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Comparative Analysis of Contaminant Levels in Leachate and Soil from Young and Old Landfills

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ABSTRACT

The leachate generated in municipal solid waste landfills tends to have extremely elevated levels of organic and inorganic pollutants influenced by the age and variety of landfills. This research aims to conduct a comparative analysis between two landfills, Krubong Landfill Sites (KLS) and Bukit Bakri Landfill Sites (BBLS). Based on the standard limit set by the Malaysia Environment Quality Act (MEQA), the average values of the leachate parameters at KLS and BBLS were recorded. These parameters include pH (8.84 for KLS and 9.08 for BBLS), temperature (30.22°C for KLS and 30.06°C for BBLS), Chemical Oxygen Demand (COD) (3695 mg L^{-1} for KLS and 11289 mg L^{-1} for BBLS), Biological Oxygen Demand (BOD) (1695 mg L^{-1} for KLS and 3325 mg L^{-1} for BBLS), and ammonia nitrogen (1107 mg L^{-1} for KLS and 1390 mg L^{-1} for BBLS). The findings of this research suggest that the age of the landfill indeed influences the characteristics of leachate and soil. KLS, being a mature landfill, demonstrated low biodegradability. On the other hand, BBLS, being a young landfill, exhibited high biodegradability. The highest heavy metal concentration in the soil sample of KLS was Barium (Ba), with 409 ppm, followed by Zirconium (Zr) at 297 ppm and Vanadium (V) at 114 ppm. For BBLS, Zirconium (Zr) and Thorium (Th) were 209 ppm, Rubidium (Rb) was detected at 86 ppm, and Chromium (Cr) was 57 ppm. In overall essence, the age of a landfill significantly influences its characteristics. Newly established landfills tend to contain a greater quantity of organic matter compared to older ones.

Keywords: Heavy metal, mature landfill, organic material, soil characterisation, young landfill

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INTRODUCTION

Leachate is a fluid percolated through diverse solid waste, acquiring dissolved or suspended matter. Landfilling is a widely preferred technique for solid waste disposal in numerous countries, with Malaysia as a prime example. Malaysia has over 230 landfills (Daud et al., 2022; Norsa'adah et al., 2020). Most are open dumpsites, which present grave environmental concerns to public health and societal well-being. Landfilling is considered the most cost-effective and environmentally sound method for solid waste disposal compared to other techniques like composting, incineration, and gasification. Nonetheless, leachate production from landfills is a significant issue related to this disposal method (Daud et al., 2020; Hussein et al., 2019).

In a landfill, a series of interconnected physical, chemical, and biological processes take place, leading to the degradation or transformation of the waste. As water permeates through the landfill, leachate is generated from the solid waste through these processes (Sackey & Miezah, 2022). The properties of the leachate and soil generated in landfills exhibit significant variability, influenced by factors such as the makeup of the solid waste, the rate of precipitation, the hydrology of the site, the degree of compaction, the design of the cover, the age of the waste, the sampling methods, the interaction of the leachate with its surroundings, as well as the design and functioning practices (Salami & Susu, 2019).

Other than that, leachate from landfills can contaminate surface water and groundwater, leading to diverse problems in forming leachate water and the amount of pollutants contained. This contamination occurs mainly when heavy rain accelerates the leachate percolating process through the soil layers at the base of the landfill, combining with groundwater to cause pollution (Detho et al., 2021a).

Leachate can be treated through various biological, chemical and physical treatments. The specific characteristics of the leachate govern the selection of a treatment method. In other words, the leachate treatment system is largely dictated by the individual properties of the leachate. The properties of leachate vary based on multiple factors, including climate, landfill age, amount of rainfall, operational practices at the landfill, and the volume and nature of the waste (Detho et al., 2021b; Zin, 2013).

Leachate from landfills contains high amounts of organic and inorganic material, heavy metals, and toxic chemicals in high concentrations. Landfill leachate constitutes a significant contributor to the contamination of both groundwater and surface water (Naveen et al., 2017). Leachate not only causes groundwater pollution but also soil contamination. Therefore, due to its characteristics, before leachate is discharged into the environment, it must be properly treated by physical, chemical and biological methods. The absorption of water leachate into the soil will cause pollution. Leachate from landfills causes pollution to ecosystems in the surrounding areas. In addition, soil contamination is also dangerous to surrounding landfills, the usage of landfills, and even to local communities that live nearby (Siddiqua et al., 2022).

Recently, researchers have been paying attention to leachate pollution and soil contamination around landfill areas due to the leachability of leachate from landfills. The soil serves as a natural filtration system for various substances present in water, including particles, toxic substances, acids, and some microorganisms. Its intricate layered composition helps reduce water runoff, capture larger particles, and neutralise acidic conditions in the soil (Dorioz et al., 2006).

