Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.25468

189 (2020) 152–164
June

Characterization of stabilized leachate and evaluation of LPI from sanitary landfill in Penang, Malaysia

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Received 12 July 2019; Accepted 18 January 2020

ABSTRACT

The high demand in developing countries has generated a large amount of municipal solid waste (MSW), which has increased the number of sanitary landfills and dumping sites. MSW has been the key to producing raw landfill leachate (LFL). A high amount of organic and inorganic compounds that exist in LFL cause several contaminations to the surface and groundwater. This study aims to analyze and compare the outcomes of leachate characterizations from the Pulau Burung sanitary landfill (PBSL). Twenty-five parameters of LFL were investigated in this study. The average range of the parameters was temperature 31.5°C, pH 8.12, chemical oxygen demand (COD) 1,566 mg/L, biochemical oxygen demand (BOD_5) 179 mg/L, BOD_5/COD 0.08, Ammoniacal nitrogen 207.5 mg/L, Turbidity 446.5 NTU, Color 1,633 Pt-Co, Total dissolved solids 5445 mg/L, and Conductivity 10.12 μS/m. Moreover, heavy metals concentration were (As, Ca, Cd, Co, Cr, Cu, Fe, Li, Mg, Mn, Mo, Ni, Se, Sr, Ti, and Zn) (0.039, 770, 0,024, 010, 0.51, 0.23, 8.6, 0.53, 644, 0.77, 0.05, 0.664, 0.055, 3,04, 0.256 and 1.039 mg/L respectively. The results obtained from this study were compared to Malaysia Environmental Quality Act 1974 and data from previous researches on sanitary landfills within West Malaysia. Additionally, the leachate pollution index (LPI) was conducted and evaluated based on certain contaminations in PBSL. The LPI value was 10.63, and this exceeded the LPI for the discharge standard of 5.710. Based on the leachate characterization and LPI values, the raw leachate was found containing a high concentration of pollutants and requires immediate treatment before being discharged to water sources.

Keywords: Landfill leachate (LFL); Leachate pollution index (LPI); Municipal solid waste (MSW)

1. Introduction

Most of the municipal wastes generated in developing countries (such as Malaysia) are transported to landfills. This habit of open dumping of solid wastes often brings about environmental pollution which is dangerous to health. The movement of surface water across these solid wastes results in environmental contamination with chemical, organic, and inorganic compounds [1,2]. Malaysia operates about 296 landfills out of which about 166 are still

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in use. Notably, only 11 out of the 166 operational landfills in Malaysia are sanitary and capable of preventing environmental contamination from landfill leachate (LFL) and gas. Table 1 presents a list of sanitary landfills in West Malaysia [3,4].

In many countries, sanitary landfilling is the commonest solid waste disposal method. In 2006, waste disposal in sanitary landfills reached 30.9% in Malaysia; however, this is estimated to reach about 45% by 2020, and this is considered the highest percentage compared to other methods of waste disposal [5]. Landfills are considered the most economical and eco-friendly method of solid waste management compared to the other waste disposal methods like incineration, gasification, and composting. Therefore, sanitary landfills can be classified into three types: anaerobic, aerobic and semi-aerobic Table 2 presents types of landfill decomposition processes. Meanwhile, the major problem associated with landfills is the leachate they produce [6,7].

LFL is a mixture of toxic and both organic and inorganic contaminants. Leachate production mainly depends on certain factors, such as the composition of solid wastes, particle size, hydrology of the site, the degree of compaction, temperature and moisture conditions, oxygen availability, as well as the age of the landfill. If left unmonitored, leachate can cause serious surface and groundwater pollution [11]. Landfills of less than five years old produce leachate which is characterized by high chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) concentrations. They also contain a high level of NH_3–N, high BOD_5/COD ratio, and pH value of <6.5. They are characterized by a bad odor and strong color. On the other hand, landfills of more than 10 y old usually produce leachates rich in NH_3–N and heavy metals concentration; such leachates are also moderately high in COD content but lower in BOD_5/COD ratio (usually <0.1). Young leachate can be effectively treated using biological treatment methods, but such methods are not effective for leachate from older landfills due to their complexity [12].

Characterization of LFL provides a focused review and guideline for the appropriate treatment procedure. This research mainly aims at studying the major characteristics of LFL in Nibong Tebal, Pulau Pinang using Pulau Burung sanitary landfill (PBSL) as a case study. The assessment of the environmental risks of this landfill was done through benchmarking with the Environmental Quality (control of pollution from the solid waste transfer station and landfill) regulations 2009 under the laws of the Malaysia Environmental Quality Act (MEQA) 1974. This study strives to provide the basic information on the characteristics of leachate from landfills, as well as to evaluate the level of pollutants by using leachate pollution index (LPI). Another aim of this study is to compare the results of different studies from different sanitary landfills in West Malaysia.

2. Decomposition process in landfills

Landfill sites receive different kinds of municipal solid waste (MSW) daily and the process of decomposition is highly distinct from one site to another. This method is very complicated and depends on several factors such as the structure of solid waste, climate change, landfill operation, age of landfill, moisture content, and pH [16]. These changes play an important role in the design, operation, and leachate treatment method [17].

