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Assessment of Contamination Potential of Leachate from Municipal Solid Waste Landfill Sites for Metropolitan Cities in India

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ABSTRACT: With increased population, rapid industrialization and life style changes, the characteristics and the rates of solid waste generation have gone under drastic change in India. Generally, in India, management of solid waste landfill is of major concern with respect to the existing circumstances. The illegal dumping of municipal solid waste on the outskirts of cities is creating major environmental and public health problems. Improper and unscientific waste management results in potential threats from leachate leakage with subsequent impact on environment (i.e. soil, air and waterbodies) and human being. It is therefore, important to evaluate the contamination potential threat of landfill leachate. This study assesses the potential contamination from the landfill leachate by an index called leachate pollution index (LPI) and suggestions are given the landfill sites of five major cities i.e. Bangalore, Chennai, Delhi, Navi Mumbai & Kolkata in India. The landfill leachate samples from these sites have been assessed using leachate pollution index for the implementation of appropriate leachate treatment techniques for reducing the adverse effects on the environment. The results show that the Pallikkaranai landfill site for Chennai city and Mavallipura landfill site for Bangalore city are highly deteriorating and may lead to increase in human health risk for nearby dwellings.

Keywords: Contamination; Dumping; Solid Waste; Landfill; Leachate.

INTRODUCTION

In recent decades the municipal solid waste (MSW) has received huge attention due to the social and environmental impacts. Various policies, strategies, plans and methods have been evolved for MSW management. These include various components such as waste reduction and waste recovery for reuse, recycling, composting and incineration for energy generation in addition to landfilling of final rejects. Landfilling is one of the simple options for MSW disposal all over the world because they offer dumping high quantities of MSW at economical costs in comparison to other waste disposal methods (Mohajeri et al., 2010; Palaniandy et al., 2009; Foul et al.,2009; Daud et al.,2009). MSW landfills are significant sources of wide range of pollutants of environmental concern. Majority of MSW disposal sites are still open dumps especially in under developed and developing countries. The generation of leachate is a result of percolation of precipitation through open landfill or through cap of the completed site (Susu & Salami, 2011). Landfill leachate is characterized by high concentration of organic and inorganic matters and heavy metals (Renou et al., 2008). A leachate characteristic is highly

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variable and depends on the waste composition, amount of precipitation, site hydrology, waste compaction, cover design, sampling procedures, interaction of leachate with the environmental and landfill design and operation (Reinhart & Grosh, 1998). Properly designed and operated MSW landfills eliminate adverse environmental impacts that result from MSW disposal alternatives like waste burning in open-air burning sites and illegal /open-pit dumping. Other adverse impacts may arise from landfills i.e. gas and leachate formation if not well managed. These environmental impacts also include fires and explosions, vegetation damage, unpleasant odors, landfill settlement/failures, contamination of soil, water and air pollution and global warming. Currently in developing countries, MSW landfills have been largely unsuccessful due to improper site selection which have limited time frame of usage. These are also receiving all of the waste materials such as MSW, commercial and industrial as well construction and demolition wastes which may contain hazardous substances leading to health risks emanating from the landfill leachate and methane gas.

MSW landfill leachate is the main source of contamination of waterbodies (i.e. ground and surface) if it is not properly collected and treated and safely disposedoff as it may percolate through the soil layers and reaching to the aquifers. Once groundwater is contaminated and making it clean enough to drink can be extremely difficult and expensive for several reasons. In developing nations especially, the problem is more serious where the landfills do not have any leachate containment i.e. collection and treatment systems. Thus, it is very essential to adopt appropriate treatment/remedial measures to avoid contamination of the underlying soils and groundwater aquifers from the leachate generated from the landfills.

Generally, the older landfills do not have barrier systems or leachate collection systems to restrict the migration of leachate to the surrounding soil and groundwater. When the landfills are in permeable soils with shallow water table, the potential of the leachate to contaminate the groundwater increases. Closed landfills can continue to pose threat to the groundwater contamination if they are not capped properly before closure to prevent the leaching of contaminants by percolating rain water.

According to an estimate all the cities and towns in India generate about 52 million tonnes of solid waste every year and this requires 1,250 hectares of landfill for every year of dumping. In India, unscientific disposal of MSW is adopted in every city, town and villages. MSW generated is usually disposed directly on low lying areas. Almost no urban local bodies (ULBs) have adequate engineering landfilling facility and MSW is disposed off in the outskirts of city along the roads. Unscientific disposal of MSW is prone to flooding and the main source of contamination of ground and surface water bodies are due to percolation of leachate. Landfilling is an accepted practice in India and the metropolitan centers like Bangalore, Delhi, Kolkata, Mumbai and Chennai have scarcity of land for dumping of solid waste and designated landfill sites are running beyond their capacity (Naveen et al., 2018).

