Assessment of Stabilization, Temporal Variation and Leachate Contamination Potential of Municipal Solid Waste Dumpsites in Bangalore

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Abstract- **One of the biggest problems associated with the dumping of solid waste is managing leachate that is formed when water passes through the deposited waste. It contains products of decomposition of organic matter and soluble ions which present a potential pollution threat for the surrounding soil, surface and ground waters. The knowledge of the composition of leachate helps to ascertain the contamination potential it poses to the immediate ecosystem and also aids to design an effective treatment technology and appropriate liners to contain the leachate. In this paper, leachate pollution index has been used to quantify the contamination potential that the dumping sites pose to the environment. This study also demonstrates the influence of various stabilization stages of the dumping sites on the composition of the leachate season wise.**

Keywords- Leachate; Contamination Potential; Leachate Pollution Index; Dumping Sites

I. INTRODUCTION

The leachate generated from municipal solid waste is a mixture of organic, inorganic, dissolved and colloidal solids. Physical, chemical and biological processes stirring simultaneously at the municipal solid waste dumpsites bring about waste decomposition as well as generation of leachate and landfill gas [1]. The leachate generated from open dumps and uncontrolled landfill sites can pose serious threat to environment (surface and ground water pollution) affecting human health; (but studies on the impact of leachate generated from solid waste dumping sites are scarce. The amount of leachate generated depends on the moisture content of the waste and also on the amount of precipitation that passes through the dump. Leachate composition depends on several factors like composition and type of wastes, waste compaction, particle size, soil moisture, type of microorganisms, temperature of the waste, climate, site operating procedures, age of the fill and hydrology of the site. Leachate is highly variable and heterogeneous [2]. It has been found that the leachate generated from the closed landfills can have equal or more contamination potential in comparison to the active landfill sites and hence, the remediation actions and post-closure monitoring should be ensured at the closed landfills till the leachate generated is stabilized and poses no further threat to the environment [3]. Such remedial measures and monitoring cannot be carried out at each and every solid waste disposal site in developing countries because it requires lot of financial assistance. Alternately by using leachate pollution index developed by Kumar and Alappat [4] a comparative analysis can be done as to which disposal site needs immediate remedial measures and rectify using the available resource.

II. MATERIALS AND METHODS

A. Background Study

Bangalore, the capital city of Karnataka is situated in the heart of the South-Deccan plateau in peninsular India to the South-Eastern corner of Karnataka State between the latitudinal parallels of 12°39'32" & 13°14'13" and longitudinal meridians of 77°19'44" & 77°50'13"at an average elevation of about 900 meters covering an area of about 2174 km^2 and serving a population of more than 7.8 million-. According to the latest estimates, Bangalore generates around 5,000 metric tonnes of municipal solid waste every day. Solid waste management is one of the biggest challenges being faced by the urban local bodies; still it has been one of the most neglected services.

B. Study Area

Nyanappanhalli (an unscientific landfill), Karnataka Compost Development Corporation (an abandoned composting unit), Kumbalgoud (an unscientific landfill), Mandur waste to energy treatment plant (Presently composting & land filling; the inert & combustible material are stored for RDF) and Mavallipura (Aerobic Composting & scientific land fill) sites were selected for the present study. Table 1 presents the salient features of the solid waste disposal sites.

TABLE I SALIENT FEATURES OF SOLID WASTE DISPOSAL SITES OF BANGALORE

Disposal Site Characteristics	Mavallipura (MA)	Mandur (M)	Kumbalgoud (KU)	KCDC (KC)	Nyanappanahalli (NY)
Since when in operation, years	2007	2008	2003	1975- 2008	2003- 2010
Total Site Area, acres	46	35	10	15.1	11
Waste filled Area	Approx 4 acres	Approx 6 acres	Approx 1.5 acres	NA	NA
Expected life of each site	20 + 15 (post closure)	20 + 15 (post closure)	NA	NA	NA
Disposal quantity (MT/day)	600 MTPD	800 MTPD	300 MTPD	300 MTPD	200 MTPD
Ownership	BOT	BOT & BOOT	BBMP	BBMP	BBMP
Waste Disposal Method	Aerobic Composting and Landfilling	Waste to energy and composting	Landfill	Compost	Landfill
Average Depth of Waste Dumped	Approx 8 mts	Approx 10 mts	Approx 7 mts	NA	NA

