Comparison of landfill leachate generation and pollution potentials in humid and semi-arid climates

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Abstract: Climate conditions e.g., rainfall water are highly affecting landfill leachate generation and characteristics. This article aims to assess leachate generation and pollution potentials from landfills in different climate conditions, e.g., humid and semi-arid regions. Leachate volumes have been estimated by hydrologic evaluation of landfill performance (HELP) model, and the main water quality parameters and heavy metals were in-situ and laboratory analysed. Results of annual leachate generation rates per one ton of waste in humid and semi-arid landfill were 0.148 and 0.079 m^3 respectively. However, leachate pollutants from humid landfill showed lower concentrations comparing with semi-arid landfill. This was reflected in LPI results of 25.1 and 29.5 for both landfills, respectively. These results concluded that semi-arid leachate gave lower generation rates and higher pollution potential than humid leachate, which can be revealed to the dilution effect of high rainfall levels in humid climates.

Keywords: landfill leachate; humid and semi-arid climates; HELP mode; leachate pollution index; LPI.

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1 Introduction

In many developing countries, landfilling is considered the dominant method for the final disposal of almost all wastes types due to its economic advantages comparing with other disposal options such as incineration (Tan et al., 2015). During wastes degradation process; various physical, chemical and biological reactions occur and resulting in highly polluted leachate and landfill gases (LFG) (Vaverková and Adamcová, 2015).

Landfill leachate is considered the most threaten by-product from landfills due to containing various inorganic and organic compounds as well as heavy metals (Vithanage et al., 2017). Therefore, it's management is one of the important issues to be considered in landfills designing and operating activities. Leachate is generated from waste moisture content and rainfall percolation to waste piles. Leachate amounts and characteristics are varying and depend on various factors e.g., wastes composition and moisture content, dumping method, landfill age and meteorological conditions (Zhang et al., 2013).

Evaluation of landfill leachate quantities and characteristics is a necessity for its treatment and management purposes, as well as to assess environmental adverse effects. As much as the factors which influencing leachate production process varying in time and space, as much as the evaluation process becomes more difficult and complex (Grugnaletti et al., 2016). Several approaches have been developed to mathematically quantify landfill leachate volumes in the last decades. These methods are varying in estimation complicity and prediction accuracy. The most used tool by engineers and designers is the hydrologic evaluation of landfill performance (HELP) model, which has been applied in different case studies recently (e.g., Berger, 2015; Malakahmad et al., 2017). While, in many developing countries, where reliable data is not extensively available, leachate estimation is usually done by the simple water balance method (WBM), such as in (Aziz et al., 2012; Nilam et al., 2016) in Malaysia.

Comparing with arid regions, high precipitation levels in humid climates lead to increase the generated leachate amounts, and affect its composition; for instance, the total organic carbon (TOC) and conductivity decrease with the increase of rainfall amounts (Chen, 1996; Petrovic et al., 2017). In addition, the high moisture content of the dumped wasteespecially in the developing countries, leads to high water storage in waste bodies, which enhance the accumulation of acids. And as a result, the carbon-based substances in such acidic landfill tend to be decomposed and converted to leachate rather than being released as gases (Yang et al., 2015).

To assess leachate pollution ability, the leachate pollution index (LPI) suggested by Kumar and Alappat (2005). LPI was used due to the fact that the results of the experimental analysis of leachate water are usually described by different physical, chemical and biological water quality parameters. These parameters are occurring at various ranges and units, and accordingly they are giving various individual pollution ratings in terms environmental impacts. Therefore, by addressing two landfills with different climate conditions, this study aims to quantify and compare leachate generation amounts in humid and semi-arid region. Moreover, to assess the main physio-chemical parameters and overall pollution of leachate water.

2 Study areas

Two landfills in both Malaysia and Palestine with different climates were addressed in this study. A sanitary landfill in humid Selangor State (SS) in Malaysia and another landfill in semi-arid Gaza Strip (GS) in Palestine. The selection process was based on the data availability and samplings accessibility to conduct this study. SS alone produce 3,923 tons of comingled MSW on a daily basis, which considered the largest portion among others states in Malaysia (Saheri et al., 2012).

