metropolitan cities of India, with a population of five million generates about 3500 tons of solid waste per day (Esakku et al., 2003). Currently, this is dumped in Perungudi Dumping Ground (PDG) and Kodungaiyur Dumping Ground (KDG). These sites are located in densely populated suburbs of Chennai. The present study was aimed to assess the leachate quality at PDG and KDG.

Materials and Methods

Site Description

PDG lies at 12° 57'13.5" North and 80° 14'5.8" East. It is a low lying and poorly drained area of marshy land permanently wet and seasonally inundated. The total area of this site is about 250 ha in which about 22 ha is used for dumping. KDG lies at 13° 07'37.6" North and 80° 16'48" East. It extends over 160 ha marshy lands adjacent to the alluvial low lands of Korattalaiyar river. The waste depth in both sites is about 3 m. There is a natural clay liner below the wastes and the groundwater table is at 5.0 m.

Leachate Collection

Leachate collection systems were established at six selected locations in each of the dumping grounds. The system consisted of a perforated PVC pipe of 10 cm diameter. This pipe was inserted to a depth of 3 m, the base of the fill (Figure 1). Monthly samples were collected using a submersible pump (model: Whale 921) during September 2002-June 2003. The samples were refrigerated at 4°C and used for chemical analyses.

Characterization

Chemical parameters were determined following standard methods (APHA, 1998). Leachate samples were

Figure 1: Typical leachate collection system.

analyzed for pH, EC, TDS, COD, BOD, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, PO_4^{3-} and NH_4–N. A Sherwood Flame photometer-410 was used to quantify Na^+ and K^+. DOC determinations were carried out in a micro C, Carbon analyser (Analytic jena). Heavy metals (Cd, Cr, Cu, Ni, Pb and Zn) were determined using a Vario 6 atomic absorption spectrometer.

Results and Discussion

Characteristics of MSW Leachates

Rainfall data for the study period were recorded and presented in Figure 2. This showed that most of the rainfall in Chennai occurred during October and November, 2002.

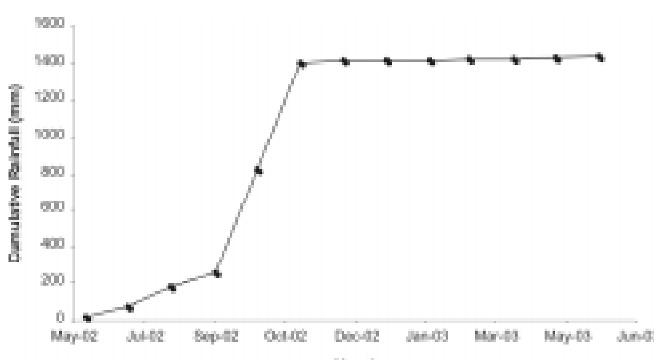

Figure 2: Cumulative rainfall in Chennai during the study period.

Characteristics of leachates collected from PDG are presented in Table 1. The pH ranged from 7.6 to 8.5 and the electrical conductivity varied from 3.44 to 12.78 mS/cm. Total dissolved solids were in the range of 2061 to 6338 mg/L. COD and BOD values ranged from 397

Table 1: Characteristics of Leachates from Perungudi Dumping Ground

Sl. No.	*Sampling month*	*No. of samples*	*EC mS/cm*	*TDS mg/L*	*COD mg/L*	*BOD mg/L*	*DOC mg/L*	*Na^+ mg/L*	*K^+ mg/L*	*Ca^{2+} mg/L*	*Mg^{2+} mg/L*	*Cl^- mg/L*	*SO_4^{2-} mg/L*	*PO_4^{3-} mg/L*
1.	Oct 2002	4	11.47	6157	1198	58.0	948	912	1111	121	130	1794	555	28.0
2.	Nov 2002	5	3.44	2061	397	30.0	268	296	316	107	56.0	459	142	16.8
3.	Dec 2002	4	9.19	4632	760	54.0	491	621	600	96.0	57.0	1203	187	23.8
4.	Jan 2003	4	10.86	5006	823	52.0	447	947	804	255	98.0	1628	123	24.8
5.	Feb 2003	4	12.23	5819	831	46.0	582	1112	827	64.0	138	1769	265	19.5
6.	Mar 2003	3	11.84	5928	847	25.0	521	1230	871	121	147	2024	95.0	29.3
7.	Apr 2003	3	12.78	6241	1069	53.0	762	1017	797	109	162	2084	183	27.7
8.	May 2003	3	12.15	6301	1043	33.0	971	1506	848	217	219	2273	66.0	2.60
9.	June 2003	3	12.42	6338	1047	40.0	974	1506	848	183	241	2213	67.0	6.50
10.	Minimum	-	3.44	2061	397	25.0	268	296	316	64.0	56.0	459	66.0	2.60
11.	Maximum	-	12.78	6338	1198	58.0	974	1506	1111	255	241	2273	555	29.3
12.	Mean	-	10.71	5387	891	43.0	663	1016	780	141	139	1716	187	19.9