In developing countries like India, MSW is mostly disposedoff in an uncontrolled manner into the open dumps without any liner and leachate collection and treatment facilities. Leachate contains high toxic effluents with a complex matrix of organic and inorganic pollutants. Leachate pollutants consists of mainly: dissolved organic matter; inorganic macro components; heavy metals and xenobiotic organic compounds. Among the various pollutant’s heavy metals, organic substances and ammoniacal nitrogen are of significant concern to the environment (Yusof et al., 2009). A dissolved organic effluent imparts a significant effect on other pollutant's characteristics due to redox reactions and hydrophobic /hydrophilic sorption (Seo et al., 2007). Ammonia is the odorous substances which are emitted from the MSW landfill sites (Fang et al., 2012). Heavy metals are highly toxic, persistent, capable to bioaccumulate and able to pollute the surrounding waterbodies to a landfill site and thus lead to ecological risk (Karbassi et al.,2015). So, leachate has the possibility of contaminating the adjoining aquatic and lithosphere system unless remedial measures are implemented. To prioritize the actions of the landfill remediation works, Kumar and Alappat (2003) developed a leachate pollution index [LPI] and the dominant group of leachate pollutants is analyzed by calculating the sub-leachate pollution indices: LPI organic, LPI inorganic and LPI heavy metals depending on the leachate characteristics. Umaer et al., (2010) reported that LPI values of four landfills in Malaysia were observed to be very high indicating that the immediate remediation works should be encouraged. Similarly, in another research by Kale et al., (2010) seasonal variation of LPI values were analyzed and they recommended that the landfill leachate has less pollution potential during post monsoon in comparison to pre-monsoon.

It is essential to assess the leachate pollution potential of a MSW landfill site to suggest the remedial measures for leachate treatment. Therefore, this research focuses on the assessment of the contamination potential threat from the leachate from the landfill sites located in the major metropolitan cities (Bangalore, Delhi, Mumbai, Kolkata, Chennai) in India by using the LPI. This index is mainly used to report the leachate pollution changes in a landfill over a period of time. The leachate trend analysis developed for the landfill can be used to assess the post closure monitoring periods. Based on the leachate trend at a given landfill site, the index facilitates the design of leachate treatment units for other landfills in the same region. The other potential application of LPI is to assess, monitor and compare leachate contamination potential of different landfills in a given geographical area. Further this will help in assessing and identifying whether the solid waste leachates are hazardous or not and also develop a sustainable leachate treatment process besides to foresee the impacts of leachate on groundwater. This study also aims to serve as a guideline for the implementation of appropriate leachate treatment technique for reducing adverse effects on the environment. Thus, five landfills sites located at Bangalore: Mavallipura landfill, Chennai: Pallikkaranai landfill, Delhi: Ghazipur landfill, NaviMumbai: Turbhe landfill, Kolkata: Dhapa landfill were taken for assessing the contamination level of these landfills.

MATERIALS AND METHODS

LPI is a simple and efficient tool for assessing the leachate contamination potential. The LPI is formulated based on the Delphi technique (Hsu & Sandford, 2007). LPI process involves: selection of leachate pollutant variables, assigned leachate pollutant weights, formulating their sub-indices curves, and finally aggregating the pollutant variables to arrive at the LPI as reported by Kumar and Alappat (2003) as:

$$LPI = \sum_{i=1}^{n} WiPi \tag{1}$$

where Wi is the weight for the i^{th} pollutant variable, Pi is the sub index score of the ith leachate pollutant variable, n is number of leachate pollutant variables used in calculating LPI. Weights are so selected that,

$$\sum_{i=1}^{n} Wi = 1 \tag{2}$$

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 as under:

$$LPI = \frac{\sum_{i=1}^{m} WiPi}{\sum_{i=1}^{m} Wi} \qquad (3)$$

where m is the number of leachate pollutant parameters for which data are available, but in that case, m<18 and ΣW<1 contamination from the pollutant to the overall leachate pollution. LPI values have grades that represent the overall leachate contamination potential of a MSW landfill. It is an ascending order scale index, wherein a lower index value indicates a good environmental condition.