Table 1
List of sanitary landfills in West Malaysia

Name of sanitary landfills	Location	In operation
Air Hitam sanitary landfill	Selangor	closed
Kulim sanitary landfill	Kedah	1996
Matang sanitary landfill	Perak	1997
Pulau Burung sanitary landfill	Penang	2001
Pulai sanitary landfill	Kedah	2001
Alor Pongsu landfill site (APLS)	Perak	2000
Seelong sanitary landfill	Johor	2004
Tanjung Langsat sanitary landfill (TLSL)	Johor	2005
Bukit Tagar sanitary landfill	Selangor	2006
Jeram sanitary landfill	Selangor	2008
Tanjung 12 sanitary landfill (TDSL)	Selangor	2010
Bukit Payong sanitary landfill	Johor	Proposed
Pagoh sanitary landfill	Johor	Proposed
Pekan Nenas sanitary landfill	Johor	Proposed
Sg Udang sanitary landfill	Melaka	Proposed
Belengu sanitary landfill	Pahang	Proposed
Teluk Mengkudu sanitary landfill	Perak	Proposed
Rimba Mas sanitary landfill	Perlis	Proposed
Kg Tertak Batu sanitary landfill	Terengganu	Proposed

Source: [8, 9, 10].

Table 2
Types of landfill decomposition process

Type	Mechanism	°C	pH	Timescale	Emissions	Ref.
Anaerobic	Five stages: aerobic, fermentation, acetogenesis, methanogenesis, oxidation	30°C–65°C	Methanogenesis (7–8) ideally (6.8–7.5)	decades to millennia	CO_2, CH_4, H_2O, trace pollutants	[13]
Aerobic	Aerobic conditions achieved by forcing air into waste mass.	54°C–66°C	7.5–8.5 Less acids are produced	2–5 y	CO_2, H_2O, trace pollutants	[14]
Semi-aerobic	Passive drawing of air into waste mass due to temperature Gradient.	40°C–50°C	above >8	above >30	CO_2, H_2O, trace pollutants	[15]

Complex biological and chemical reactions happen when the decomposition process starts at the landfill site [18]. Consequently, five stages can occur: initial adjustment phase (Phase I), transition phase (Phase II), acidogenic phase (Phase III), methane fermentation phase (Phase IV), and finally maturation phase (Phase V). Decomposition rates in each phase are dependent on physical, chemical, and microbiology factors at the landfill site [19].

2.1. Initial adjustment phase

The air that is confined inside a landfill creates a microbial decomposition of biodegradable organic matter, which usually happens at an aerobic state of the first adjustment point. The production of leachate at this point is slight [21].

2.2. Transition phase

Organic biodegradable matters go through a process of microbial decomposition. At the initial point, a complex solution is produced by the leachate created under aerobic states, with a pH level almost similar to that of neutral. As soon as the discarded waste is closed off in the landfill, it is cut off from any oxygen supply, which makes the microbial decomposition phase continue to occur until the oxygen within is depleted [22].

With the heat produced through aerobic degradation, the heat level of leachate can go up to approximately 80°C–90°C, and in the case of maintained heat, this temperature can magnify the leachate production at a later phase. The leachate processing at this point occurs when the covered waste causes moisture to be discharged while being compacted and short-circuited of rainfall [22].

2.3. Acidogenic phase

The anaerobic phase occurs when the oxygen in the covered landfill is depleted. At the initial stage of this phase (acidogenic phase), a significant level of concentrations of soluble degradable organic matters and a slight to strong acidic pH level are produced. The presence of CO_2 causes acidic pH to be stronger [23].

The production of organic acids and acidic leachate causes the pH reduction of the leachate to five or below, and this decrease in pH level results in the removal of important nutrients in the leachate as well as the disintegration of heavy metals. On the other hand, this stage sees an increase in ammonium and metal concentrations, while complex molecules are reduced. The completion of the whole process occurs within approximately four months, while it takes between 1 and 2 y for the stabilization of landfill gas generation level [23].

2.4. Methane fermentation phase

Leachate reaches a neutral or slightly alkaline state in methanogenic conditions, which usually occurs within the span of a few months or even years. Methane and CO_2 are generated by methanogens, and gas present in landfills comprises of between 55% and 60% of methane, and between 40% and 45% of CO_2 (with hints of other gases) when the methanogenic state is stabilized [24].

Mesophilic bacteria, which thrive in temperatures of around 30°C–35°C, and thermophilic bacteria, which grows in temperatures of around 45°C–65°C, are two kinds of bacteria that consume CO_2 and acetate. Albeit the slow and time-consuming reaction process, a benefit is an established leachate pH level between 7 and 8. This reduces the heavy metals in leachate [25].

2.5. Maturation phase

Once the biodegradable refuse has been turned to CO_2 and methane, the aerobic states may reappear with the growth of new aerobic microorganisms, which will take the place of anaerobic forms; hence, the re-establishment of aerobic states [25]. The leachate characteristics during the stage of decomposition in landfills are demonstrated in Fig. 1.

3. Materials and methods

3.1. Landfill site description

PBSL, with an area of 624,000 m^2, is located at the Byram reserves, Nibong Tebal (Fig. 2 location of the study area), Penang at 50°12′00.73″ N and 100°25′31.99″ E [26]. Out of the stated area of PBSL, about 330,000 m^2 are operational, daily receiving around 1,800,000 kg of solid municipal and non-dangerous industrial waste. Around 600,000 kg of the solid waste received at PBSL is generated from Penang Island while the rest are from Penang mainland. PBSL has a natural marine clay liner due to its location near to the seashore [27]. Waste disposal at PBSL during its first 10 y of operation (starting around the early 1980s to 1990s) lacked proper management and there was no leachate control. However, the landfill initiated a semi-aerobic system operation in 1991, which complied with the set standard for Level