The waste area of SS landfill is about 150 acres (60 hectares); which was divided into six phases for ten-years lifespan began from 2007 till 2016 (Abushammala et al., 2014). The first four phases were from 2007 to 2014 (two years for each phase), while the last two phases were in the years 2015 and 2016. This was due to the increase of the received waste quantities in the last two years. In addition, forty cells as overall were felled by comingled MSW during the period 2007–2016. The area of each phase was divided into eight cells for each phase, except the last two phases since they consisted of only four cells. The landfill's lining system is consisting of four layers, namely (from the bottom) high-density polyethylene (HDPE), drainage layer, waste layer and clay cover layer.

On the other hand, GS landfill is located on the eastern borders of the middle governorate in GS. It has an area of 60,000 m^2, with dimensions of about 400 × 150 metres in length and width, respectively. The dumping of comingled MSW in the landfill started in 1997, and with leachate collection and lining systems. The average commingled wastes disposed in GS landfill for the period from 1997 to 2014 were about 101,969 ton/year (MDLF, 2012). The lining system in GS landfill is consisting of five layers, namely (from the bottom) base coarse layer, asphalt layer, aggregate layer, compacted solid waste layer and sandy soil cover layer.

In this study, daily climate data was collected from the nearest meteorological stations to both landfills. Subang and Khan Younies station for SS landfill and GS landfill, respectively. These datasets were collected from the Malaysian Meteorological Department (MMD) and Palestinian Meteorological Office (PMO).

3 Materials and methods

3.1 Leachate quantification

HELP model was developed to conduct water balance analysis of landfills by the United States Environmental Protection Agency (US EPA) (Schroeder and Ammon, 1994). HELP model applies different empirical and numerical equations in evaluating leachate amounts. For instance, runoff estimation is performed by soil conservation service (SCS) curve number (CN) method, while evapotranspiration is computed by the modified Penman method. In addition, the vertical drainage is estimated by Darcy's law, and the saturated lateral drainage is modelled based on an analytical approximation of Boussinesq equation on steady-state solution.

These processes and others are applied in a sequential order on a daily basis starting with a surface water balance at the landfills surface and followed by the estimation of evapotranspiration from the top soil profile to leachate water drainage through the landfill layers (Schroeder and Ammon, 1994). The application of HELP model to estimate landfill leachate quantities has been well established in different recent studies such as (Abunama et al., 2017; Berger, 2015; Grugnaletti et al., 2016).

In HELP model, leachate estimation was performed as a function of daily meteorological data for each landfill. Climate data included precipitation, evapotranspiration, solar radiation, temperature, and seasonal relative humidity as listed in the previous sections. Besides that, the landfills design and operation parameters such as the layers' characteristics, the recycling ratio, and the runoff CN were utilised in the leachate simulation, as illustrated in Table 1.

Table 1 Summary of data inputs and layers types in HELP model for both landfill

Data category	*Parameter*	*Unit*
Climate data	Daily precipitation	mm
	Daily solar radiation	MJ/m^2
	Daily temperature	°C
	Average wind speed	km/hr
	Seasonal relative humidity	%
	Maximum leaf area index	-
	Evaporation zone depth	cm
Landfill design data	Area	Acres
	Runoff CN	-
	Percent of landfill where runoff is possible	%
Solid waste parameters	Dumped waste Layer thickness	m
	Total porosity	vol./vol.
	Field capacity	vol./vol.
	Wilting point	vol./vol.
	Moisture content	vol./vol.
	Hydraulic conductivity	cm/sec

Layer types	*Lining configuration*	
	SS landfill	*GS landfill*
Clay cover	1	1
Waste	2	2
Drainage layer	3	3
Asphalt	-	4
Base course	-	5
HDPE layer	4	-

3.2 Leachate characteristics

The main characteristics of raw leachate samples from both landfills were in-situ and laboratory analysed. Six samplings were collected from SS landfill, while one sample was analysed in GS landfill. In-situ tests were included pH, temperature and dissolved oxygen (DO), and the analytical instruments used in the analysis were calibrated based on the manufacturer's instructions. In-situ tests were included temperature, DO, pH, electric conductivity (EC), and salinity. These instruments were calibrated based on the manufacturers' instructions.