The Mavallipura landfill site (lat.13°50’ N, long.77°36’ E) is located in north of Bangalore city at about 20km from the city and is used as a processing site for MSW generated in the city. The site is of about 40 ha. of which approximately 14ha is used for landfill. The landfill was operated by M/s Ramky Environmental Engineers was started in 2007 and can sustain about 600 tonnes of waste on daily basis. However, the Bruhat Bengaluru Mahanagara Palike (BBMP) has been sending almost 1,000 tonnes of garbage from Bangalore city every day. Citizens around the site were demanding that the landfill site must be stopped immediately as it is illegal and unscientifically managed and thus it is now closed for land filling. The data for this landfill was used for analysis as reported by Naveen et al.,(2017).

Delhi, India's capital territory, is a massive metropolitan area in the northern India and lies between latitudes of 28°24’17’’ and 28°53’00’’ North and longitudes of 76°50’24’’ and 77°20’37’’ East. Delhi city generates about 9,000 metric tonnes of municipal solid waste every day out of which 60% is disposedoff in the landfill. Ghazipur landfill site is located in East Delhi and falls under the category of uncontrolled waste disposal facility. The data for this landfill as reported by Afsaret al., (2015) was used for calculating the LPI.

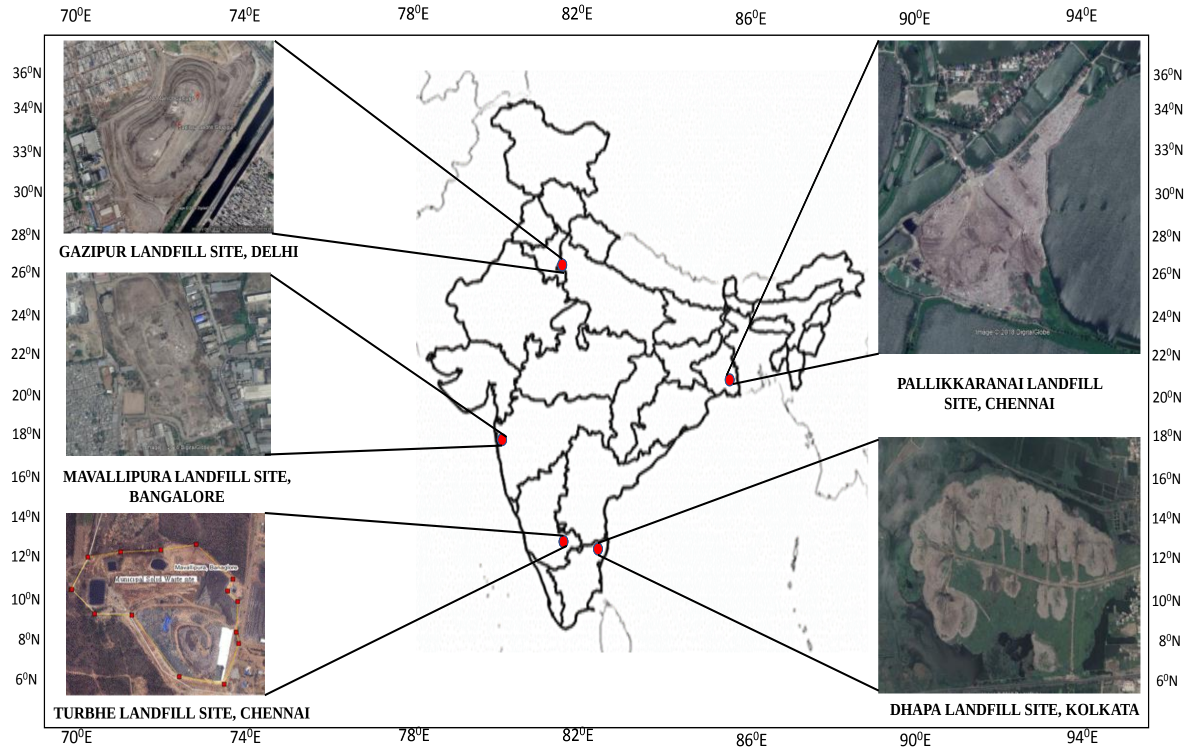

Fig. 1. Location map of landfill sites in India under study

Table 1. Leachate pollution index for the Mavallipura landfill leachate

Pollutant	Sample	W_i	P_iw_i
pH	7.4	0.055	0.275
TDS, mg/l	2027	0.050	0.40
BOD_3, mg/l	1500	0.061	3.36
COD, mg/l	10400	0.062	4.96
TKN, mg/l	2330	0.053	5.035
AN, mg/l	1803	0.051	5.10
Iron, mg/l	11.16	0.044	0.22
Copper, mg/l	0.151	0.050	0.25
Nickel, mg/l	1.339	0.052	0.26
Zinc, mg/l	3	0.056	0.28
Lead, mg/l	0.3	0.063	0.31
Chromium, mg/l	0.021	0.064	0.64
Chlorides, mg/l	660	0.048	0.2544
Mercury, mg/l	BDL*	-	-
Arsenic, mg/l	BDL	-	-
Cyanide, mg/l	BDL	-	-
	LPI = 30.10		