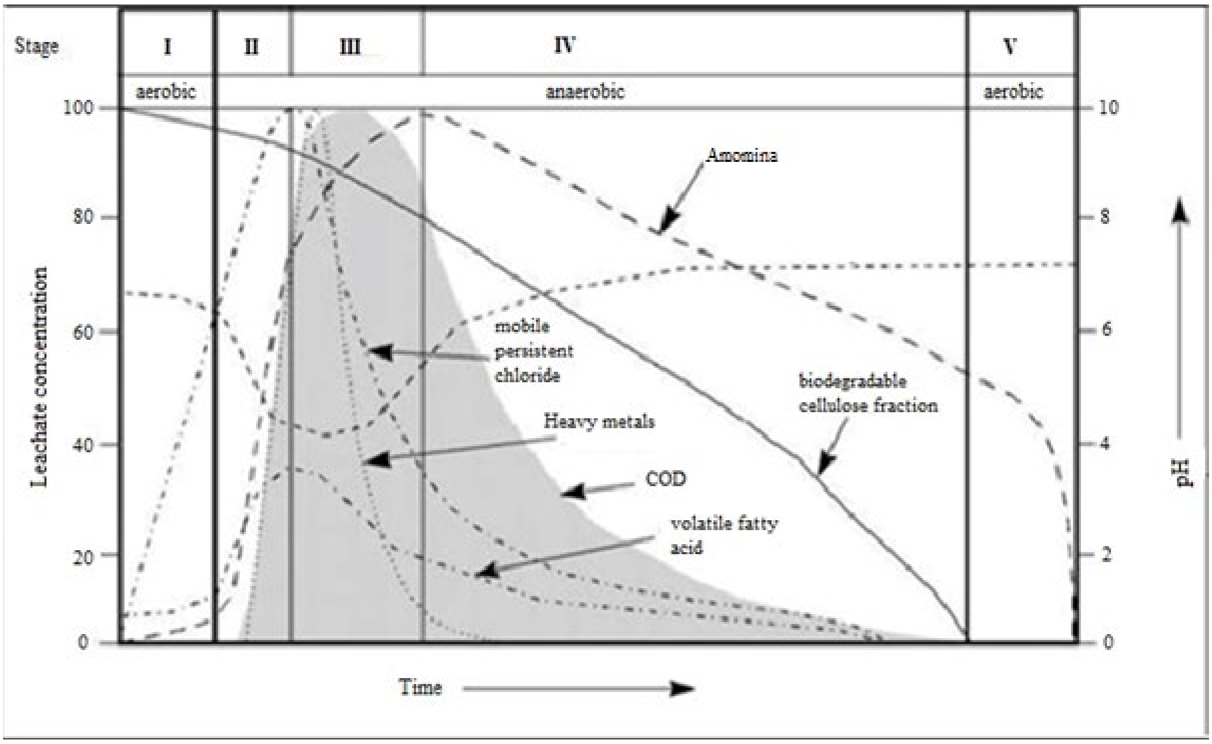

Fig. 1. Leachate characteristics during decomposition process in landfill [13,20].

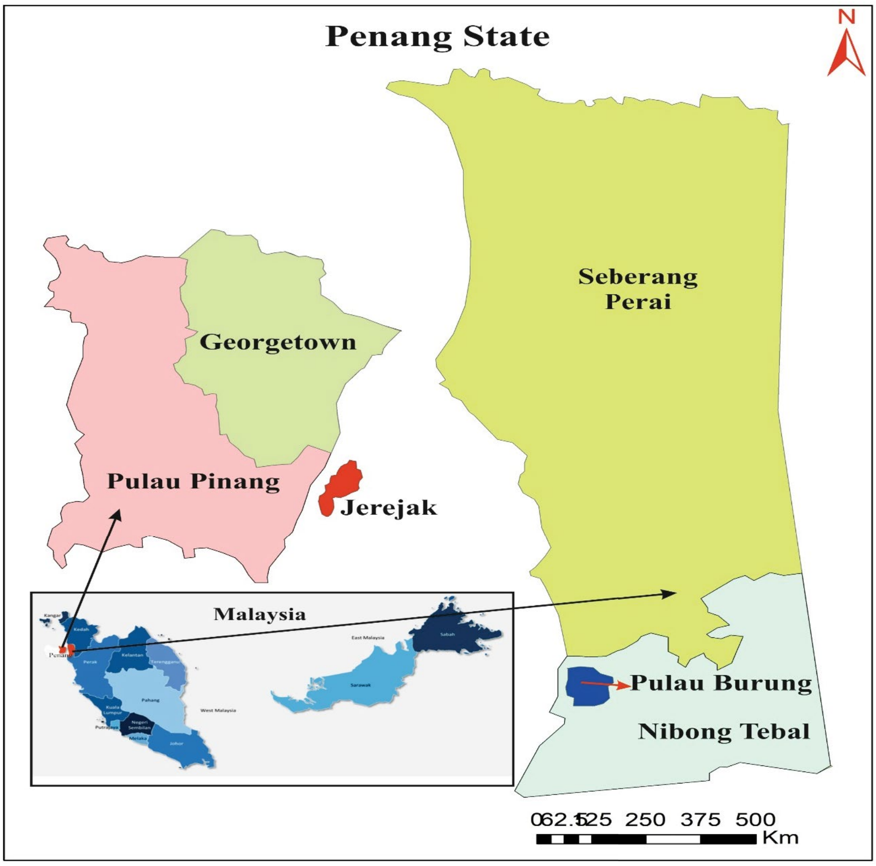

Fig. 2. Location of the study area [30].