Table 2: Characteristics of Leachates from Kodungaiyur Dumping Ground

Sl. No.	*Sampling month*	*No. of samples*	*EC mS/cm*	*TDS mg/L*	*COD mg/L*	*BOD mg/L*	*DOC mg/L*	*Na^+ mg/L*	*K^+ mg/L*	*Ca^{2+} mg/L*	*Mg^{2+} mg/L*	*Cl^- mg/L*	*SO_4^{2-} mg/L*	*PO_4^{3-} mg/L*
1.	Sept 2002	5	7.33	6173	572	15.0	349	730	88.0	382	134	994	1697	3.30
2.	Oct 2002	2	12.98	8124	1370	25.0	1028	1620	1535	286	180	2282	833	20.5
3.	Nov 2002	5	1.71	1391	131	8.00	147	123	191	137	40.0	203	371	5.90
4.	Dec 2002	1	3.86	2932	232	8.00	265	241	235	136	88.0	497	72.0	18.0
5.	Jan 2003	1	4.42	3088	340	18.0	337	473	476	176	129	547	41.0	42.0
6.	Feb 2003	1	4.96	3320	272	18.0	361	568	561	128	145	537	43.0	23.0
7.	Mar 2003	1	4.91	3408	287	30.0	384	568	529	144	114	537	41.0	51.0
8.	Apr 2003	1	5.42	3562	480	18.0	437	417	508	128	136	537	51.0	45.0
9.	May 2003	1	5.47	4124	400	18.0	509	769	548	180	158	596	31.0	14.1
10.	June 2003	1	5.67	3836	397	30.0	600	769	620	224	170	616	27.0	6.90
11.	Minimum	-	1.71	1391	131	8.00	147	123	88.0	128	40.0	203	27.0	3.30
12.	Maximum	-	12.98	8124	1370	30.0	1028	1620	1535	382	180	2282	1697	51.0
13.	Mean	-	5.67	3996	448	19.0	442	628	519	192	129	735	321	22.97

to 1198 and 25 to 58 mg/L, respectively. Dissolved organic carbon ranged from 268 to 974 mg/L. The mean values (mg/L) recorded for the inorganic ions were: chloride-1716, sulphate-187, phosphate-20, sodium-1016, potassium-780, calcium-141 and magnesium-139.

The characteristics of the leachates collected from KDG presented in Table 2 indicate that the leachates were slightly alkaline (7.6 to 8.8). The Electrical Conductivity ranged from 1.71 to 12.98 mS/cm. A wide variation (1391 to 8124 mg/L) in TDS was noticed. While the COD ranged from 131 to 1370 mg/L, the BOD ranged from 8 to 30 mg/L. Dissolved organic carbon was in the range of 147 to 1028 mg/L. The mean values for inorganic ions (mg/L) were: chloride-735, sulphate-321, phosphate-23, sodium-628, potassium-519, calcium-192 and magnesium-129.

From Tables 1 and 2, it is evident that the pollution potential of leachates collected from PDG and KDG is low as revealed by low COD and BOD values. It is known that as a landfill ages, the COD and BOD of leachate would decrease (Reinhart and Grosh, 1998). According to Christensen et al. (1994), BOD decreases faster and can approach zero while COD will remain in the leachate and is comprised of humic and fluvic compounds. This may be the reason for the low BOD and medium COD ranges observed in the present study. Pacey has reported that stabilized landfills exhibit less than 1000 mg/L of COD and less than 100 mg/L of BOD. Comparison of the leachate quality with Indian standards for disposal of treated leachates into public sewers (MoEF, 2000) reveals that pH (5.5-9.0) and BOD (<350 mg/L) were within limits and TDS (>2100 mg/L) values were above the limit. Chloride (>1000 mg/L) and NH_4–N (> 50 mg/L) were above the disposal limits in PDG leachates and below the disposal limits in KDG leachates.

