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Research Article

Variability of Parameters Involved in Leachate Pollution Index and Determination of LPI from Four Landfills in Malaysia

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Landfill sites are potential sources of human and environmental hazards. Leachate produced form these waste dumping sites is heterogeneous and exhibits huge temporal and seasonal variations. Leachate pollution index (LPI) provides an overall pollution potential of a landfill site. The parameters required to calculate LPI from a landfill site are discussed in terms of their variations over time, and their significance has been highlighted in the context of LPI. The LPI values of two semiaerobic and two anaerobic landfill sites in Malaysia have been calculated in this study. Pulau Burung Landfill Site (PBLS) was found to have the highest LPI score while Ampang Jajar Landfill Site (AJLS) showed the lowest LPI as compared to other landfills. It is concluded that LPI value can be used as a tool to assess the leachate pollution potential from landfill sites particularly at places where there is a high risk of leachate migration and pollution of groundwater.

1. Introduction

Landfills are the primary means of municipal solid waste (MSW) disposal in many countries worldwide because they offer dumping high quantities of MSW at economical costs in comparison to other disposal methods such as incineration. Landfill leachate produced form MSW landfill sites is generally heavily contaminated and consist of complex wastewater that is very difficult to deal with [1–4]. The generation of leachate is a result of percolation of precipitation through open landfill or through cap of the completed site [5]. Leachate is characterized by high concentration of organic matter (biodegradable and non-biodegradable), ammonia nitrogen, heavy metals, and chlorinated organic and inorganic salts [6]. The characteristics of leachate are highly variable [7] depending on the waste composition [2], amount of precipitation, site hydrology, waste compaction, cover design, sampling procedures, and interaction of leachate with the environment, landfill design and operation [8]. Organic content of leachate pollution is generally measured in terms of biological oxygen demand (BOD_5) and chemical oxygen demand (COD). The concentrations of leachate contaminants may range over several orders of magnitude [9]. A combination of pollutants (BOD_5, COD, ammonia, inorganic salts, etc.) in higher concentrations renders landfill leachate as a potential source of contamination both to ground and surface waters, hence necessitates its treatment prior to discharge to water resources [10]. 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 [11]. Leachate can contaminate groundwater where landfills are not provided with liners and surface water if it is not collected and treated prior to its discharge. The overall pollution potential of landfill leachate can be calculated in terms of leachate pollution index (LPI) as proposed by Kumar and Alappat [12]. Because identification and quantification of pollutants in landfill leachate is the major limitation for its successful treatment [13], LPI can be used as a mean to determine whether a landfill requires immediate attention in terms of introducing remediation measures. Most of the landfills in developing countries including Malaysia are not designed with proper leachate collection mechanism. There are 230 landfills in Malaysia recognized officially [14]. Most of these landfills do not come under sanitary landfill classification because there are no facilities for collection and/or treatment of leachate and there is no infrastructure to collect landfill gas [14]. Many of these landfill sites are located near rivers and streams which are a major source of agriculture and productivity, industrial and domestic water supply. The present study was carried out to determine and compare the LPI for leachate collected from four landfill sites, that is, semiaerobic Pulau Burung Landfill Site (PBLS), anaerobic Kulim Landfill Site (KLS), semiaerobic Ampang Jajar Landfill Site (AJLS) and improved anaerobic Kuala Sepetang Landfill Site (KSLS).

2. Significance and Variations of LPI Parameters

2.1. PH. Leachate is generally found to have pH between 4.5 and 9 [15]. The pH of young leachate is less than 6.5 while old landfill leachate has pH higher than 7.5 [16]. Initial low pH is due to high concentration of volatile fatty acids (VFAs) [17]. Stabilized leachate shows fairly constant pH with little variations and it may range between 7.5 and 9. Kulikowska and klimiuk [7] and Tatsi and Zouboulis [18] reported similar range of pH from old landfill sites, that is, 7.46–8.61 and 7.3–8.8, respectively.

2.2. TDS. TDS comprises mainly of inorganic salts and dissolved organics. TDS is one of the parameters taken into consideration for licensing discharge of landfill leachate in many countries such as the U.K. [19]. The amount of TDS reflects the extent of mineralization and a higher TDS concentration can change the physical and chemical characteristics of the receiving water [20]. The increase in salinity due to increase in TDS concentration also increases toxicity by changing the ionic composition of water.