Mavallipura

The Mavallipura dump yard is situated in Hesaraghatta zone, 18 km North West of Bangalore city about 7.5 km away from the National Highway 7 at an elevation ranging between 51.38 m to 38.65 m above MSL occupying an area of 46 acres. Solid waste is disposed by aerobic composting and scientific landfilling. There is a water body at a distance of 2 km and an air force base at a distance of 8.5 km.

Mandur

The Mandur disposal unit occupies an area of 35 acres (Process Plant – 25 acres and Power Plant – 10 acres) and is located in Mandur Village, Bangalore East taluk along the Mandur – Gundur linking road, Budigere cross, NH – 4. Energy recovery from municipal solid waste in the form of refuse derived fuel and composting is a dual purpose initiative of M/s Srinivasa Gayithri Resource Recovery Limited (SGRRL) and Bangalore Mahanagara Palike (BMP).

Kumbalgoud

The landfill site was an abandoned quarry before with an area of about 10 acres. The dumping of waste started around 2003. It receives around 300 MTPD waste which is landfilled. The leachate from the waste is drained to the nearby Subrappanpalya Lake which has become a leachate collection pond. Charred industrial waste from nearby industries is also being dumped on the adjacent vacant land from late 2009.

Karnataka Compost Development Corporation (KCDC)

Karnataka Compost Development Corporation (KCDC) was established in 1975 to treat city's garbage for the production of compost based organic manure and vermin-compost. The dumping site is located in southwestern part of Bangalore in one of the most urbanized areas near Haralakunte township about 2 km away on National Highway 7 occupying an area of 15.10 acres. KCDC used to treat around 300 M tons garbage per day by aerobic decomposition windrow method. Now it is an abandoned solid waste disposal site as it has stopped receiving waste since 2008. The untreated leachate from the site finds entry into the dugwell located behind the waste dump and the nearby Haralakunte Lake.

Nyanappanhalli

The landfill site was an abandoned quarry before with an area of about 11 acres. The dumping of waste started intermittently around 2003 and the landfill activity was at its peak in 2008. It is located adjacent to an apartment and a few meters away from residences. The unsegregated waste was being dumped one side at a time without proper leachate collection system. The quarry always held rain water and there was no care taken to drain the quarry or seal it by grouting before using it for dumping. Dumping has been stopped since 2010. Presently it looks like a hillock as it has been covered with soil and leveled.

III. METHODOLOGY

Leachates from each site and belonging to varied stabilization stages were collected in 1L labeled clean plastic bottles rinsed out with the sample prior to collection, for physico-chemical analysis on a seasonal basis for the year 2009 and 2010. No precipitation had occurred in the week preceding sampling for pre-monsoon samples. To determine the quality of leachates, integrated samples were collected from randomly selected leachate drains at the site [5] where available or else from the base of the waste dump or from leachate ponds. The samples collected were brought to the laboratory immediately and refrigerated at 4°C. pH, electrical conductivity (EC), total dissolved solids (TDS) were measured using HACH HQ30D meter in the field. Nitrate and fluoride were analyzed using ion selective electrode method, phosphate and sulphate using spectrophotometer (6400-JENWAY), bicarbonate, calcium, magnesium, chloride, total Kjeldahl nitrogen and ammonical nitrogen by titrimetric methods. Analytical methods followed were according to "Standard methods for examination of water and wastewater" [6].. Sodium and potassium was determined using flame photometer. For the analysis of biological oxygen demand (BOD), 300ml capacity BOD bottles were used for the collection of samples and analysis was done using Winkler's modified titrimetric method. COD was analyzed using open reflux digestion method. 100ml plastic bottles were used to collect samples for heavy metal analysis, the samples were acidified with 2 ml of conc. HNO_3 to prevent precipitation of metals and growth of algae and were digested using an Ethos-D microwave digester, followed by analysis using atomic absorption spectrophotometer (Shimadzu AA-6300).