II sanitary landfills through the establishment of a regulated tipping technique. In 2001, PBLS was improved to a Level III sanitary landfill through the establishment of controlled leachate and tipping recirculation Table 3 classification of landfills. Later in 2012, PBSL was handed over to a private company to ensure its proper management and daily operation [28].

3.2. Leachate sampling

LFL samples were manually collected from Pulau Burung landfill pond, Nibong Tebal, Pulau Pinang, Malaysia from January 2019 to July 2019. Each month had one round of sample collection for identifying the changes in leachate characterization. The samples were collected in polyethylene bottles which were previously cleaned and soaked before sample collection. However, due to the lack of equipment and unsafe collection from the center of the pond, the collection took place from three locations along the side of the lake. Within 24 h of collection, the samples were stored in cold storage at 4°C to minimize the biological and chemical reactions. All the characterization steps were performed at the Environmental Laboratory, School of Industrial Technology, Universiti Sains Malaysia. However, before analysis, the leachate samples were conditioned by placing them at room temperature for 2–3 h to be manually homogenized.

3.3. Leachate characterization

Two measurements were performed during the examination of the LFL; the first was an in-situ measurement and the second was done in the laboratory. Six water quality parameters (pH, temperature, turbidity, dissolved oxygen (DO), total dissolved solids (TDS), and conductivity) were measured in-situ using Sension5 portable multi-parameter analyzer. Turbidity was measured using a 2100P portable turbidimeter. The other parameters were measured in the laboratory; for instance, the color was measured using a DR 2800 HACH spectrophotometer after an initial filtration process; a DR 2800 HACH spectrophotometer with a high range limit [31] was used to measure the COD concentration using a closed reflux colorimetric technique; NH_3–N level was measured based on the 380 Nessler method using a portable DR2800 spectrophotometer at 425 nm; BOD_5 was determined following the recommended procedure. Before this analysis, the non-seeded dilution samples were incubated for 5 d to stabilize them. The obtained data were compared with MEQA (1974) [32] and other previous studies.

3.4. Heavy metals characterization

Samples of LFL were filtered using a filter of 0.45 µm pore size and evaluated for the concentration of heavy metals using inductively coupled plasma-optical emission spectrometry (ICP-OES) technique. All of the chemicals and reagents were analytical grade. ICP multi-elements standard solution IV and deionized water, as well as calibration blank and calibration standards, were used throughout the research.

4. Leachate pollution index

LPI formulation method involves selecting variables, deriving weights for the selected pollutant variables, formulating their sub-indices curves, and finally aggregating the pollutant variables to arrive at the LPI [33]. The rating was done on a scale of ‘1’ to ‘5’. The value ‘1’ was used for the parameter that has the lowest relative significance to the leachate contamination while value ‘5’ was to be used for the parameter that has the highest relative significance [34]. The ratings of each parameter are then used to calculate the weight of the parameters. The different weights indicate the significance of each of the 18 parameters.

Some pollutants do not show any pollution; however, using the minimum value of 5 units will ensure that the LPI value will not result in zero. Eq. (1) is only used if data for all 18 parameters exist and are analyzed. The LPI is calculated based on this equation:

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

Table 3
Classification of landfills

Class	Type of waste permitted
I	Landfills that accept all types of MSW: Household waste as well as other wastes such as putrescible waste, bulky waste, construction and demolition waste, vegetative waste, dry industry waste, animal and food processing waste, asbestos waste, and some industrial wastes.
II	Managed landfills that have specific category of non-hazardous waste: Landfills composed mainly of clean fill. Moreover, they also consist of dry industrial wastes, construction and demolition waste, vegetative waste, and asbestos containing waste.
III	A scientifically engineered facility built on the ground that is designed to hold and isolate waste from the environment. Mainly non-hazardous waste, bulky waste, and vegetative waste.
IV	Landfills that accept only limited types of wastes: Inert waste, non-putrescible wastes that degrade very slowly or do not degrade, such as construction and demolition wastes, agriculture waste, and commercial waste.

Adopted from [29].

Where LPI = the weighted additive LPI, Wi 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.

However, when the data for only some parameters (<18) are available, the LPI can be calculated using the concentration of the available leachate pollutants. In that case, the LPI can be calculated based on the following Eq. (2):

$$\mathrm{LPI} = \frac{\sum_{i=1}^{m} \mathrm{WiPi}}{\sum_{i=1}^{m} \mathrm{Wi}} \tag{2}$$

where *m* is the number of leachate pollutant parameters for which data is available.

The weight factor or pollutant weight (*W*) shows the significance level of each pollutant to the overall leachate pollution. In this research, the weight factors for each pollutant variable are briefly summarised in Appendix 1 [33]. Moreover, the sub-index value, *P*, was obtained by referring to sub-index average curves of pollutants as expressed in Appendix 2 [34]. The *P* values obtained for the parameters were multiplied with the respective pollutant weight (*W*). The weighted sum of all the parameters indicates the overall leachate LPI for each landfill.

5. Results and discussion

The quality of the LFL needs to be analyzed so that the most effective treatment process can be designed. Table 4 illustrates some of the raw characteristics of LFL from PBSL analyzed from January 2019 until June 2019.