Leachate samples were collected and preserved in specific plastic bottles, and stored in a cold room during conducting the laboratory tests. Lab. tests contained Biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), phosphate (PO_4), nitrate (NO_3), ammoniacal nitrogen (NH_3-N) and total coliform (TC), etc. While, the measured heavy metals were iron (Fe), Copper (Cu), aluminium (Al), silver (Ag), potassium (K), calcium (Ca), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), lead (Pb), magnesium (Mg), manganese (Mn), and arsenic (As). These metals were analysed using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-OES).

3.3 Leachate pollution potentials

LPI is a useful technique for estimating landfills leachate contamination capacity, and it provides a numerical and comparative measure to judge landfill leachate contamination threats. This method was applied in different recent studies such as (Muralidhar Yadav et al., 2014; Rafizul et al., 2012). For instance, Umar et al. (2010) applied the LPI approach to compare leachate pollution ability from four different landfills in Malaysia after collecting a single leachate sample.

LPI can be estimated using the following equation, which was proposed by Kumar and Alappat (2005):

$$LPI = \sum_{i=1}^{n} Wi * Pi \tag{1}$$

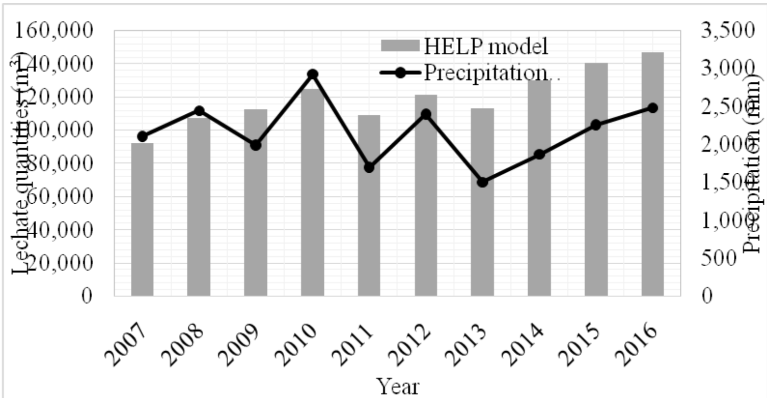
where LPI is the weighted additive LPI, Wi is the weight of the i^{th} pollutant variable $\left(\sum_{i=1}^{n} Wi = 1\right)$ [Table 3 in Kumar and Alappat (2005)], Pi is the sub-index score of the i^{th} leachate pollutant variable [Figure 1 in Kumar and Alappat (2005)], n is number of leachate pollutant variables included in LPI estimation.

In case some of the leachate pollutant variables which used to calculate LPI are not measured, therefore the LPI can be evaluated by using the other available leachate pollutants concentrations. Hence, LPI can be estimated using equation (2):

$$LPI = \frac{\sum_{i=1}^{m} Wi * Pi}{\sum_{i=1}^{m} Wi} \tag{2}$$

where m is the number of the available leachate pollutant parameters. Hence, $m < 18$ and $\sum_{i=1}^{m} Wi < 1.$ In this study, ten available parameters were used to calculate the LPI in both NEM and SWM seasons. These parameters were pH, BOD_5, COD, AN, Fe, Cu, Ni, Zn, Pb, and Cr.