Heavy Metals

The heavy metal profile of leachate at PDG and KDG is presented in Tables 3 and 4. The Indian standards for disposal of landfill leachates into inland surface water are 1, 2, 3, 3, 1 and 5 mg/L for Cd, Cr, Cu, Ni, Pb and Zn respectively (MoEF, 2000). The concentrations of all the heavy metals were within these regulatory limits (Tables 3 and 4). These results are in line with low values of leachable metal contents reported for the fine fractions of dumpsite soils (Esakku et al., 2003) and the lower metal contents observed for other leachates (Christensen et al., 1994; Robinson, 1995; Revans et al., 1999).

Table 3: Heavy Metal Profile of Leachates from Perungudi Dumping Ground during 2002-2003

Sl. No	*Metals*	*Cd*	*Cr*	*Cu*	*Ni*	*Pb*	*Zn*
1.	No. of Samples	17	24	27	35	35	35
2.	Min.	2.07	18.80	26.00	142.00	9.00	19.00
3.	Max.	28.03	240.20	80.00	726.00	205.00	101.00
4.	Mean	15.87	83.85	42.48	410.74	118.69	61.26
5.	± SD	8.50	56.03	15.11	174.59	47.56	19.91
6.	Limits*	1000	2000	3000	3000	1000	5000

All values are in µg/L

* Indian Standard limits for disposal of treated leachates

Table 4: Heavy Metal Profile of Leachates from Kodungaiyur Dumping Ground during 2002-2003

Sl. No	*Metals*	*Cd*	*Cr*	*Cu*	*Ni*	*Pb*	*Zn*
1.	No. of Samples	14	16	17	19	19	19
2.	Min.	0.75	17.00	36.00	90.00	9.00	6.00
3.	Max.	37.39	277.00	229.00	1050.00	296.00	350.00
4.	Mean	9.09	59.06	118.65	485.11	74.05	125.80
5.	± SD	9.83	61.03	62.10	197.09	64.60	96.84
6.	Limits*	1000	2000	3000	3000	1000	5000

All values are in µg/L

* Indian Standard limits for disposal of treated leachates

Heavy metal concentrations in landfill leachates are known to be controlled by complexation, oxidation-reduction, sorption and precipitation processes (Pacey, 1999; Flyhammar and Hakansson, 1999; Revans et al., 1999). These attenuation mechanisms would have contributed to the low metal concentration in PDG and KDG leachates. Since metal solubility decreases with increasing pH, the leachate samples with pH values >7.5 enhance the precipitation of heavy metals as hydroxides and carbonates and hence account for the lower metal contents. Leachates from landfills in methanogenic condition are generally known to have lower metal contents (Revans et al., 1999).

Ammonia Nitrogen

Table 5 presents the data of ammonia nitrogen in leachates collected from PDG and KDG. In PDG leachates the ammonia nitrogen ranged from 0 to 626.4 mg/L, which is higher than that recorded in KDG (0-365.5 mg/L). Ammonia nitrogen is known to be continuously released into leachates during the degradation of wastes and cause pollution problems (Robinson, 1995). Ehrig (1988) has reported that there was no significant difference in ammonia concentration in acidic and methanogenic phases of landfills.

Table 5: Ammonia Nitrogen Profile of PDG and KDG Leachates

Sl. No.	*Particulars*	*PDG*	*KDG*
1.	No. of Samples	20	35
2.	Minimum	0.00	0.00
3.	Maximum	626.40	365.50
4.	Mean	221.14	31.75
5.	Standard Deviation (±)	199.19	88.47

All values in mg/L

Comparison of PDG and KDG Leachates

From Tables 1 and 2 it is evident that the maximum and minimum TDS values were noted in monsoon (October and November, 2002). This may be attributed to initial enhanced leaching followed by the effect of rainfall dilution. Figures 3 and 4 depict the correlation between electrical conductivity and total dissolved solids in the leachate samples. Specific conductance is a gross indicator of the total dissolved ions present in leachates (Johnsen and Carlson, 1976). The mean EC and TDS values are presented in Figure 5. TDS/EC correlation factor for PDG leachates is 0.5 and that of KDG is 0.7. These are in line with the range of 0.55 to 0.7, reported normal TDS/EC ratios in Standard methods (APHA, 1998). A comparison of leachate quality parameters between PDG and KDG is shown in Table 6. PDG leachates contained higher TDS (> 5000 mg/L) than that in KDG leachates (<5000 mg/L). Figure 6 compares the mean BOD and COD obtained for leachates from PDG and KDG. COD and BOD of PDG leachates were almost twice that of KDG leachates. These differences in COD and BOD may be attributed to the variation in degradable fractions of the solid waste at the sampling points of PDG and KDG (Joseph et al., 2003).