6. Physicochemical characteristics

Ten parameters were monitored during the sample collection period and the data were presented as minimum, maximum, and average values according to the sampling month. The obtained data were compared with those of leachate effluent from MEQA and with data from previous studies on sanitary LFL characteristics around West

Table 4
Characteristics of raw leachate at PBSL

No	Parameters (mg/L)	Min	Max	Average	MEQA*
1	Temperature	30	33	31.5	40
2	pH	7.91	8.33	8.12	6.0–9.0
3	Ammoniacal nitrogen	145	270	207.5	5
4	BOD_5	150	208	179	20
5	COD	1,302	1,830	1,566	400
6	BOD_5/COD	0.06	0.1	0.08	–
7	Turbidity	222	671	446.5	–
8	Color	1,320	1,946	1,633	100
9	TDS	4,010	6,880	5,445	–
10	Conductivity	7.87	12.38	10.12	–
11	Arsenic, As	0.009	0.070	0.039	0.05
12	Calcium, Ca	478	1,062	770	–
13	Cadmium, Cd	0.004	0.020	0.024	0.01
14	Cobalt, Co	0.092	0.125	0.10	–
15	Chromium, Cr	0.442	0.583	0.51	0.05
16	Copper, Cu	0.026	0.44	0.23	0.20
17	Iron, Fe	7.205	9.995	8.6	5.0
18	Lithium Li	0.459	0.609	0.53	–
19	Magnesium, Mg	597.5	690.6	644	–
20	Manganese, Mn	0.148	1.397	0.77	0.20
21	Molybdenum Mo	0.009	0.097	0.05	–
22	Nickel, Ni	0.596	0.733	0.664	0.20
23	Selenium Se	0.043	0.068	0.055	0.02
23	Strontium Sr	2.251	3.824	3.04	–
24	Titanium Ti	0.226	0.287	0.256	–
25	Zinc Zn	0.526	1.553	1.039	2.0

All units in mg/L except for pH, BOD/COD ratio, temperature (°C) turbidity (NTU) and conductivity (μs/cm) and colour (Pt-Co)
*Environmental Quality (control of pollution from the solid waste transfer station and landfill) Regulation 2009 under the Laws of MEQA 1974 (MDC, 1997).

Malaysia. Evaluation of LPI for certain parameters was essential to calculate the leachate pollution potential.

6.1. Temperature

The climatic condition of the landfill site is the major factor that determines the temperature of the collected raw leachate. The climate of the landfill site is considered similar to that of other states in Peninsular Malaysia with a daily temperature range of between 30°C–40°C. The average recorded leachate temperature was 31.5°C. The temperature of the leachate is also influenced by the two major weather conditions (dry and rainy seasons) of the landfill site. A study from [35] reported that the temperature of PBSL leachate was at the range of 30.5°C in the past few years. The reported temperature ranges from previous works and that of this study showed that the temperature value conformed to the MEQA 1973-allowable limit. Thus, there is no need for further treatments to reduce leachate temperature.

6.2. pH

The observed pH values of leachate from PBSL varied within 7.91–8.33, with an average pH value of pH 8.12. The observed results for pH Table 4 were consistent with those from previous reports for stabilized leachate from different sanitary landfills in Table 5 (should be more than 7.5) [36–38]. The major event that contributes to the pH of the leachate is the degradation of organic materials to produce ammonia and carbon dioxide. The degradation products dissolve in the leachate to generate ammonium ions and carbonic acid. The generated carbonic acid can easily dissociate into hydrogen cations and bicarbonate anions; thereby affecting the systems' pH value. Furthermore, the pH of leachate can be affected by the partial pressure of the produced CO_2 upon its contact with the leachate. However, the pH values of leachate from PBSL were higher than the supposed 7 or >7, highly likely due to the ongoing of the methane fermentation stage that stabilizes the pH level of leachate to between 7 and 8. Nonetheless, the observed pH range of leachate in this study conformed to the MEQA (1974) permissible limit; hence, no further adjustment was necessary on the leachates' pH before its discharge.

6.3. Ammoniacal nitrogen

The high ammonia nitrogen content of leachate is the major factor that accounts for algal growth; it also disrupts biological treatment processes, promotes eutrophication, and reduces DO [39]. As such, ammonia nitrogen is lethal to microbes [15,40]. The average ammonia nitrogen value recorded from PBSL leachate was 207.5 mg/L and the range was between 145–270 mg/L Table 4; however, [41] reported that PBSL has a very high concentration of NH_3–N with a value of (1,810–1,070 mg/L). Additionally, based on the data presented from the same landfill at different times by [42], the concentrations of NH_3–N were also high in raw leachates due to the accumulation and long periods of time while higher values of 1,560–3,800 and 1,040–1,690 mg/L were previously recorded by other studies [3,36–38]. Although PBSL is categorized as an old landfill, the NH_3–N value was still higher compared to the MEQA recommendation (5 mg/L).

6.4. Biochemical oxygen demand (BOD_5)

This is the required or consumed oxygen to sustain microbial decomposition of organic materials in water or wastewater. The unit of measurement for this parameter is the consumed volume of oxygen (in mg/L) within 5 d at a fixed temperature of 20°C in the dark. Being that the maturity of landfills decreases with time, BOD_5 measurement is used to determine the maturity of landfills by measuring the amount of biodegradable organic mass in leachate [40]. In this study, the range of BOD_5 recorded at PBSL was 150–208 mg/L while the average was 179 mg/L. However, previous studies on different landfills within West Malaysia reported BOD_5 ranges of 107.5–419.1, 174–280, and 311–693 mg/L for Air Hitam sanitary landfill (AHSL), Kulim sanitary landfill (KSL), and Matang sanitary landfill (MSL), respectively. These results are in the same range as the results from PBSL [37,43,44]. The permissible level of BOD_5 based on Malaysian standards is 20 mg/L; thus, the level of BOD_5 for PBSL was over the permissible level as reported by the previous studies Table 5.