IV. RESULTS AND DISCUSSION

A. Leachate Composition

The pre-monsoon leachate samples showed higher concentration of pollutants as compared to post-monsoon samples which can be attributed to the dilution effect by rain water (Table 2).

TABLE II PHYSICO-CHEMICAL CHARACTERISTICS OF LEACHATE SAMPLES: PRE AND POST-MONSOON, IN MG/L, EXCEPT TEMP (˚C), PH AND EC (μS/CM)

Pre-monsoon						Post-monsoon						Leachate disposal Standard (MoEF, 2000)
Parameter	**MAL6**	**KCL2**	**NYL7**	**ML6**	**KUL3**	**Parameter**	**MAL6**	**KCL2**	**NYL7**	**ML6**	**KUL3**	
Temp	30.85	31.1	31.5	30.75	31.2	**Temp**	26.75	26.7	29.1	26.9	23.85	
pH	8.325	8.355	7.97	7.27	7.46	**pH**	7.995	8.675	7.98	7.37	7.715	5.5 - 9.0
TDS	12364	7100	9880	6985	6183	**TDS**	9392	4874	8750	4974	5521	2100
EC	19876	11942	16301	11574	9988	**EC**	14108	8217	14467	8210	9033	
SO_4^{2-}	309	275	264	299	288	**SO_4^{2-}**	233	240	236	240	250	
HCO_3^-	4270	2135	2928	2379	2135	**HCO_3^-**	2623	1769	1830	1647	2257	
Cl^-	3900	2250	1800	2100	1700	**Cl^-**	3150	1350	1300	1950	1700	1000
NO_3^-	74	31	78	43	54	**NO_3^-**	59	21	60	28	47	
PO_4^{2-}	2.459	2.304	3.865	3.588	2.007	**PO_4^{2-}**	1.552	1.541	2.446	1.851	1.243	
BOD_5	1780	1015	1100	730	845	**BOD_5**	1240	565	950	560	690	30
COD	3600	2267	2667	1467	1733	**COD**	2933	1733	2133	1147	1320	250
TKN	392	303	420	322	244	**TKN**	294	208	364	238	235	100
AN	283	247	375	258	165	**AN**	157	143	263	126	120	50
F^-	0.55	0.3	0.4	0.2	0.45	**F^-**	0.35	0.2	0.35	0.1	0.3	2
Ca^{2+}	1010	420	380	560	436	**Ca^{2+}**	708	342	340	400	340	
Mg^{2+}	482	238	195	305	222	**Mg^{2+}**	343	157	171	195	189	
Na^+	1545	1066	1353	1146	1186	**Na^+**	1260	807	860	875	919	
K^+	315	268	718	599	598	**K^+**	247	207	534	452	489	
Fe	48.865	11.896	91.220	71.835	47.135	**Fe**	29.690	8.735	46.750	56.420	34.855	
Zn	0.961	3.319	3.235	2.027	0.987	**Zn**	0.585	1.775	2.935	1.621	0.891	5
Ni	0.982	0.263	3.720	0.915	2.182	**Ni**	0.582	0.116	2.050	0.657	1.754	3
Cu	0.536	3.028	4.777	0.104	1.637	**Cu**	0.368	2.315	2.468	0.069	1.145	3
Pb	0.191	0.200	0.381	0.269	0.408	**Pb**	0.133	0.135	0.320	0.171	0.362	0.1
Cr	0.098	0.085	1.512	0.076	0.076	**Cr**	0.059	0.063	0.970	0.057	0.062	2
Cd	0.144	0.178	0.198	0.194	0.152	**Cd**	0.090	0.129	0.148	0.160	0.134	2
BOD/COD	0.49	0.45	0.41	0.50	0.49	**BOD/COD**	0.42	0.33	0.45	0.49	0.53	0.12

Alkaline pH (Table 2) of MAL6 and KCL2 samples indicate that they are undergoing methanogenic phase in which the leachate becomes almost stabilized as alkaline pH of the leachate indicates biochemical activity at its peak [7]. Such leachate samples have to be treated with high coagulant doses for chemical treatment. NYL7, ML6 and KUL3 leachate samples are probably in acidogenic phase as the pH values are comparably lower owing to the presence of volatile acids produced as a byproduct of fermentation reaction.