Table 6: Comparison of Mean Values of PDG and KDG Leachate Quality Parameters

Sl. No.	*Site*	*EC mS/cm*	*TDS mg/L*	*COD mg/L*	*BOD mg/L*	*DOC mg/L*	*NH_4-N mg/L*	*BOD/COD ratio*	*COD/DOC ratio*
1	PDG	10.71	53871	891	43.0	663	221.14	0.05	1.34
2	KDG	5.67	3996	448	19.0	442	31.75	0.04	1.01

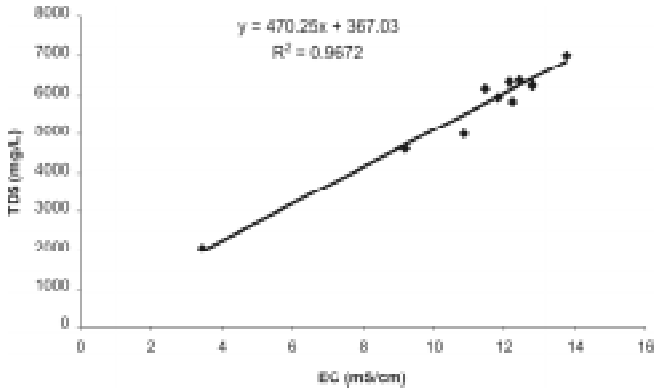

Figure 3: Electrical conductivity vs total dissolved solids for Perungudi dumping ground leachates.

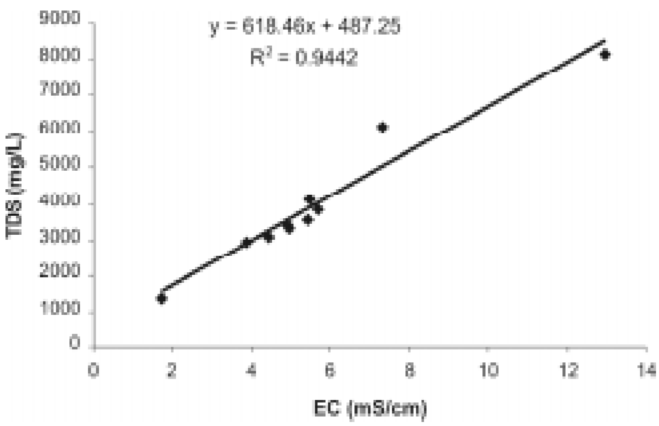

Figure 4: Electrical conductivity vs total dissolved solids for Kodungaiyur dumping ground leachates.

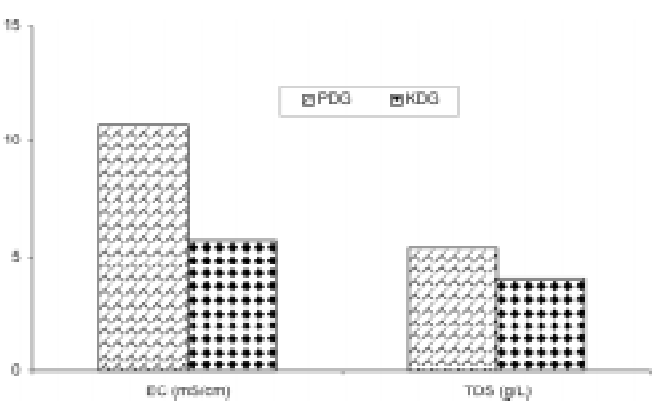

Figure 5: Comparison of mean electrical conductivity and total dissolved solids values of Perungudi dumping ground and Kodungaiyur dumping ground leachates.