6.5. Chemical oxygen demand

Leachate from PBSL presented COD values ranging from 1,302–1,830 mg/L with an average value of 1,566 mg/L. The observed COD values from the leachates showed that PBSL is at the methanogenic phase since landfills at the methanogenic phase usually have COD values ranging from 500–4,500 mg/L; however, some of the previous reports have shown lower COD values at this phase [3,12,43,44] while others have shown higher COD values [36,37] in the acidic phase. [45] reported that COD leachate at PBSL was over 2,000 mg/L. The variations in the COD values could be attributed to several factors such as the age of the landfill [46], the site peculiarities, the layout of the landfill, regional weather, as well as solid waste characteristics. The measured COD levels in this study are relatively high possibly due to the toxicological effect of its high organic matter content as reported by [11]. Typically, leachate should have a COD value of less than 400 mg/L before its discharge into the environment. Thus, the risk of environmental contamination must be reduced by treating the leachate before discharge.

6.6. Biochemical oxygen demand/chemical oxygen demand

Generally, the age of landfills is determined through the BOD_5/COD ratio, which reflects the degree of its biodegradation. Lower BOD_5/COD ratios indicate higher concentrations of non- biodegradable organic materials [40]. There are three leachate phases - acid phase for young leachate, intermediate phase for partially stabilized leachate, and methanogenic phase for stabilized leachate. BOD_5/COD ratios of more than 0.5 are considered young leachate, while those that range from 0.1–0.5 are considered partially stabilized leachate [47]. BOD_5/COD ratios of less than 0.1 are considered stabilized leachate. Based on Table 2, the range

Table 5
Summary of characteristics of leachate at different sanitary landfills in West Malaysia

Ref.	State	Landfill sites	Parameters									
			Temperature°C	pH	Ammoniacal nitrogen (mg/L)	BOD_5 (mg/L)	COD (mg/L)	BOD_5/COD	Turbidity NTU	Colour Pt-Co	TDS (mg/L)	EC (µS/m)
[5]	Selangor	BTSL	29	6.6	4,300	27,000	59,000	–	3,600	15,300	–	670
[48,49,37]	Selangor	AHSL	26.6–29.5	8–8.5	107.5–419.1	3,500±	3,607–10,234	0.34	1,815	26,350	830 ± 104	20 ± 2.3
[36,50,37,51]	Selangor	JSL	32–37	8.00–8.73	1,560–3,800	201–836	3,583–5,807	0.035	405–940	3,450	6,556–14,680	29.67– 37.0
[52]	Selangor	TDSL	–	8.07	17.2	1,971	6,050	–	–	–	–	–
[43,12]	Kedah	KSL	–	7.27–7.92	174–280	7–69	105–131	0.06–0.52	12.7–67	192 – 440	–	7.27–7.92
[53,3,54,55]	Perak	APLS	25.9–31.6	7.85–8.64	1,040–1,690	113–343	2,950–4,675	0.03–0.08	40.1	10,650 –20,300	1,800 – 9,257	16,128
[44,56]	Perak	MSL	28–31	7.96–8.17	311–693	60–184	470–1,261	0.12–0.16	15 – 41	2,220 – 6,398	–	–
[57]	Johor	TLSL	–	–	129	77.1	974	–	–	4042	–	–

– Not available

of BOD_5/COD ratio for PBSL was between 0.06–0.1 with an average value of 0.08. Table 5 also showed that different sanitary LFL around West Malaysia is a combination of partially stabilized and stabilized leachates [3,44].

6.7. Turbidity

The turbidity of leachate is contributed by the colloidal fine suspensions like clay, silt, and finely divided organic and inorganic matters. The turbidity value recorded for PBSL ranged from 222–671 NTU with an average of 446.5 NTU. However, Table 5 showed that the levels of turbidity of sanitary landfills within West Malaysia could be as low as 15–41 NTU [42] and as high as 3,600 NTU [5]. Currently, the turbidity value of PBSL leachate has placed the landfill within the range for a mature landfill.

6.8. Color

The oxidation of ferrous to ferric form, as well as the consequent formation of ferric hydroxide colloids and complexes with fulvic and humic substances, contributed to the dark brown color of the leachate [59]. The value of the measured color at the PBSL pond was from 1,320–1,946 Pt-Co with an average of 1,633 Pt-Co. The color concentration measured for the samples collected from the PBSL pond was observed to be lower compared to the color concentration of the same landfill in the past few years [42]. On the other hand, higher values of up to 26,350 Pt-Co were recorded by previous studies [35,37,38]. Table 4 presents the specified allowable discharge standard in terms of leachate color concentration in Malaysia.

6.9. Conductivity and TDS

The level of these parameters is commonly influenced by the amount of dissolved organic and inorganic materials in a solution; hence, they are used to determine the level of salinity and mineral contents of leachate. The total mineral content also portrays the overall pollutant load and strength of the leachate. The presence of elements like potassium, sodium, chloride, ammonia salts, nitrate and sulfate accounts for the salt content of leachate [60]. The leachate samples of PBSL have a TDS range of 4,010–6,880 mg/L with an average of 5,445 mg/L. The same TDS range of 6,556 mg/L was reported by [50,51]. The conductivity results were between 7.87–12.38 µS/m with an average of 10.12 µS/m Table 4. Additionally, the same range of electric conductivity of (22.36 µS/m) was recorded by [42] in PBSL. The comparison of previous data that were recorded in Table 5 demonstrates that the EC results were within 20–29.67 µS/m [37,38,50,51]. Higher TDS and EC in leachate may portray the overall level of pollutants due to the degradation of organic matter.