The TDS (Fig. 1 a1, a2) is very high for MAL6 and NYL7 samples in both pre and post-monsoon seasons. All the leachate samples have a higher TDS concentration in both pre and post-monsoon seasons when compared to the recommended concentration set by MoEF [8] (Table 2).

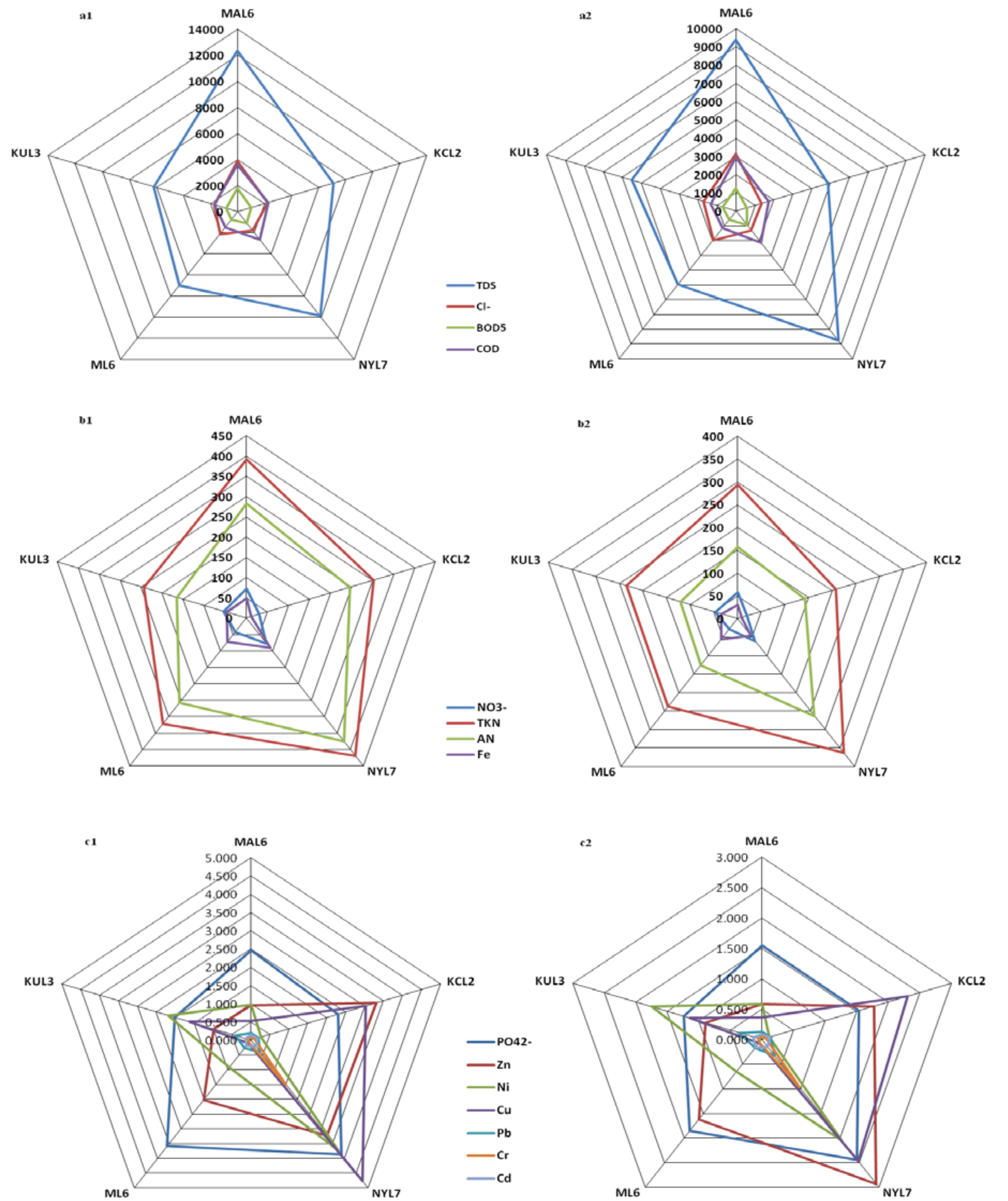

Fig. 1 Radar plot showing physico-chemical parameters of leachate samples

All the leachate samples are found to contain high chloride, BOD and COD (Fig. 1 a1, a2) in both pre and post-monsoon seasons, exceeding the recommended standards for the disposal of leachate. The biodegradability ratio BOD_5/COD (Table 2) is in the range of 0.4-0.6 for all the leachate samples except for KCL2 in post monsoon being 0.33 indicating that most of the organic material has undergone biodegradation.

Most of the nitrogen in the leachate samples is in ammonical form than in the form of nitrates (Fig. 1 b1, b2) which is due to the de-amination reaction occurring during the stabilization of leachates [9, 10]. So the least concentration of nitrates is found in old leachate samples.

Contrary to other studies, where phosphate concentration was found to be low in old leachate samples when compared with fresh leachate samples [10] much smaller differences were observed in this study.

Among the heavy metals, the smallest Fe concentration (Fig. 1 b1, b2) is found in KCL2 as only segregated organic waste was used for composting and also owing to increase in pH values leading to lesser metal solubility as Fe^{2+} gets oxidized to Fe^{3+} which is insoluble in alkaline conditions. Higher concentration of Fe is found in NYL7 and ML6 samples in both pre and post-monsoon seasons which can be due to the leaching of Fe from unsegregated (iron, steel and tin based scraps) waste dump and higher metal solubility because