Figure 1 Annual leachate amounts vs. annual precipitation rates in SS landfill

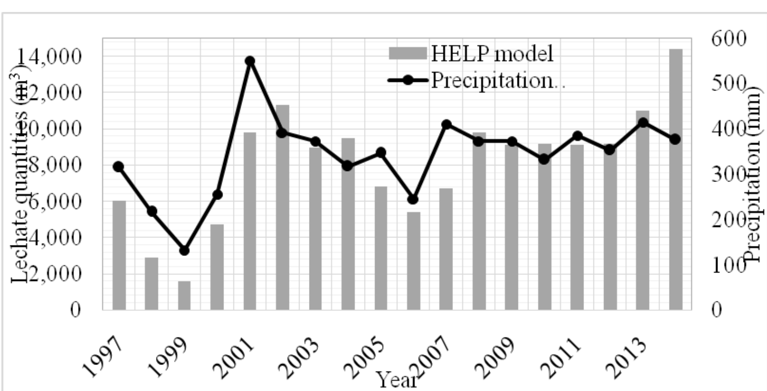


4 Results and discussion

4.1 Generated leachate amounts

The hydrological performance of the landfill in SS was simulated by HELP model for ten years (from 2007 to 2016). Figure 1 presents the annual precipitation volumes versus the annually generated leachate as estimated by HELP model. As shown in the figure, leachate generation rates are proportionally varying with the rainfall amounts in most of the modelling years.

Figure 2 Annual leachate generation vs. annual precipitation rates in GS landfill



The average infiltrated water from rainfall to the wastes through the study simulation period was 27,824 m^3 per year, which is about 21.3% of the average precipitation (130,730m^3). Also, the evapotranspiration and runoff lost were accounted for 73,525 m^3 and 29,080 m^3 with percent of 56.2% and 22.2% as averages, respectively. The main outsource of rainfall water balance is through evapotranspiration, which counted about 56% of rainfall waster. These results are matching with other studies such as Agamuthu et al. (2011), who identified evapotranspiration as the main loss of rainfall.

In the second case study which is GS landfill in, leachate quantities were estimated using HELP model for a period of 18 yrs. (1997–2014). Figure 2 presents the annual rainfall rates versus the annually generated leachate, and leachate amount is proportionally linked to the precipitation level.

The average annually generated leachate amounts suing HELP model were 8,087 m^3. Also, the average surface runoff portion was about 6.8% of the total precipitation, and it counted of 1,396 $m^3.year^{-1}$. However, evapotranspiration was the highest fraction of the landfill water budget, since the landfill area is located in a semi-arid region. Evapotranspirationamounts reached to approximately 11,042 m^3 per year (53.8% of precipitation) through the study period (1997–2014). A close ratio was estimated by Alslaibi et al. (2013), where the modelled evapotranspiration volumes were about 57.87% of rainfall in the period (1997–2007).

4.2 Leachate generation ability

In order to compare the leachate generation ability between the two regions, the annual leachate generation rate per one ton of wastes for each case study were estimated. As shown in Table 2, landfills in semi-arid climate areas showed less leachate generation potential comparing with SS landfill in the humid area. For instance, leachate generation rates per one ton in GS and SS landfill were 0.079 and 0.148, respectively. This can be referred to the high rainfall rates in humid climates, as well as due to the high initial moisture content of the dumped wastes in SS. Other recent studies such as Yang et al. (2015) also indicated to the regional variation of leachate amounts due to climate conditions as well as waste moisture content.

Table 2 Leachate generation potential in both regions based on HELP model results

Parameter	*Unit*	*GS landfill*	*SS landfill*
Annual rainfall rate	mm/yr.	342.1	2,155
Average leachate generation	m^3/yr.	8,087	119,437
Average dumped waste	ton	101,969	805,352
Leachate generation rate per ton	m^3/yr. ton	0.0793	0.1483

According to the current study, the leachate generation rates per one MSW ton in SS landfill using HELP model was around 148.3 $L.ton^{-1}$, and the measured results showed that around 141.2 L of leachate were generated per each wastes ton. Whereas, Agamuthu and Long (2007) reported that the leachate generation rate from the Malaysian's MSW landfills is around 150 $L.ton^{-1}$. Whereas, around 79.3 L of leachate are annually produced in GS landfill from each wastes ton as average, which very close to previous results reported by Alslaibi et al. (2013) about 75.6 $L.ton^{-1}$.