In addition to leachate, soil plays a crucial role in landfill sites. It acts as a medium where contaminated materials are deposited and absorbs the leachate produced during the waste decomposition. Soil is a natural resource that requires careful monitoring due to its constant interactions with other media, such as air, groundwater, and surface water, through processes like evaporation, erosion, and infiltration (Ramaiah & Krishnaiah, 2014).

Soils have different textures like sandy, loamy, and clay soil, which were used as filters to reduce the quantity of organic and inorganic composition in leaching liquid. Texture and soil types will contribute to different absorption quantities and types of organic and inorganic compositions at a certain distance and depth of landfills. Therefore, soil is able to filter the content of inorganic substances present in the leachate water that goes through it. The type of inorganic substance that the soil can absorb depends on soil type and natural content in the soil itself. Therefore, soils become contaminated by leachate landfills because of their ability as a filter (Kanmani & Gandhimathi, 2013).

The age of a landfill strongly influences the properties of leachate. With an increase in landfill age, the biological decomposition of the deposited waste shifts from a relatively short decomposition phase to a longer phase, encompassing two sub-phases: acidic and methanogenic (Aziz, 2010). According to reports, the leachate from these two stages contains a variety of different substances. Volatile fatty acid concentrations in leachate from more recent landfills (young leachate) tend to be higher, which suggests that the leachate is more likely to be in the acidic phase. Younger landfills enter the acidic phase, and with time, they transition into the methanogenic phase. In the methanogenic phase, fatty acids from the acidic or acidogenic phase are converted into methane and carbon dioxide. This conversion between the two phases is time-consuming, as organic matter needs to decompose into gaseous and liquid fermentation products (Lindamulla et al., 2022). The properties of leachate and soil at the landfill were important to determine the lead of contamination and to identify the correct treatment for leachate and its pollutants.

Therefore, in this study, the characteristics of leachate and soil, two different ages of landfills, i.e., young landfill (<5 years) and old landfill (>10 years), were investigated. Moreover, this research aims to conduct a comparative analysis between two landfills, Krubong Landfill Sites (KLS) and Bukit Bakri Landfill Sites (BBLS). Thus, this study can better understand leachate and lead to more efficient managerial solutions and treatability options.

MATERIALS AND METHODS

Location of Landfills

The samples of leachate and soil were gathered from selected locations, namely the Bukit Bakri Landfill site (BBLS) in Muar and the Krubong Landfill site (KLS) in Melaka, Malaysia. During leachate and soil sample collection, safety equipment, storage for sample and procedure were followed. Leachate was kept in a closed container and labelled at cold storage at 4°C before being tested in the laboratory. For soil sample collection, grab samples with depths 0m and 1m were put in plastic bags and labelled separately. The landfill location shown in Figures 1 and 2 is selected based on the different ages of the landfill.

BBLS was selected because the landfill was constructed in 2010 and is less than five years old. BBLS is situated at Latitude 2.0417° and Longitude 102.6722° Muar to Melaka. It has a total land area of 14.6 hectares and a leachate-gathered pond. The site accepts approximately 200–270 tons of waste.