of low pH. NYL7 has the highest concentration of almost all the heavy metals (Fig. 1 c1, c2) in both pre and post monsoon seasons which could be attributed to the presence of discharged batteries, photographic processing chemicals, paints, fluorescent lamps and scrap metallic items resulting from the unsegregated waste haphazardly being dumped. Moturi *et al.* [11] and Mor *et al.* [12] have also reported the presence of the above heavy metals in leachate.

B. Leachate Pollution Index

The leachate pollution index (LPI) is an efficient tool to determine the detrimental effect the leachate of the dumping site can have if not treated properly. It is a quantitative measure of the leachate contamination potential and is calculated using the equation [3]:

$$LPI = \sum_{i=1}^{n} Wi\ Pi \qquad (1)$$

Where LPI = the weighted additive LPI, W_i = the weight for the *i*th pollutant variable, pi = the sub- index score of the *i*th leachate pollutant variable, *n* = number of leachate pollutant variables used in calculating LPI

And
$$\sum_{i=1}^{n} Wi = 1$$

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

$$LPI = \frac{\sum_{i=1}^{m} Wi\ Pi}{\sum_{i=1}^{m} Wi} \qquad (2)$$

where m is the number of leachate pollutant parameters for which data are available, but in that case, m < 18 and

$$\sum_{i=1}^{m} Wi < 1$$

The temporal variation in leachate samples from different dumping sites, belonging to different stabilization stages is expressed using leachate pollution index. LPI of all the leachate samples for both the seasons exceeded the standard LPI of 7.4 estimated for leachate disposal (Fig. 2). LPI for pre-monsoon season is comparatively more due to the dilution of leachate by rainwater in post monsoon season. The trend in LPI followed the following sequence- NYL7>MAL6>KCL2>ML6>KUL3.