4.3 Leachate characteristics

The main water quality characteristics and heavy metals of the generated leachate from the selected landfills in the two regions were determined. Raw leachate water from both landfills were in-situ tested, collected and laboratory analysed. The main statistics of the physiochemical characteristics and heavy metals (range and mean) are presented also in Table 3.

pH values of GS landfill was 8.1, while in SS landfill the pH ranged between 8.08–8.5 and with average 8.3. pH results in both landfill refer to the age of maturity, where stabilised leachate usually shows fairly constant pH with little variations in the range between 7.5 and 9 (Kulikowska and Klimiuk, 2008). However, EC in the arid landfill (GS landfill) were 57.2mS/cm. The high values for EC are attributable to high levels of anions and cations. However, for SS landfill in the humid climates, EC level was lower and it scores 29.67 in Jumaah et al. (2016) and 12.4 mS/cm according to Razali et al. (2016).

In addition, high biological oxygen demand (BOD_5) and chemical oxygen demand (COD) levels are due to the decomposition of organic wastes, and an indication of high organic content and severe contamination. In this study, both BOD_5 and COD levels were higher in arid landfills. Hence, BOD_5 and COD results of GS landfill were 25,110 and 47,250 mg/l respectively. While, in SS landfill, BOD_5 and COD results were 2,381 and 40,165 mg/l– as mean, respectively. It is worth to note that, the COD result was with agreements with other studies (i.e., Razali et al., 2016), however the BOD_5 were very higher in the same mentioned study.

The high chloride concentration (11,560 mg/l) in leachate samples for GS landfill is indicate the presence of soluble salts in the municipal solid waste materials of the study area due to the mixing of domestic waste (Naveen et al., 2017), since the fact that the major fractions of dumped wastes are domestic and kitchen wastes which are possible sources of high chloride levels (Kale et al., 2010). The possible anthropogenic sources of chloride are kitchen wastes from households, restaurants, and hotels.

In addition, raw leachate samples from GS landfill showed higher ranges of ammoniacal nitrogen (AN), which is considered an indication of leachate pollution potential. The high AN in the leachate samples can be revealed to the hydrolysis and fermentation process of the nitrogenous fractions of the organic biodegradable substrates (Elsamadony and Tawfik, 2015), as well as to the domination of amino acids throughout the organic compounds destruction process (Emenike et al., 2011; Yusoffa et al., 2013). Both, phosphorous (PO_4) and nitrate (NO3) in SS landfill were scored 277 and 618 mg/l as average, respectively, but both values were not estimated in GS landfill. PO_4 is one of the main elements necessary for growth of plants, which can promote eutrophication in surface water bodies. While, NO_3 are considered the primary contaminant that leaches into groundwater. However, total coliform (TC) tests were only done in SS landfill, and the results were between 10,200–12,600 CFU/100 ml, with average of 11,567 CFU/100 ml. TC is considered as an indication of biological water pollution, which are influenced by human or animal waste.

Heavy metals were examined using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-OES). The analysed heavy metals are Fe, Cu, Al, Ag, K, Ca, Cd, Cr, Ni, Zn, Pb, Mg, Mn and As (Table 3) in SS landfill, while some of these elements were measured in GS landfill. It’s worth to note that, heavy metals results of SS raw leachate were in agreement with recently conducted measurements by other studies (Jumaah et al., 2016; Razali et al., 2016).