2.3. BOD_5 and COD. In the initial acidogenic biodegradation stage, the leachate is characterized by high BOD_5 and COD [21]. Young landfill leachate is characterized by high BOD_5 (4000–13,000 mg/L) and COD (30,000–60,000 mg/L) [22]. According to Tatsi et al. [23], young leachate may have BOD_5 as high as 81,000 mg/L. A much higher value of COD (70,900 mg/L) is reported in leachate obtained from the Thessaloniki Greater Area (Greece) by Tatsi and Zouboulis [18]. A decrease in BOD_5 and COD is often reported with the increase in age of the landfill. For stabilized leachates, COD generally ranges between 5000–20,000 mg/L [24]. The BOD_5/COD ratio provides a good estimate of the state of the leachate and this ration for young leachate is generally between 0.4-0.5 [25]. During the methanogenic phase, the organic strength of the leachate is reduced by methanogenic bacteria such as *methanogenic archaea* and the concentration of VFAs also declines which results in a ratio of BOD_5/COD less than 0.1 [25, 26].

2.4. Total Nitrogen. Ammonium represents the major proportion of total nitrogen. In comparison to soluble organics, the release of soluble nitrogen from waste into leachate continues over longer period [7]. As a result, the concentration of ammonia nitrogen increases with the increase in age of the landfill which is due to hydrolysis and fermentation of nitrogenous fractions of biodegradable refuse substrates [16]. Ammonia is considered as a major long-term pollutant because of its stability under anaerobic conditions Ammonia concentration differs highly in leachates from different landfills from tens or hundreds of mg N_{NH4}/L to couple of thousands (2000 mg N_{NH4}/L) to several thousands (>10000 mg N_{NH4}/L) [7, 18, 27, 28]. The mean concentration of ammonia in leachate ranges between 500–1500 mg/L after a period of 3–8 years of waste placement and continues to be within this range over 50 years [7]. According to Li and Zhao [24], ammonia nitrogen in stabilized leachate might range between 3000–5000 mg/L. Ammonia nitrogen is ranked as a major toxicant to living organisms, as established by various toxicity analyses using bioassays and various test organisms such as *Salmo gairdnieri* and *Oncorhynchus nerka* [25]. Higher concentrations of ammonia are also known to enhance algal growth, promote eutrophication due to decreased dissolved oxygen [25]. Due to its toxicity it can also disrupt biological leachate treatment operations [29].

2.5. Heavy Metals. In general, the concentration of heavy metals in landfill leachate is fairly low [15]. Concentration of heavy metals in a landfill is generally higher at earlier stages because of higher metal solubility as a result of low pH caused by production of organic acids [7]. As a result of decreased pH at later stages, a decrease in metal solubility occurs resulting in rapid decrease in concentration of heavy metals except lead because lead is known to produce very heavy complex with humic acids [30]. A lower concentration of Cd (0.006 mg/L), Ni (0.13 mg/L), Zn (0.61 mg/L), Cu (0.07 mg/L), Pb (0.07 mg/L), and Cr (0.08 mg/L) were found in 106 Danish landfills by Christensen et al. [15] and Kjeldsen and Christophersen [31]. The high dissolved organic carbon (DOC) concentration in leachate renders the metals nontoxic because only the free metals are known to exhibit toxicity [32, 33]. However, the solubility and mobility of metals may increase in the presence of natural and synthetic complexing ligands such as EDTA and humic substances [21]. Further, colloids have great affinity for heavy metals and a significant but highly variable fraction of heavy metals is associated with colloidal matter [15, 34]. According to Baun and Christensen [35], less than 30%, typically less than 10% of the total metal concentration is present in free metal ion forms and the rest is present in colloidal or organic complexes. Jensen and Christensen [34] found that 10–60% of Ni, 30–100% Cu and 0–95% Zn were constituted in colloidal fractions. The solubility of the metals can also increase because of the reducing condition of the leachate which changes the ionic state of the metals (i.e., Cr (VI) $\rightarrow$ Cr (III), and As (V) $\rightarrow$ As (III) [21, 36–38].