7. Heavy metals

It is well known that sanitary LFL contains varying concentrations of different heavy metals and other contaminants. The concentrations of heavy metal are usually low in the leachate formation stage and during the acid formation stage, they can reach the highest levels. However, the complex reactions that happen with humic and other organic compounds decrease the metal concentration towards the later stages of the landfill stabilization process [61].

This research reported characteristics of leachate in terms of the existence of heavy metals and the highest concentration associated with the active status of PBSL. The concentration of heavy metals that were measured in PBSL was found much higher than the discharge limits. The greater concern of heavy metals is Cd, Cr, Cu, Fe, and Ni as presented in Table 4.

The higher Cadmium (Cd) content that was found in PBSL with an average of 0.024 mg/L was also observed in different active landfills as reported by [5,7,44] in Bukit Tagar sanitary landfill (BTSL) 11.25 mg/L and in MSL 0.190 mg/L. However, lower levels were reported in [36,37,50,51] with 0.03 mg/L. In fact, these variations mainly depend on the composition of MSW disposed of in landfills.

Leachate from PBSL reported higher concentrations of Chromium (Cr) and Copper (Cu) in all the samples and exceeded the standard limits with an average of 0.51 and 0.23 mg/L, respectively. Moreover, the concentrations of Cr are due to the presence of wood preservatives and paint products in the waste at the landfill [7]. Heavy metals are greatly hazardous pollutants not only due to their level of toxicity, but also their high solubility in water making them not easily removed [62]. These elements were also reported in several studies within West Malaysian sanitary landfills such as [7,12,43] in Kedah at KSL with Cr of 0.100 mg/L and a higher concentration of Cu at 10.95 mg/L as mentioned by [5] in BTSL Selangor.

The total iron (Fe) concentration is mostly higher in all landfills mainly due to the dumping of metal scrap and tin-based garbage with different types of MSW. This may also explain the reason for the high levels of Fe in PBSL. The Fe concentration in PBSL ranges from a minimum of 7.205 mg/L to a maximum of 9.995 mg/L, with an average of 8.6 mg/L. Other studies have reported the same results as presented by [36,37,50,51] at Jeram sanitary landfill (JSL) located in Selangor.

According to [62], waste that contains discarded batteries, household batteries, paint products, and metallic items causes a high increase in the levels of heavy metals such as nickel. Therefore, the average value of Ni was found slightly higher than the standard in PBSL with a value of 0.664 mg/L, as presented in other landfills in Table 6 [7,36,37,44,50,51]. Other heavy metals such as As, Mn, and Zn in all samples reveal lower concentrations and they remain within the allowable limits for leachate discharge.

8. Leachate pollution index

LPI is a very important tool for quantifying the pollution potential of leachate at the landfill sites [63]. Thus, after the physic-chemical and heavy metals parameter characterization, the LPI was identified for PBSL leachate. Table 7 demonstrates the potential of leachate pollutants in terms of pollution rating (LPI) for PBSL landfills and also compares them to LPI for leachate discharge standard of the Environmental Quality (control of pollution from the solid waste transfer station and landfill) Regulation 2009 under the laws of MEQA 1974 (MDC, 1997). However, in the same table, it can be

Table 6
Characteristics of heavy metal elements in leachate at different sanitary landfills in West Malaysia

Ref.	State	Landfill sites	Parameters									
			Arsenic, As (mg/L)	Calcium, Ca (mg/L)	Cadmium, Cd (mg/L)	Chromium, Cr (mg/L)	Copper, Cu (mg/L)	Iron, Fe (mg/L)	Magnesium, Mg (mg/l)	Manganese, Mn (mg/l)	Nickel, Ni (mg/l)	Zinc Zn (mg/l)
[5]	Selangor	BTSL	3.6	397.8	11.25	–	10.95	84.3	29.1	17.85	–	17.55
[48,49,38]	Selangor	AHSL	0.011–0.232	0.949–1.059	0.006–0.374	0.002–0.004	0.011–0.013	0.045–0.159	0.314–0.416	0.005–0.011	<0.2	0.013–0.032
[36,37,50,51]	Selangor	JSL	0.16	31.15	0.03	0.09	0.01	7.3	–	0.04	0.32	0.10
[43,12,7]	Kedah	KSL	–	–	–	0.100	0.03	0.38	–	0.09	0.07	0.09
[54,58]	Perak	APLS	–	–	–	0.09	4.00	9.96	–	0.26	–	0.46
[44,7]	Perak	MSL	–	–	0.190	–	0.090	2.300	–	0.090	0.170	–