Figure 1. Location points and geomorphological map

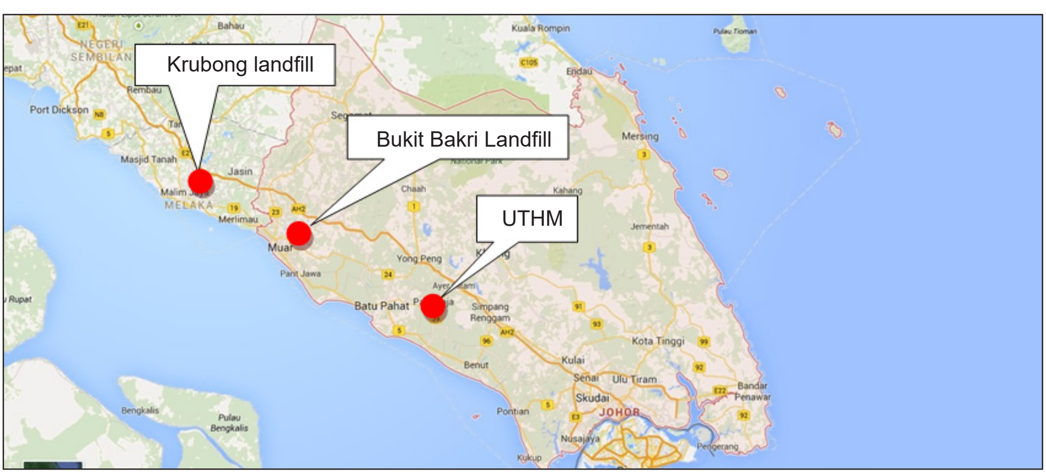

Figure 2. Location of landfills

KLS is the oldest landfill, constructed in 1996 and classified as a mature landfill older than ten years. The landfill sites selected are classified as young and old landfills. KLS is situated at Latitude 2.286362° and Longitude 102.251043° Krubong to Melaka. It occupies a total area of 242 hectares and is equipped with a leachate-gathered pond and treatment plant. The site accepts approximately 900 tons of waste.

Leachate Samples Collection at the Site

Leachate was gathered from the collection pool using a submersible pump at a depth of 1500 mm, and the sample points were the routes of leachate that were active with stream flow. Sampling was done thrice a month, and the samples were taken throughout the study for February and March, which is within the dry season. The leachate samples were placed into a polytetrafluoroethylene (TFE) plastic bottle until it was full and tightly closed. Then, they were transported back to the laboratory to be tested for BOD, COD, and pH content. Then, the leachate sample brought back to the lab was filtered through a 0.7µm glass microfiber filter to ensure no suspended solids were in the leachate during the testing procedure. Each sample was duplicated and stored in a cool room.

Characteristics of Leachate

The samples were gathered and examined to evaluate their properties and stability. Physical characteristics such as temperature and pH measurements were assessed after the sampling process. The chemical characteristics, COD, BOD and ammonium nitrogen, were determined using a DR 6000, and the readings were recorded in units of mg L^{-1} according to the standard method (Eaton & Franson, 2005). The concentration of metal Thorium (Th), Zirconium (Zr), Rubidium (Rb), Chromium (Cr), Vanadium (V), Gallium (Ga), and Cerium (Ce) was quantified using an inductively coupled plasma-optical mass spectrometer (ICPMS). Leaching tests are widely used to estimate the release of potentially hazardous elements from waste (Hashim et al., 2022). The test was conducted to ensure all the manufactured brick samples were satisfied and complied with standards. The USEPA SW 864 Method 1311 was used for the leachability testing in this research. All the experiment work was analysed at the Environment Laboratory, UTHM. The results were compared to those previously published by Eaton and Franson (2005).

Soil Collection at Site

Soil samples were collected using Soil Auger due to the hardness and compactness of the soil in this landfill, as illustrated in Figure 3. Soil samples were collected to test the heavy metal concentration. The method used to take the soil sample is the grab samples method. Ten sampling points have been identified and collected at 5 m to 10 m around the parameter area of the landfill with depths of 0 m and 1m around the parameter area of the landfill to make a complete coverage around. The weight of each soil sample is about two kilograms. Collected samples were placed in plastic bags and labelled separately with each point. The same method is repeated at different points. Then, the soil samples were brought back to the laboratory for testing part.

Figure 3. Soil collection techniques

Soil Preparation

Soil samples were placed on plates and oven-dried at 100± 5°C for 24 hours to ensure they were dry. After drying, soil samples were ground and crushed to facilitate sieving. All this work was done in the Geotechnical Engineering Laboratory, UTHM.

Pellet Preparation

Soil samples were shaped into pellets. The pellet should be in fine powder condition because X-rays can only penetrate a few millimetres from the sample's surface. The soil samples that have been dried and crushed have to sieve through 63 μm. Then, soil samples were mixed with wax at a ratio of 9:3, where 9 g were used for the soil sample, and 3 g were used for wax. Wax sticks the soil sample particles together in the pressed pellets process. Next, the samples were pressed into pellets using a compression machine and analysed. All the work has been done in the Environmental Analytical Laboratory, UTHM, as shown in Figure 4.