2.6. Phenol. Christensen et al. [15] reports the concentration of phenolic compounds in a landfill between 1–2100 μg/L. Phenolic compounds are readily degradable under aerobic conditions while their degradation under anaerobic conditions is uncertain [15].

2.7. Chlorides. According to Deng and Englehardt [29], the concentration of chlorides may range between 200–3000 mg/L for a 1-2 year- old landfill and the concentration decreases to 100–400 for a landfill greater than 5–10 years old. Bowman et al. [39] found chlorides as high as 8000 mg/L in Newington landfill leachate in Sydney. Because chlorides are usually not attenuated by soil and are extremely mobile under all conditions, they have a special significance as the tracer element of leachate plume linking the groundwater [40].

3. Materials and Methods

Leachate samples were collected from four landfill sites; the Pulau Burung landfills (PBLS), Ampang Jajar Landfill Site (AJLS), Kuala Sepetang Landfill Site (KSLS) and Kulim Landfill Site (KLS).

PBLS is a semiaerobic landfill situated within Byram Forest Reserve at 5°24′ N, 100° 24′ E and encompasses an area of 23.7 ha. This site is contained by a natural marine clay liner [41]. In 1991, it was upgraded to sanitary landfill level II by a controlled tipping technique and was further upgraded to a sanitary landfill level III through leachate recirculation and controlled tipping in 2001 [42].

AJLS is a semiaerobic closed landfill site situated at 5.24′.0′′N and 100.24′.22′′E with a total surface area of 17 acres. Receiving both municipal and industrial wastes, this landfill was started as a dump in the early eighties and it had neither any leachate collection system nor defined space for waste dumping. During operation the landfill received approximately 650 tons of solid waste per day. The landfill possesses no base liner which resulted in heavy pollution of nearby river and groundwater in its early stages.

Kuala Sepetang landfill site is located at 4.49′.20.08′′N and 100.40′.44.08′′E. The landfill receives about 300 tons of solid waste daily and is classified as improved anaerobic landfill. The landfill is around 12 years old. Natural marine clay and local soil are used as cover material for dumped waste. Leachate produced is collected in a collection pond and is not provided any treatment.

The samples were carefully collected from the landfill site and temperature and pH were measured onsite. The samples were then transferred to the laboratory in an ice cooler and stored in a cold room at 4°C. Prior to analysis, the samples were allowed to return to room temperature and measurements for leachate parameters were carried out. The parameters measured for each landfill are given in Tables 1 and 2. pH was measured on site using a portable pH meter (Hach, sens ion 1, USA). All the parameters were measured according to the standard methods for the examination of water and wastewater [43]. After measuring the laboratory parameters, the LPI was calculated according to.

$$\mathrm{LPI} = \frac{\sum_{i=1}^{m} w_i p_i}{\sum_{i=1}^{m} w_i}, \quad (1)$$

where LPI is the weighted additive leachate pollution index, m is the number of leachate pollutant parameters for which data is available, w_i is the weight for ith pollutant variable, p_i is the sub index score of the ith leachate pollutant variable. When all the leachate parameters are unknown, $m < 18$ and

$$\sum_{i=1}^{m} w_i < 1. \quad (2)$$

4. Results and Discussion

Table 1 shows the PBLS and KLS leachate characteristics and LPI obtained for these landfill sites. Since the data for all the parameters required for LPI was not available, the LPI has been calculated on the basis of the available data. The concentration of TDS, COD, TKN, and NH_3-N was higher in PBLS leachate while KLS contained relatively higher value of BOD_5 as seen in Table 1. A significant difference between individual pollution ratings of TKN and NH_3-N for both landfill sites was observed due to the distinct difference in TKN and NH_3-N concentrations. Although the concentration of COD in PBLS leachate was higher than KLS leachate, the difference was insignificant in terms of individual and consequently cumulative pollution ratings. The concentration of heavy metals was fairly similar for both the landfills except for Pb where PBLS almost has twice higher concentration than KLS (Table 1). The two sites also exhibited notable differences for chlorides and total coliforms. However, the difference in the concentrations of chlorides for PBLS and KLS had insignificant influence on individual and cumulative pollution ratings. But, the concentration of total coliforms in KLS leachate was much higher than PBLS which resulted in significantly higher cumulative pollution rating in comparison to PBLS. It is clear from Table 1 that the higher concentrations of TKN, NH_3-N, total coliform and to some extent Pb significantly influenced the cumulative pollution ratings of PBLS. Because the individual pollution ratings of TKN and NH_3-N were lower for the case of KLS, the cumulative pollution rating of KLS was consequently lower in comparison to PBLS.