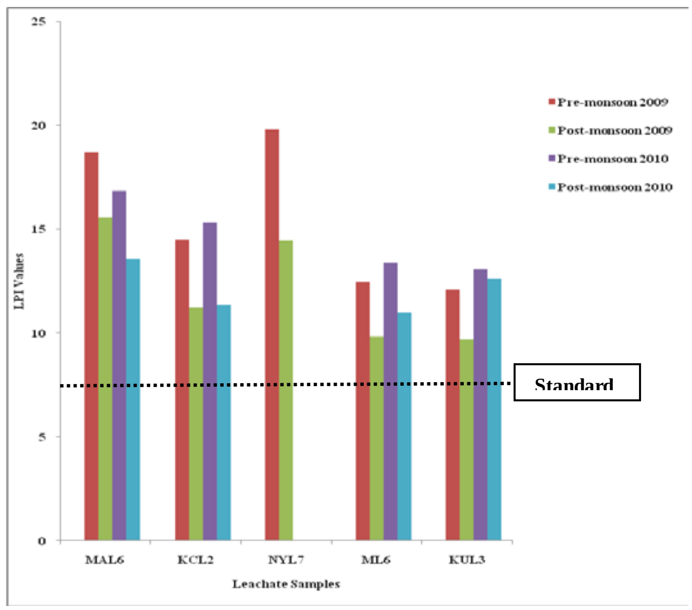

Fig. 2 Bar plot showing LPI of leachate samples

C. Principal Component Analysis

PCA is used to analyze interrelationships between a large number of variables expressed as a new set of variables called factors (add reference). Contribution of a factor is significant when the corresponding eigen value is greater than one (Kaiser criterion). More the score of a variable, more will be the variable contribution to the variation accounted for by that particular PC.

TABLE III PRINCIPAL COMPONENT ANALYSIS OF LEACHATE SAMPLES: PRE AND POST-MONSOON

	Pre-monsoon				**Post-monsoon**			
	1	*2*	*3*	*4*	*1*	*2*	*3*	*4*
pH	**0.599**	0.079	-0.726	-0.33	0.063	-0.068	-0.849	**0.521**
TDS	**0.919**	0.387	-0.053	0.045	**0.931**	0.366	0.002	0.002
EC	**0.904**	**0.412**	-0.095	0.062	**0.869**	**0.494**	-0.020	0.023
SO_4^{2-}	**0.55**	-0.602	**0.437**	0.379	-0.671	-0.189	**0.529**	**0.484**
HCO_3^-	**0.971**	0.202	0.099	0.085	**0.779**	-0.402	0.313	0.364
Cl^-	**0.95**	-0.252	-0.103	0.15	**0.754**	-0.554	0.203	-0.288
NO_3^-	**0.588**	**0.676**	**0.403**	-0.19	**0.790**	**0.428**	0.389	0.204
PO_4^{2-}	-0.159	**0.761**	0.036	**0.63**	0.113	**0.878**	-0.210	-0.415
BOD_5	**0.977**	0.069	-0.126	-0.16	**0.991**	0.115	0.052	0.045
COD	**0.913**	0.258	-0.234	-0.21	**0.945**	0.022	-0.314	0.084
TKN	**0.58**	**0.744**	-0.194	0.27	**0.614**	**0.781**	0.073	-0.083
AN	0.29	**0.861**	-0.307	0.282	0.360	**0.902**	-0.238	0.025
F^-	**0.719**	0.089	0.272	-0.63	**0.736**	0.328	0.120	**0.580**
Ca^{2+}	**0.918**	-0.276	0.17	0.228	**0.856**	-0.451	0.006	-0.251
Mg^{2+}	**0.881**	-0.335	0.119	0.311	**0.867**	-0.439	0.149	-0.185
Na^+	**0.886**	0.366	0.277	-0.07	**0.890**	-0.406	0.191	-0.080
K^+	-0.486	**0.631**	**0.599**	0.084	-0.251	**0.678**	**0.687**	-0.070
Fe	-0.031	**0.773**	**0.53**	0.346	-0.035	**0.449**	**0.640**	-0.622
Zn	-0.423	**0.484**	-0.759	0.108	-0.281	**0.882**	-0.355	-0.128
Ni	-0.154	**0.843**	0.392	-0.33	0.058	**0.731**	**0.596**	0.327
Cu	-0.277	**0.71**	-0.447	-0.47	-0.193	**0.587**	-0.539	**0.573**
Pb	-0.528	**0.453**	**0.593**	-0.4	-0.178	**0.571**	**0.628**	**0.498**
Cr	-0.075	**0.988**	-0.064	-0.12	0.175	**0.979**	-0.089	0.045
Cd	-0.575	**0.568**	-0.293	**0.51**	-0.781	**0.509**	0.177	-0.317
Eigen Value	10.804	7.475	3.323	2.399	10.018	8.259	3.93	2.793
% Variance	45.017	31.144	13.844	9.994	40.073	33.035	15.72	11.171
Cumulative %	45.017	76.161	90.006	100	40.073	73.108	88.829	100