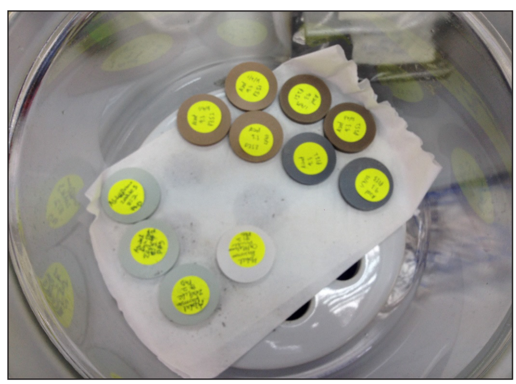

Figure 4. Pellet preparation

Laboratory Test for Soil Sample

Soil samples were analysed using X-Ray Fluorescence (XRF) to evaluate the heavy metal concentration in the soil sample. The soil samples were prepared in pellet shape before being used by the test XRF machine. The pellet processing should be in fine powder condition because X-rays can only penetrate a few millimetres from the surface of samples. Major element contents for the soil sample were measured using XRF equipment in the Environmental Analytical Laboratory at UTHM. XRF tool is a quantitative and qualitative analysis technique and very sensitive detection. The detection limit of this device depends on the elements to be analysed and the sample matrix, and detection limits are typically between 10 and 100 ppm (part per million). XRF is frequently used for analysing major and trace elements in rock, minerals, and sediment due to its relatively easy and inexpensive sample preparation. This technique does not require sample digestion or fusion complex and is likely to increase the risk of errors.

RESULTS AND DATA ANALYSIS

Leachate Properties

Two landfills were selected in this study based on their age and activity characteristics of landfill. The leachate and soil collection samples were composed manually at two landfill sites, Bukit Bakri and KLS. The samples were preserved in a container filled with ice at 4°C upon collection. A bottle of each sample (90 mL) for each site was also preserved in the container in case of need for data reproduction, according to Eaton and Franson (2005). The results of samples obtained from both sites during laboratory testing are illustrated in Table 1. Two different ages of landfills, i.e., young landfills (<5 years) and old landfills (>10 years), were investigated in this study. The average leachate properties values at KLS and BBLS, i.e., temperature (30.22°C and 30.06°C), pH (8.84 and 9.08), COD (3695 mg L^{-1} and 11289 mg L^{-1}), BOD (1695 mg L^{-1} and 3325 mg L^{-1}), and ammonia nitrogen (1107 mg L^{-1} and 1390 mg L^{-1}), were recorded based on MEQA standard limit.

Table 1
Properties of leachate at BBLS and KLS

Parameters	Bukit Bakri Landfill			Krubong Landfill		
	Range		Average	Range		Average
	High	Low		High	Low	
pH (0-14)	9.31	8.67	9.08	9.37	8.68	8.84
Temperature (°C)	29.72	28.12	30.06	32.58	28.12	30.22
COD (mg L^{-1})	18460	4425	11289	5210	3200	3695
BOD (mg L^{-1})	3690	3510	3325	2350	1073	1695
Ammonia, NH_4^+ (mg L^{-1})	1519.52	1231.05	1390	1407.21	950.74	1107

pH Measurement

Figure 5 shows the comparison of pH value between BBLS and KLS. Results from BBLS show that it increases from an 8.90 pH value to a 9.27 pH value. A stable landfill is frequently greater than a young landfill (Kulikowska et al., 2008). KLS shows that pH values rise from 8.80 to 8.97. The variation may arise from the stable leachate generated while fermenting methane, either during or after the process. The Environmental Quality Regulation 2009 and Malaysian Environmental Quality Act (Act-127) provide a permitted pH range of 6.0 to 9.0 (Aziz et al., 2010).

Temperature Measurement

Figure 6 shows the temperature values from both sites plotted against the time. The temperatures of the samples obtained from both sites are different. The temperatures highly depend on the local climate. From week 1 to week 2, the temperature is high because of sunny days in all locations, and from week 3 to week 4, the temperature drops from 30.06°C to 29.26°C due to rainy days. Figure 6 represents comparison temperatures between BBLS and KLS. The results show that from both landfill sites, the value of temperatures gradually decreased from 33.64°C to 28.30°C due to the sunny season to the rainy season. The decreasing trend for temperature in the site was affected by seasonal variations, ages of waste and location of waste, which have significant effects on temperatures (Keerio et al., 2020).