Table 3 Physiochemical characteristics and heavy metals of raw leachate samples from both landfills

Category	*Parameter*	*Unit*	*GS landfill*	*Alslaibi et al. (2013)*	*SS landfill*		*Jumaah et al. (2016)*
					Range	*Mean*	
In-situ tests	Temp	°C	-	-	30.6–39.5	35.2	-
	pH	-	8.1	8.3	8.08–8.5	8.3	8.7
	DO	mg/l	-	-	0.3–0.9	0.5	-
	DO%	%	-	-	5–14	7.5	-
	EC	mS/cm	57.2	32.2	-	-	29.67
Lab. tests	TSS	mg/l	-	-	350–2,180	1,205	5,348
	BOD_5		5,110	4,000	2,013–2,908	2,381	14,790
	COD		47,250	25,280	30,720–51,840	40,165	49,000
	BOD_5/COD ratio	-	0.108	0.158	-	0.059	0.301
	AN	mg/l	-	3,473	123–1,354	712	3,800
	PO_4		-	-	184–342	277	-
	NO_3		-	440	140–1,040	618	-
	Cl		11,560	9,440	-	-	2,700
	TC	CFU/100 ml	-	-	10,200–12,600	11,567	-
Heavy metals	Fe	mg/l	1.3	-	7.06–14.45	10.6	-
	Cu		0.84	0.01	0.027–0.062	0.042	0.03
	Al		2	-	1.78–3.69	2.657	-
	Ag		-	-	0–0.005	0.002	-
	K		-	-	101–2,112	1,254	-
	Ca		-	-	60.4–117.6	94.8	-
	Cd		0.08	0.01	0–0.018	0.01	0.01
	Cr		0.04	-	0.38–0.787	0.584	-
	Ni		0.44	-	0.162–0.294	0.221	-
	Zn		13	0.01	0.445–0.835	0.648	0.49
	Pb		0.52	0.004	0.012–0.022	0.016	0.02
	Mg		-	-	38.2–95.3	69.9	-
	Mn		0.16	-	0.268–0.448	0.355	-
	As		-	-	0–0.556	0.33	-

The high concentrations of potassium (K), calcium (Ca) and magnesium (Mg) were due to the presence of putrescible wastes (kitchen and food wastes) which accounted the highest portion of the waste received in Malaysia's landfills. Besides that, the Malaysian landfills leachates generally contain high quantities of these substances (Fauziah and Agamuthu, 2007).

While, the high concentrations of Cd, Pb, Ni, and Zn in both landfills suggest that the wastes are mainly from municipal origin containing refused batteries, photography, paint products, metallic items, and fluorescents light lamps. In addition, concentrations of Cr reveal the presence of wood preservatives and paint products in the waste, whereas high

Mn concentrations suggest a strong reducing environment (which is an atmospheric condition in which oxidation is prevented by removal of oxygen and other oxidising gases or vapours) (Kale et al., 2010).

Furthermore, the results in Table 3 showed high concentrations of Fe which were an indication of dumping metal scrap and steel wastes (Yusoffa et al., 2013). The oxidation of ferrous to ferric, and ferric hydroxide colloids formation causes the reddish brown colour of leachate (Kanmani and Gandhimathi, 2013). Similarly, Al concentrations were high and indicated for the dumping of electronic and aluminium wastes (Kale et al., 2010).

Fe and Al levels were relatively lower in GS landfill, due the fact that part of the metal scraps is separated and sold by collectors and waste pickers (Caniato and Vaccari, 2014). Finally, the trace elements concentrations such as Ni, Pb, Zn, etc. in both case studies confirm that the majority of wastes were originated from MSW containing batteries, photography, paints and fluorescent light bulbs (Moody and Townsend, 2017).

4.4 Leachate pollution ability

In order to estimate the landfills leachate pollution ability in both regions, ten chemical parameters were used to calculate the LPI as presented in Table 4. These parameters were pH, BOD_5, COD, chloride, iron, copper, nickel, zinc, lead, and chromium.