The four factors or PCs explain 100% of the total variance during pre and post-monsoon. PC1 accounts for 45% of the total variance in pre-monsoon and 40.1% in post-monsoon, which is due to the strong loading of TDS, EC, HCO_3^-, Cl^-, NO_3^-, BOD, COD, TKN, F^-, Ca^{2+}, Mg^{2+} and Na^+ **.** Higher TDS and EC are because of large concentration of cations and anions indicating the presence of inorganic materials in the leachates while higher HCO_3^-, F^-, Ca^{2+}, Mg^{2+} and Na^+ suggest input from weathering of rock minerals and also the ion exchange processes involved. BOD and COD indicate the organic strength of the leachate. Higher Cl^-, NO_3^-, and TKN are the consequence of degradation of waste besides natural processes occurring in the background.

PC2 exhibited 31.1% of the total variance in pre-monsoon and 33% in post-monsoon, with strong positive loading of EC, NO_3^-, PO_4^{2-}, TKN, AN, K^+, Fe, Zn, Ni, Cu, Pb, Cr, Cd. High PO_4^{2-} concentration is due to the degradation of organic waste which contains phosphorous in the form of phospholipids and phospho-proteins. Ammonical nitrogen results from the de-amination of amino-acids during degradation of waste. Higher concentration of Fe, Zn, Ni, Cu, Pb, Cr and Cd can be attributed to the presence of refused batteries, fluorescent lamps, paints, chemicals for photographic processing, wood preservatives and scrap metallic items in the dumped waste.

PC3 is characterized by the strong loading of SO_4^{2-}, K^+, Fe, Pb and accounts for 13.8% of the total variance in pre-monsoon and 15.7% in post-monsoon

PC4 is characterized by the strong loading of PO_4^{2-}, Cd and accounts for 9.9% of the total variance in pre-monsoon and 11.2% of the variance in post-monsoon is due to the strong loading of pH, SO_4^{2-}, F^-, Cu and Pb.

It can be concluded that most of the significant factors which result from the interrelationships between a large number of variables highlight the anthropogenic inputs rather than the background processes. Also by knowing the interrelationships among the above parameters it is easier to design a leachate treatment plant.

D. Cluster Analysis

In cluster analysis the objects are grouped in such a way that similar objects fall into the same class or group. The levels of similarity at which observations are merged result into a dendrogram. Hierarchical cluster analysis was applied using Ward's method and Euclidean distance as a measure of similarity. The physicochemical parameters analyzed were used as the criteria to assess the similarity between the leachate samples. The dendrogram of leachate samples yielded four and three major clusters for pre and post-monsoon analysis respectively (Fig. 3a, 3b).