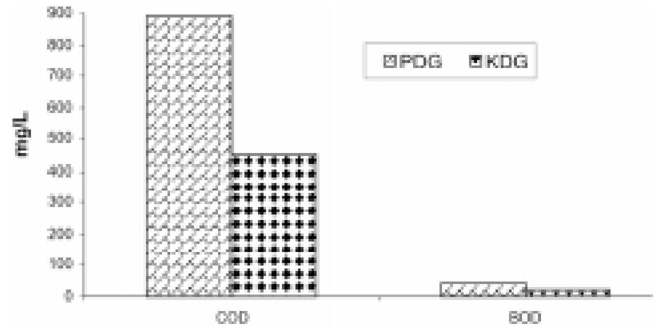

Figure 6: Comparison of mean chemical oxygen demand and biochemical oxygen demand values of Perungudi dumping ground and Kodungaiyur dumping ground leachates.

Variations in organic indicator ratios (BOD/COD and COD/DOC) of the leachates obtained from PDG and KDG are presented in Figures 7 and 8. BOD/COD ratios indicate the proportion of biodegradable organic matter to total organic matter, which decreased with the age of the landfill (Westlake, 1995; Copa et al., 1995). From Figure 7 it is evident that for both sites, the BOD/COD ratio varied from 0.02 to 0.1. A value less than 0.1, is known to represent stabilized landfill leachates (Miller et al., 1974; Chian and De Walle, 1977; Christensen, 1994).

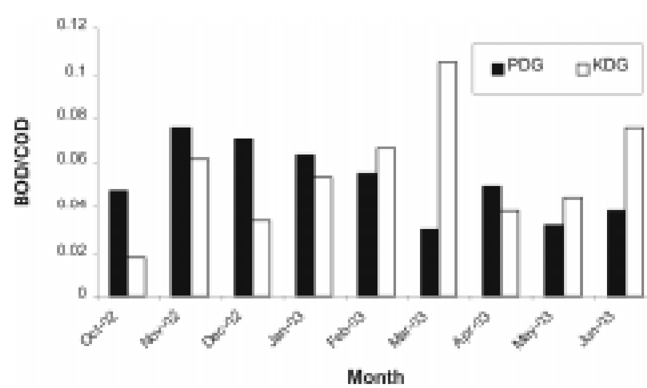

Figure 7: Variation of biochemical oxygen demand/ chemical oxygen demand for Perungudi dumping ground and Kodungaiyur dumping ground leachates.

The COD/DOC ratio for leachates (Figure 8) collected from PDG and KDG ranged from 0.7 to 1.7 indicating

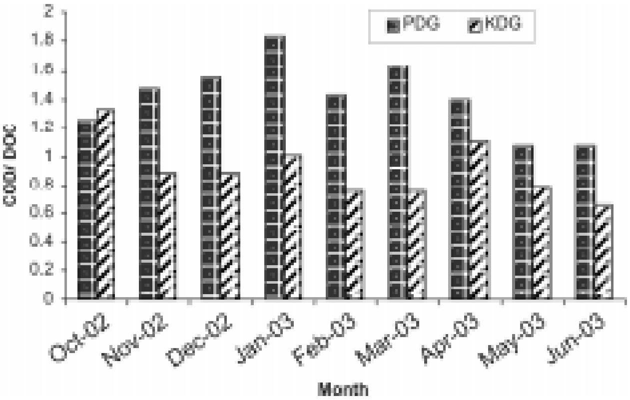

Figure 8: Variation of chemical oxygen demand/dissolved organic carbon ratio for Perungudi dumping ground and Kodungaiyur dumping ground leachates.

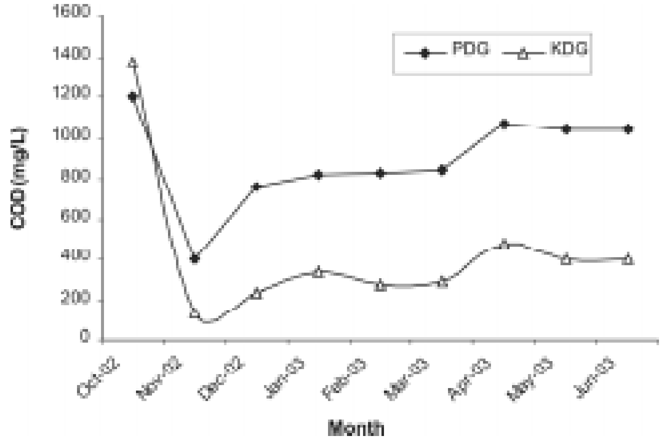

Figure 9: Chemical oxygen demand variation of Perungudi dumping ground and Kodungaiyur dumping ground leachates.