– Not available

Table 7
Leachate pollution index (LPI) for PBSL

Parameters	Pollutant concentrations PBSL landfill	Sub-index value pi PBSL landfill	Pollutant weight wi PBSL landfill	Overall pollutant rating piwi PBSL landfill	Standard pollution rating standard
pH Value	8.12	5	0.055	0.275	0.275
TDS	5,445	12	0.050	0.6	–
(BOD_5) at 20°C	179	9	0.061	0.549	0.366
COD	1,566	40	0.062	2.48	0.930
TKN	–	–	–	–	
Ammonia nitrogen	207.5	20	0.051	1.02	0.255
Total iron	8.6	5	0.045	0.225	0.225
Copper	0.23	5	0.050	0.25	0.250
Nickel, Ni	0.664	6	0.052	0.312	0.260
Zinc	1.039	5	0.056	0.28	0.280
Lead	–	–	–	–	–
Total chromium	0.51	6	0.064	0.384	0.320
Mercury	–	–	–	–	–
Arsenic	0.039	5	0.061	0.305	0.305
Phenolic compounds	–	–	–	–	–
Chlorides	–	–	–	–	–
Cyanide	–	–	–	–	–
Total coliform bacteria	–	–	–	–	–
Total landfill			0.607	6.455	3.466
LPI values				10.63	5.710

clearly seen that data for TKN, lead, mercury, phenolic compounds, chlorides, cyanide and total coliform bacteria values were not available due to the lack of equipment, which made them impossible to be analyzed. Hence, they were not used in computing the LPI for the sanitary landfill. In this study, LPI was calculated based on the availability of data from the leachate. As observed from the leachate characterization, most of the parameters were at a high level and had a major effect on the LPI calculations [64].

According to the obtained data calculated by LPI, PBSL LPI was 10.63. The LPI for this active landfill was sharply higher compared to the standard discharge limits. In general, LPI values higher than the standard are not acceptable [65]. This can lead to further consequences such as polluting the groundwater within the vicinity of the landfill and also the surrounding soil since this landfill is located in a critical area between the shore and agricultural land [66,67]. The high levels of PBSL (active landfill) are attributable to high concentrations of BOD_5, COD, Ammonia nitrogen and certain metal elements such as Cu, Ni, Cr and Fe. Higher values were also reported by [65,68], whilst [69] presented LPI data containing relatively higher concentrations of BOD_5, COD and NH_3–N at the same study area and different landfill sites. Furthermore, [70] stated the LPI in Kolonnawa, Bandaragama, and Ratnapura landfills in Sri Lanka have the highest values of 442.5, 31.31 and 25.93, respectively. It should be noted that heavy metals can form colloids or complexes with organic compounds causing high concentrations of heavy metals compared to other landfills. Meanwhile, a study by [71] showed that LPI for Warri Metropolis landfill in Nigeria has low levels of LPI values from 6.377 to 7.438, indicating relatively lower contaminant potential due to low concentrations of heavy metals, young age of the landfill, low population, and organic origin of the wastes.

9. Leachate phase and treatment

The selection of a proper leachate treatment method before discharge largely depends on the characteristics of LFL. However, the age of the landfill is one of the main factors that affect leachate characteristics. Leachate can easily be identified based on the age of the landfill. The classification according to [72] is as follows: 1 y–young (aerobic phase), between 5–10 y–medium (acidic phase), and over 10 y old (methane phase) Table 8.

It is advised to initiate leachate treatment along with landfill operation because the biological treatment in the young landfills often results in a high level of biodegradable organic matter removal. This process becomes more difficult at older ages and the compounds will become recalcitrant, thereby requiring a higher treatment cost. Leachates that contain high organic materials (COD of >10,000 mg/L, $0.4 < BOD_5/COD < 0.8$) and low concentration of nitrogen ammonia are best treated using biological treatment methods. However, leachates that contain a high ammoniacal nitrogen concentration and a low level of biodegradability require a physical-chemical process combined with biological treatment [42,73].

10. Conclusion

Sanitary landfill is considered as one of the essential ways of dealing with high organic and inorganic matters

Table 8
Characterization of leachate based on age and comparison with leachate at PBSL

Parameters	Units	PBSL	Landfill age (years)		
			<5	5–10	>10
pH	–	8.12	6.5	6.5–7.5	7.5–9
COD	(mg/L)	1566	3,000–60,000	3,000–15,000	100–2,800
BOD_5	(mg/L)	179	2,000	–	100–200
BOD_5/COD	–	0.08	0.5–1.0	0.06–0.5	<0.1
NH_3–N	(mg/L)	207.5	10–800	30–1,800	20–900
TDS	(mg/L)	5445	2,500–14,000	4,000–55,000	1,100–6,400

and less calorific value waste, where leachate can be produced from the degradation of waste and precipitation penetration and commonly contains soluble components that exist in the waste. The identification of the critical pollutants in leachate requires a proper characterization of the LFL. This study investigated leachate collected from PBSL for twenty-five characterization parameters and the results showed the concentration of the organic compound of the leachate (expressed as COD, BOD_5, NH_3–N, and Color) and heavy metal elements such as Cd, Cr, Cu, Fe, Mn, Ni, and Se exceeded the limits set by the Malaysian standard MEQA. Additionally, other results from different landfills within West Malaysia were compared with that of PBSL. LPI played an important role in identifying the pollution potential of leachate at the landfill. Consequently, the raw leachate was found to contain high levels of pollutants and as such, requires an immediate efficient treatment to minimize the leaking of the pollutants into surface and groundwater.

Acknowledgement

The author would like to sincerely thank Universiti Sains Malaysia (USM), specifically all of the laboratory assistants in the Department of Technology and Industry School. Many thanks to the management staff and workers in Pulau Burung sanitary landfill (PBSL) for providing access to the landfill for the leachate collection.

Symbol

LPI	—	The weighted additive leachate pollution index
Wi	—	The weight for the *i*th pollutant variable
Pi	—	The sub index score of the *i*th leachate pollution variable
n	—	Number of leachate pollutant variable
m	—	Number of leachate pollutant variable which data is not available
PBSL	—	Pulau Burung sanitary landfill
LFL	—	Landfill leachate
MSW	—	Municipal solid waste

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