* BDL denotes below detection level

Table 2. Leachate pollution index for the Ghazipur landfill leachate

Pollutant	Sample	Wi	Pi Wi
pH	7.6	0.055	0.275
TDS, mg/l	9636	0.050	5.02
BOD_3, mg/l	2757	0.061	4.29
COD, mg/l	4400	0.062	5.10
TKN, mg/l	46.2	0.053	0.529
AN, mg/l	25.9	0.051	0.613
Iron, mg/l	7.5	0.044	0.222
Copper, mg/l	0.6	0.050	0.249
Nickel, mg/l	0.25	0.052	0.313
Zinc, mg/l	0.4	0.056	0.338
Lead, mg/l	ND	0.063	0
Chromium, mg/l	0.4	0.064	2.42
Chlorides, mg/l	38.4	0.048	0.82
	LPI = 28.41		

Table 3. Leachate pollution index for the Dhapa landfill leachate

Pollutant	Sample	Wi	Pi Wi
pH	8.0	0.055	0.1375
TDS, mg/l	24110	0.050	2.8
BOD_3, mg/l	4296	0.061	3.172
COD, mg/l	7337	0.062	4.216
TKN, mg/l	814.48	0.053	1.272
AN, mg/l	561	0.051	2.958
Iron, mg/l	7.474	0.044	0.225
Copper, mg/l	0.072	0.050	0.3
Nickel, mg/l	0.042	0.052	0.26
Zinc, mg/l	0.466	0.056	4.526
Lead, mg/l	0.374	0.063	0.378
Chromium, mg/l	0.19	0.064	0.32
Chlorides, mg/l	6906	0.048	3.12
	LPI =28.903		

The Dhapa site is located in Kolkata, India in the state of West Bengal at latitude 22º 34′ N and longitude 88º 24′E. It is under the supervision of the Kolkata Municipal Corporation (KMC). The disposal site has been operating as an open dump since 1981. This site neither has any bottom liner nor is outfitted with any leachate management system. The location of Dhapa dumping site is shown in Fig.1. The data of this landfill site as reported by De et al., (2016) was used for calculating the LPI.

The site is located in Navi Mumbai, Maharashtra. It is located between 19° 5' and 19° 15' (N) latitude and 72° 55' (E) longitude. The data of this landfill site as reported by Mishraet al.,(2016) was used for analysis.

The site located south of Velachery lies between the old Mahabalipuram road in the east, Velachery-Tambaram road on the west, Sittalappakkam on the south and Alandur on the north and serves Chennai for disposal of waste. The area is low lying marshy land and is connected to the sea via the Buckingham canal and the Kovalam Estuary at the southern end of the depression. The dumpsite lies between 2 to 3 km west of the Buckingham Canal and is at 3.5 to 4.5 km west of the Bay of Bengal coastline. Every day, Pallikkaranai landfill receives waste of about 100-120 metric tonnes generated from Alandur. This waste not sent to the nearby site in Perungudi which receives nearly about 2,200 metric tonnes of solid waste per day. The data of this landfill as reported by Artiningsih et al., (2018) was used for analysis.

Table 4. Leachate pollution index for the Turbhe landfill leachate

Pollutant	Sample	Wi	Pi Wi
pH	7.77	0.055	0.1925
TDS, mg/l	18366	0.050	2.25
BOD_3, mg/l	3391	0.061	2.684
COD, mg/l	6444	0.062	4.34
Iron, mg/l	165.93	0.044	0.315
Copper, mg/l	3.61	0.050	1.4
Nickel, mg/l	0.381	0.052	0.26
Zinc, mg/l	7.58	0.056	0.392
Chromium, mg/l	0.844	0.064	0.384
Chlorides, mg/l	3583	0.048	1.392
LPI =25.10			