The characteristics of leachate from AJLS and KSLS and the resulting LPI from these landfill sites are given in Table 2. As can be seen from Table 2, the concentrations of TDS, BOD_5, COD, TKN and NH_3-N represent a significant difference between AJLS and KSLS leachate. The higher concentrations of TDS, COD, TKN and NH_3-N for KSLS leachate imply higher individual and cumulative pollution rating and consequently higher LPI value. Although the concentration of heavy metals showed slight variations, it has no effect on individual pollution ratings (Table 2). The concentration of total coliforms was higher for AJLS but this difference was not as significant as was in the case of PBLS and KLS (Table 1), hence the difference in LPI values of AJLS and KSLS is little influenced by the difference in the concentrations of total coliforms (Table 2). The concentration of chlorides in KSLS leachate was more than five times higher than AJLS, but the cumulative pollution rating for chlorides in KSLS was only 1.4 times higher than AJLS (Table 2).

Figure 1 gives graphical representation of LPI values for each landfill site. The comparison of LPI values for four landfill sites shows that semiaerobic PBLS has the highest LPI value, while the LPI value for closed semiaerobic AJLS

Table 1: Characteristics and LPI of leachate from PBLS and KLS*.

Parameter	Value		Individual pollution rating (p_i)		weights (w_i)		Cumulative pollution rating ($p_i w_i$)	
	PBLS	KLS	PBLS	KLS	PBLS	KLS	PBLS	KLS
pH	8.3	7.8	5	5	0.055	0.055	0.275	0.275
TDS	9693	6900	19	15	0.050	0.050	0.95	0.75
BOD_5	358	515	11	15	0.061	0.061	0.671	0.915
COD	1788	1593	47	42	0.062	0.062	2.914	2.604
TKN	1685	612	60	20	0.053	0.053	3.18	1.06
NH_3-N	1380	503	100	55	0.051	0.051	5.1	2.8
Total iron	3.6	6	5	5	0.045	0.045	0.225	0.225
Cu	0.01	0.2	5	6	0.050	0.050	0.25	0.3
Ni	0.1	0.2	6	6	0.052	0.052	0.312	0.312
Zn	0.3	0.3	6	6	0.056	0.056	0.336	0.336
Pb	3	1.6	27	11	0.063	0.063	1.7	0.693
Cr	0.2	0.1	5	5	0.064	0.064	0.32	0.32
Hg	—	—	—	—	—	—	—	—
As	—	—	—	—	—	—	—	—
Phenol	6	3	10	8	0.057	0.057	0.57	0.456
Chlorides	622	290	7	5	0.048	0.048	0.336	0.24
Cyanide	—	—	—	—	—	—	—	—
Total coliform	50	0.81×10^4	40	90	0.052	0.052	2.08	4.68
Total					**0.819**	**0.819**	**19.21**	**15.97**
LPI							**23.45**	**19.50**

* All values in mg/L except pH and total coliform; total coliform unit (CFU/100 mL).

Table 2: Characteristics and LPI of leachate from AJLS and KSLS*.