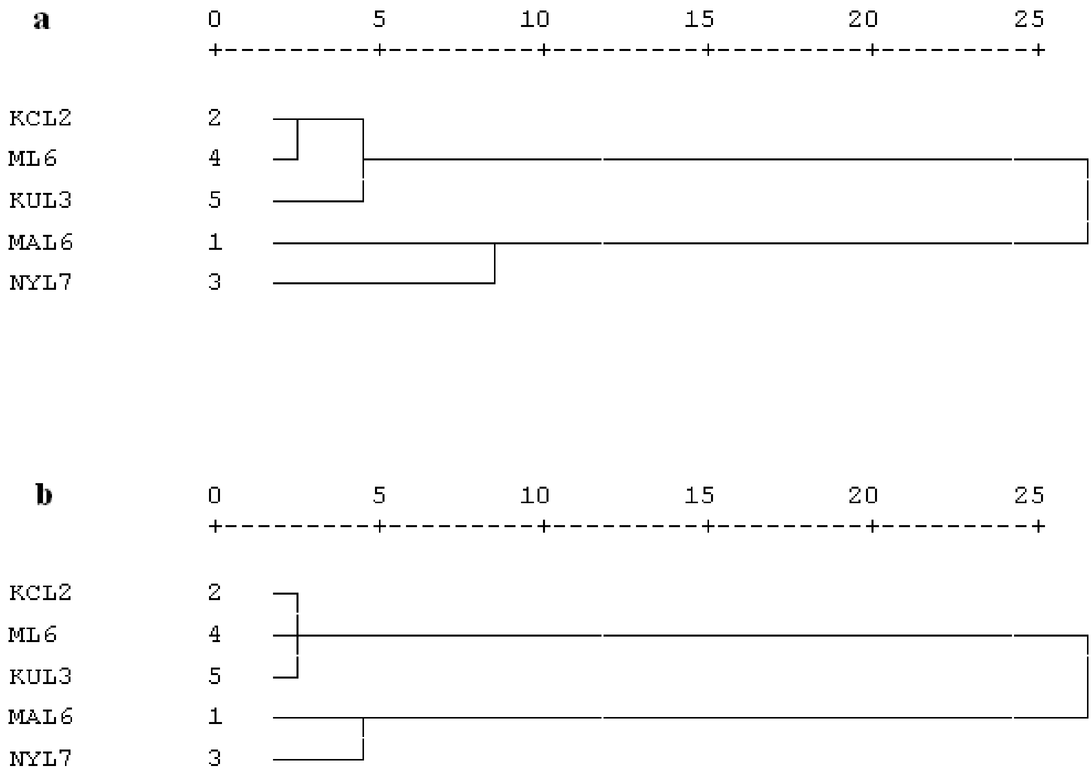

Fig. 3 Dendrogram showing clustering of leachate samples during Pre-monsoon (a) and Post-monsoon (b)

During pre-monsoon, MAL6 being highly polluted leachate sample formed a separate cluster. NYL7 is the next most polluted leachate sample and formed a second cluster. KUL3 represented a moderately polluted leachate sample formed a separate cluster. ML6 and KCL2 being the least polluted leachate samples also formed a separate group.

In the post-monsoon season the clustering pattern of the leachate samples showed a slightly different trend. MAL6 again remained the highly polluted leachate sample forming a separate cluster. NYL7 remained the next most polluted leachate sample and formed a separate cluster as in pre-monsoon. KUL3, ML6 and KCL2 formed a separate cluster of least polluted leachate samples after being affected by the dilution with rain water.

V. CONCLUSION

The leachate samples from all the solid waste dump sites demonstrate high concentration of almost all the physico-chemical parameters analyzed. It is obvious from the results that BOD, COD, chloride and ammonical nitrogen are the principal pollutants of all the dump sites and their concentration vary depending on the stabilization stage of the dumpsite. Also LPI of all the leachate samples for both the seasons exceeded the standard LPI of 7.4 estimated for leachate disposal indicating the detrimental effect it can pose if the containment, treatment and monitoring measures are not taken care. The leachates from different dumping sites have varied composition so different treatment methods will have to be adopted. Site specicific leachate treatment plants based on the characteristics of waste and leachate composition and concentration should be made mandatory at all the solid waste disposal sites. Also the monitoring of these sites should be done regularly even after the closure of the site to prevent the aftereffects on the environment.

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