Table 5. Leachate pollution index for the Pallikkaranai landfill leachate

Pollutant	Sample	Wi	Pi Wi
pH	7.5	0.055	0.275
TDS, mg/l	16428	0.050	2
BOD_3, mg/l	5193	0.061	3.355
COD, mg/l	25975	0.062	5.58
TKN, mg/l	757	0.053	1.325
AN, mg/l	565	0.051	2.856
Iron, mg/l	63	0.044	0.270
Copper, mg/l	0.401	0.050	0.300
Nickel, mg/l	0.812	0.052	0.338
Zinc, mg/l	1.41	0.056	0.308
Phenolic, mg/l	7.83	0.057	0.855
Chromium, mg/l	0.64	0.064	4.16
Chlorides, mg/l	3253	0.048	1.2
Total Coliforms, MPN/100ml	>1600	0.052	5.2
LPI =37.11			

Leachate characteristics of five landfill sites demonstrate high variations in terms of physical, chemical, and biological parameters. LPI is a good tool to compare pollution potential of various landfill sites in metropolitan cites in India. Among the five landfill sites, Pallikkaranai has the highest LPI value while Turbhe landfill sites has the lowest LPI.

Also, these landfill leachate is also influenced by several important factors such as municipal solid waste composition, elapsed time, temperature, moisture and available oxygen. Generally, the leachate quality with similar waste types may be different in landfills located in varied climatic regions. Furthermore operational practices in landfills also influence the leachate quality. The important reaction in MSW is the degradation of organic materials to produce carbon dioxide and small amount of ammonia. Their dissolution in the leachate leads to the formation ammonium ions and carbonic acid. The carbonic acid dissociates with ease to produce hydrogen cations and bicarbonate anions, which influence the level of pH of the system. Additionally, leachate pH is also influenced by the partial pressure of the generated carbon dioxide gas that is in contact with the leachate.

Pallikkaranai and Turbhe landfill sites leachate are having high total dissolved solids. This total dissolved solidsare majorly influenced by the total amount of dissolved organic and inorganic materials present in the solution and are used to demonstrate the degree of salinity and mineral contents of the leachate. Total mineral content further reflects the strength and overall pollutant load of the leachate. The salt content in these Pallikkaranai & Turbe landfill leachates is due to the presence of potassium, sodium, chloride, nitrate, sulphate and ammonia salts. Finally, the extremely high values for conductivity are attributable to high levels of cations and anions.

The level of inorganic elements present in leachate is dependent principally on the ease of leaching the inorganic constituents present in the municipal solid waste materials and the stabilization process in the landfill.

Mavallipura, Turbhe, Dhapa & Ghazipur landfills leachate samples were found to have considerably high concentrations of all the major anions like chlorides, nitrates, sulphate as concentration of chloride is highest, while sulphate concentration is the lowest. The high chloride content in the leachate sample reflects the significant presence of soluble salts in the municipal solid waste materialsss. The high chloride content in landfill leachate sample is attributed to the large amount of sewage, agricultural and other animal waste deposited in the site. Prior to anaerobic activity sulphate is converted to sulphide and metal sulphide precipitates in leachate sample. The high chloride content in groundwater is from pollution sources such as domestic effluents, fertilizers, septic tanks, and leachates. If chloride content is high in groundwater that is injurious to people suffering from diseases of heart and kidney. The zinc values are elevated possibly due to localized sources of pollution. The low concentrations chromium can cause nausea and vomiting. Lead is toxic to people, farm animals and crops in both acute and chronic exposures even at fairly low concentrations. Low concentrations silver are harmful to people. Small quantities of iron are essential for plant growth. At low concentration cadmium have undesirable toxic effect on humans and animals. In Mavallipura landfill sites, the ammonia found to be high due to the aquatic environment via municipal effluent discharges and excretion of nitrogenous wastes from animal and indirect means such as air deposition, nitrogen fixation and runoff from the agricultural lands. If ammonia is present in water bodies at high concentration levels, it is difficult for aquatic organisms to sufficiently excrete the toxicant, leading to toxic build up in internal tissues and blood and potential death.