Parameter	Value		Individual pollution rating (p_i)		weights (w_i)		Cumulative pollution rating ($p_i w_i$)	
	AJLS	KSLS	AJLS	KSLS	AJLS	KSLS	AJLS	KSLS
pH	7.5	8.1	5	5	0.055	0.055	0.275	0.275
TDS	2543	12568	7	26	0.050	0.050	0.35	1.3
BOD_5	48	85	7	26	0.061	0.061	0.427	0.488
COD	599	990	20	35	0.062	0.062	1.24	2.17
TKN	822	1176	25	39	0.053	0.053	1.235	2.06
NH_3-N	566	996	60	100	0.051	0.051	3.06	5.1
Total iron	3	5	5	5	0.045	0.045	0.225	0.225
Cu	0	0.7	5	5	0.050	0.050	0.25	0.25
Ni	0	0.3	5	5	0.052	0.052	0.26	0.26
Zn	0.01	0.2	5	5	0.056	0.056	0.28	0.28
Pb	0.3	0.4	5	5	0.063	0.063	0.31	0.31
Cr	0	0.05	5	5	0.064	0.064	0.32	0.32
Hg	—	—	—	—	—	—	—	—
As	—	—	—	—	—	—	—	—
Phenol	2	4	7	9	0.057	0.057	0.39	0.51
Chlorides	124	655	5	7	0.048	0.048	0.24	0.336
Cyanide	—	—	—	—	—	—	—	—
Total coliform	0.66×10^4	0.16×10^4	87	76	0.052	0.052	4.52	3.95
Total					**0.819**	**0.819**	**13.47**	**17.83**
LPI							**16.44**	**21.77**

* All values in mg/L except pH and total coliform; total coliform unit (CFU/100 mL).

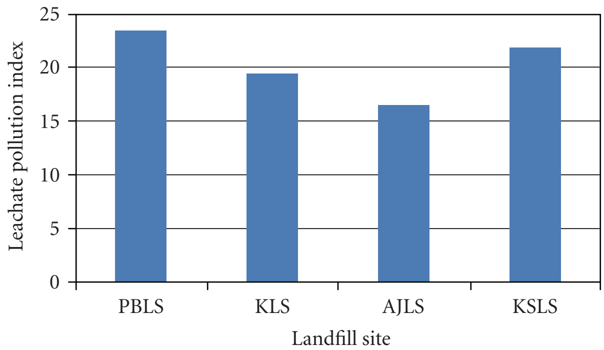

Figure 1: Leachate pollution index for four landfill sites.

is the lowest. The LPI value of anaerobic KSLS is slightly higher than anaerobic KLS but both these anaerobic landfill sites have lower LPI value than semiaerobic PBLS. Kumar and Alappat [12] calculated LPI values for two active landfill sites and reported higher LPI (36.4 and 39) than PBLS (23.45), KLS (19.50) and KSLS (21.77). This can be ascribed to the lower individual pollution ratings of PBLS, KLS and KSLS due to the relatively lower concentrations of BOD_5, COD, TKN, NH_3-N and to some extent the chlorides than the landfill sites studied by Kumar and Alappat [12]. The lower LPI value for AJLS suggests that the landfill leachate is stabilized which is also indicated by the BOD_5 and COD values given in Table 2. The lower LPI value for a closed landfill site has also been reported by Kumar and Alappat [12]. The authors reported LPI value of 15.97 for Nagu Chi Wan (NCW) landfill site which is almost similar to the LPI value reported for AJLS (16.44) in this study. The similarity of LPI value for these two sites is worth mentioning because the NCW landfill site studied by Kumar and Alappat [12] and AJLS in this study were of similar age. The fact that PBLS is currently operational and is receiving domestic and industrial wastes, higher LPI value shows that the leachate produced from PBLS should be attended first if the local management has to choose among the four landfill sites for leachate management and treatment. Because the characteristics of landfill leachate changes over time, the LPI value will also differ from one sampling period to another, hence the LPI value would correspond to the leachate samples analysed at a particular time for a specific landfill site.

5. Conclusion

Leachate characteristics demonstrate high variations and which range of physical, chemical, and biological parameters may vary over several order magnitude. LPI is a good tool to compare pollution potential of landfill sites. Among the four sites, semiaerobic PBLS has the highest LPI value while semiaerobic AJLS has the lowest LPI. It is interesting to note that the semiaerobic PBLS is better comparable with KSLS anaerobic landfill in terms of LPI value. In the similar manner semiaerobic AJLS is comparable to anaerobic KLS based on the value obtained for LPI. Although LPI of the four studied landfill sites is not very high, the leachate shall be treated prior to discharge for individual pollution parameters such as BOD_5, COD, and ammonia to meet individual standards. The landfill sites requiring immediate attention can also be prioritized based on the value of LPI to avoid big pollution incident. Because changes in individual quality parameters alter the value of LPI, it can be used as a reliable tool to report seasonal and site specific variations in quality of landfill leachate.

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