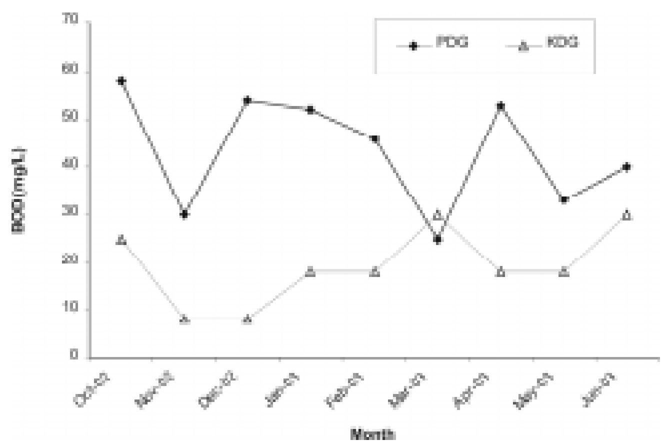

Figure 10: Biochemical oxygen demand variation in Perungudi dumping ground and Kodungaiyur dumping ground leachates.

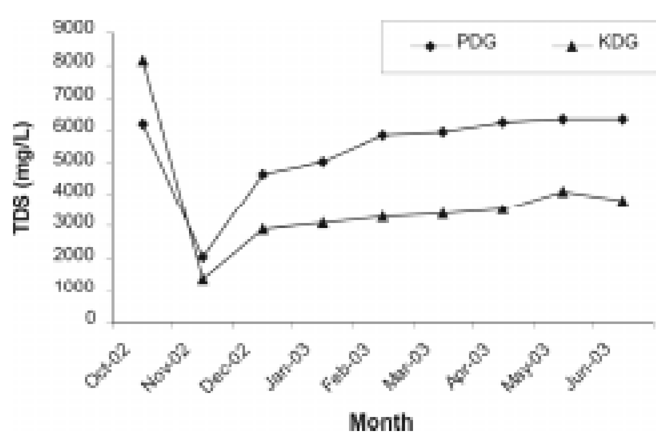

Figure 11: Total dissolved solids variation in Perungudi dumping ground and Kodungaiyur dumping ground leachates.

low oxidisable organic constituents. This ratio is known to vary from 4 to 1.3 depending on the nature of the organic compounds of the leachate (Rickert and Hunter, 1971). A low COD/DOC ratio indicates the oxidised state of carbon, where the carbon availability as an energy source for microbial growth is reported to be less (Venkatramani et al., 1974; Chian and De Walle, 1977). Though microbial studies were not carried out for these leachates less BOD values were noticed. A detailed investigation on microbial growth may throw light on these aspects. Insignificant variations in organic indicator ratios with time were noticed (Figures 7 and 8).

Variations in Leachate Quality

Figures 9, 10 and 11 present the seasonal variations in leachate quality parameters. All the measured parameters showed a sudden fall in November 2002 indicating the dilution effect due to heavy rainfall in Chennai during the period. The values increased gradually from then on with fluctuations. This is in contrast to the findings of Aluko et al. (2003). They have reported higher concentrations of contaminants in leachates in wet seasons than that of dry seasons in a landfill in Nigeria, which is in operation for about eight years. Chennai dumpsites are about 20 years old. The differences in age and climatic conditions may be the main reasons for the differences noticed in leachate quality variation in wet and dry seasons.

Conclusion

An analysis of the organic and inorganic constituents including heavy metals and ammonia of leachate from MSW open dumpsites in Chennai was carried out during

September 2002-June 2003. The major conclusions drawn from the study are as below:

- Pollution potential of the leachate from the PDG and KDG is not significant.
- COD/DOC and BOD/COD ratios were in line with those of stabilized landfills.
- Ammonia concentrations were in the range of 0 to 600 mg/L.
- pH, BOD and heavy metal contents were within regulatory limits for disposal of treated leachates as per Indian Standards.
- COD and TDS exceeded the disposal limit of 250 and 2100 mg/L, respectively.
- Monsoon dilution modified the leachate quality.

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