Table 4 LPI estimation in both landfills

No	*Parameter*	*Value*		*Individual pollution rating*[(a)] *pi*		*Weights* [(b)]*wi*	*Overall pollution rating (pi*wi)*	
		GS landfill	*SS landfill*	*GS landfill*	*SS landfill*		*GS landfill*	*SS landfill*
1	pH	8.1	8.2	2.5	3.5	0.055	0.14	0.19
2	BOD_5	5,110	2,381	55	40	0.061	3.36	2.44
3	COD	47,250	40,165	95	90	0.062	5.89	5.58
4	AN	3,473	712	100	80	0.051	5.10	4.08
5	Iron	1.3	12.0	5	5.5	0.045	0.23	0.25
6	Copper	0.84	0.04	6	5	0.05	0.30	0.25
7	Nickel	0.44	0.23	5.5	5	0.052	0.29	0.26
8	Zinc	13.0	0.68	8	5	0.056	0.45	0.28
9	Lead	0.52	0.02	7	5	0.063	0.44	0.32
10	Chromium	0.04	0.73	5	6	0.064	0.32	0.38
Total						0.559	16.50	14.03
LPI value						29.52	25.10	

Note: [(a)]Figure 1 and [(b)]Table 3 in Kumar and Alappat (2005).

Hence, it was observed that the differences in both BOD_5 and AN concentrations were significantly influenced the individual (pi), and consequently the cumulative/overall pollution ratings between the two regions. In addition, the concentration of COD in GS landfill was higher than that in SS landfill, thus the individual pollution rating differences (pi*wi) were also higher.

However, the slight differences of heavy metals (Fe, Cu, Ni, Zn, and Pb) showed low variances in both individual and total pollution ratings. While the concentrations of Cr and As showed higher differences comparing with the other heavy metals in terms of pollution ratings.

Finally, the overall/cumulative LPI results showed lower LPI value in SS landfill (25.1) than that in GS landfill(29.5). The calculated LPI values at both sites (Table 4) are comparable with other landfills and can be utilised in further studies (Kumar and Alappat, 2005). In the comparison of LPI values between the study's sites, they reveal that the leachate pollution potential measured by LPI values for the landfills in the semi-arid environment was higher than that in the humid region. This may refer to the dilution effect caused by the rainfall rates in humid areas. Other studies (e.g., Chen, 1996) reported that the leachate characteristics, such as TOC and conductivity decrease with the increase of rainfall amounts. In addition, this study results agree with Salleh and Hamid (2013) study's results where the high rainfall levels in humid climates i.e., Malaysia have a significant effect to COD, TOC, NH4-N, and heavy metals where their concentration is reduced due to rainfall water.

5 Conclusions

In this study, two different case studies – SS landfill in a humid area and GS landfill in a semi-arid area – were addressed to assess landfills leachate generation and pollution ability. The produced leachate was varied between the two regions, for instance, the annual leachate generation rates per one ton in GS landfill and SS landfill were 0.079 and 0.148 m^3 respectively. This revealed that the landfills in semi-arid climate areas show less leachate generation potential comparing with humid areas.

These variances can be referred to the high rainfall rates in humid climates comparing with arid areas. However, both landfills received high initial moisture content since they are located in developing counties and the majority of the dumped wastes were organic constitutes. In addition, the study showed that in both regions, the main outsource of the rainfalls water balance was through evapotranspiration. These results are matching with other studies such as (Agamuthu et al., 2011; Alslaibi et al., 2013) who identified the evapotranspiration as the main loss of rainfall water due to the meteorological conditions in both landfills.

Based on the raw leachate samplings and laboratory tests, the pollutants concentrations in the produced leachate in semi-arid climates were higher than that in humid regions leachate. For example, both BOD_5 and COD levels were higher in the semi-arid landfill – BOD_5 and COD results of GS landfill were 5,110 and 47,250 mg/l respectively. In contrast, the average BOD_5 and COD results in the humid landfill were 2,381 and 40,165 mg/l, respectively.

In consequence, the results of the overall LPI showed lower value in SS landfill (18.7) than that in GS landfill (27.9), thus the leachate pollution potentials for 'semi-arid' landfills were higher than that in the humid region. This also can be referred to the dilution effect caused by the high rainfall levels in humid areas. While, the rating analysis of each pollutant of the leachate water quality parameters revealed that BOD_5, AN, and COD were the key factors which caused the major differences.

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