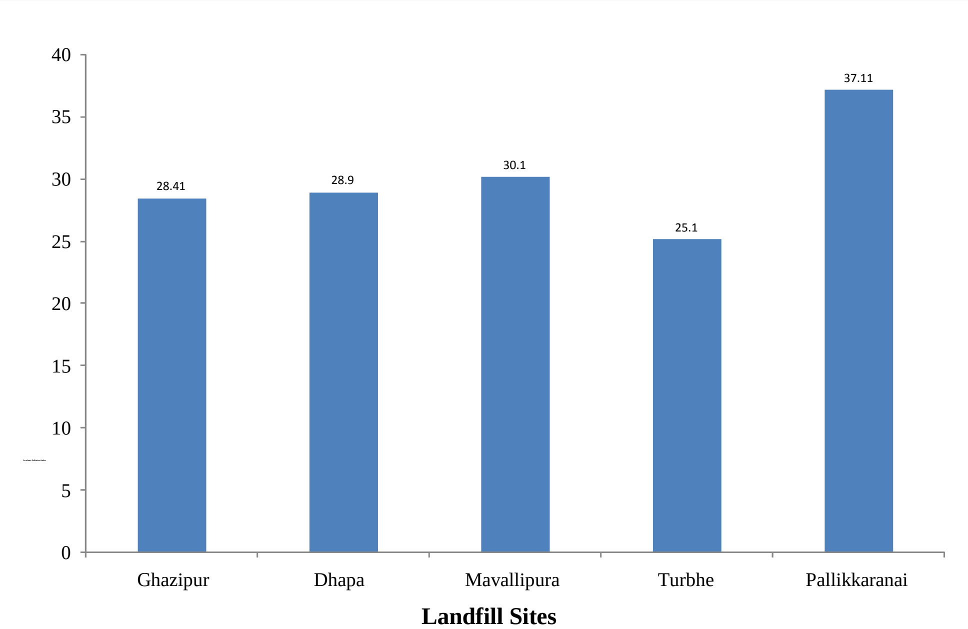

Fig. 2. Comparison of leachate contamination potential of the landfill sites

The leachate pollution index value of the leachate disposal standards to inlands surface water as per Municipal Solid Waste (Management and Handling) Rules, 2000, Government of India is 7.378. Fig.2 shows that the Turbhe landfill site results least in leachate potential Index of 25.1 when compared with other 4 landfill sites. For Dhapa landfill site and Ghazipur landfill site the leachate potential Index values were almost similar. But Mavallipura landfill site leachate potential index values were estimated to be slightly higher (30.1) than Dhapa landfill & Ghazipur landfill sites. The highest leachate potential index of 37.11 was observed in Pallikkaranai landfill site owing to potential toxicity and higher metal and organic concentrations. Significantly high ammo-N and organic-N were recorded in all five leachate samples suggesting for immediate treatment for the stalled leachate fractions in these MSW landfill sites.

Protection measures are mentioned below:

1. Leachate problem can be minimized by restricting water flow into the landfill through surface water diversion and reducing water accumulation in these landfill sites by frequent pumping coupled with the daily soil cover. A low-permeability cover affects the water infiltration into the landfill area.
2. Construction of leachate collection and gas venting facilities can be installed.
3. It must be ensured that only non-recyclable and inert waste is disposed off in the landfill sites and no hazardous and bio-medical waste is dumped in landfills. Thus, adequate waste segregation and utilization with bioprocesses like anaerobic digestion/composting for organic waste treatment and management and incineration for biomedical waste can be followed before landfilling of inert materials.
4. Leachate produced from the landfill siteshas to be effectively collected and treated with advanced microbial technologies as anaerobic digestion and bio-filters. This also helps in checking the deterioration of groundwater resources from leachates from MSW landfill sites.

5. Various leachate management strategies can be adopted in the municipal landfills sites such as (a) leachate recirculation and (b) single pass leaching. The leachate recirculation methods are simple and affordable and are apparently appropriate for landfill located in warm areas with low rainfall. On the contrary, the single pass leaching strategy caters to containment and removal of toxicants before it is discharged.

CONCLUSIONS

1. The leachate samples of these five landfill sites have shown high concentrations of organic and inorganic constituents. Heavy metals concentration was in traces indicating that the waste dumped is a predominantly municipal waste.
2. The highest leachate potential index was observed in Pallikkaranai landfill site owing to potential toxicity and higher metal and organics concentrations.
3. High value of LPI of Pallikkaranai landfill site indicated that leachate generated is loaded with more organic and inorganic pollutants.
4. All five landfill sites have neither any base nor leachate collection nor treatment system. Therefore, all the leachate generated finds its path into the surrounding soil and groundwater environment.
5. The LPI value indicates the leachate contamination potential of all five landfill sites in a given geographical area on a comparative scale and is a hazard identification tool.
6. The higher values of LPI demand that the leachate generated from landfill sites should be treated on priority and site should be monitored on continuous basis.
7. The possible treatment option with high organic strength may be to use aerobic biological treatment process with extended aeration to take care of high ammonia nitrogen with nitrification followed by denitrification.

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