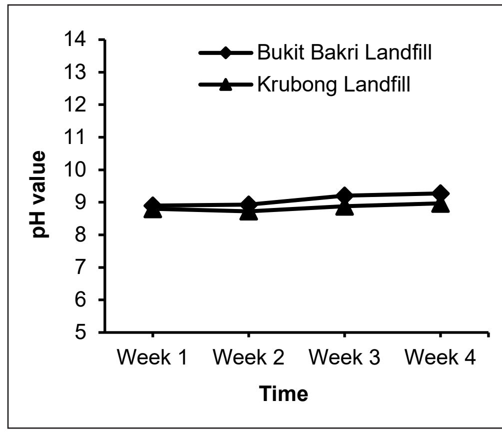

Figure 5. pH range comparison between BBLS and KLS

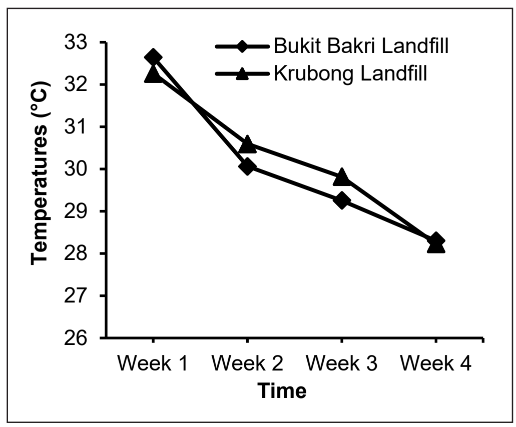

Figure 6. Temperature range comparison between BBLS and KLS

Chemical Oxygen Demand (COD) Analysis

From Figure 7, the trend of the COD measurements is increasing on rainy days. COD values from both sites increase from sunny days to rainy days because organic matter from solid waste increases with the rainy week, which increases COD values. The result we can see here is that the COD values of sample BBLS (young landfill) are higher than KLS (old landfill). The maximum values indicated for BBLS were 18293 mg L^{-1}, which seemed to exceed the acceptable levels stated by the Environmental Quality (Pollution Control from Solid Waste Transfer Stations and Landfills) Regulation 2009. COD values

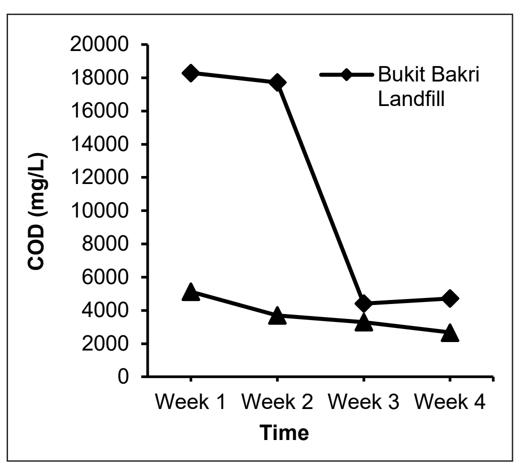

Figure 7. COD value of BBLS and KLS

were in the previous study, normally between (18000 and 2600 mg L^{-1}) (Aziz et al., 2010). Meanwhile, the COD value from KLS, the results show that (5123 to 2667 mg L^{-1}) were decreased due to dilution of seasonal variation, likely influenced by rainfall, which led to a reduction in the concentration of landfill leachate produced at the landfill site (Zainol et al., 2012). The results were a gradual decrease in both landfill COD values.

Biochemical Oxygen Demand (BOD) Analysis

Figure 8 demonstrates the BOD value of BBLS and KLS. BOD values from BBLS from week 1 to week 3 showed similar values, but in week 4, they decreased from 3583 mg L^{-1} to 2552 mg L^{-1}. Meanwhile, the BOD value for KLS decreased from 2608 mg L^{-1} to 1128 mg L^{-1}. In this study, BOD changes with landfill age. Generally, BOD levels for young landfills typically vary from 2000 to 30000 mg L^{-1}, while for older landfills, the range was 100 to 200 mg L^{-1} (Tchobanoglous et al., 1993). The BBLS value in this research aligns with previous researchers' findings (Bashir et al., 2010). Nevertheless, the BOD for BBLS and KLS values seemed to exceed the acceptable levels (50 mg L^{-1}), and the landfill leachate required treatments to be environmentally accepted.

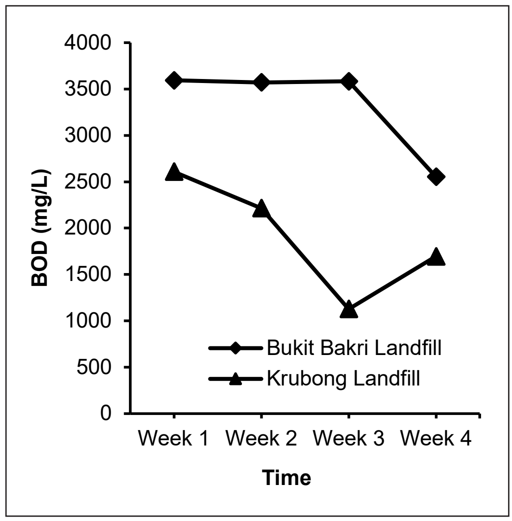

Figure 8. BOD value of BBLS and KLS

Ammonia Nitrogen Measurement

Figure 9 represents the ammonia-N value between BBLS and KLS, which slightly increases weekly. Ammoniacal nitrogen levels in leachate samples from the BBLS and KLS ranged between 1316-1337 mg L^{-1} and 1112-1051 mg L^{-1}, respectively. However, higher values ranging from 1189 to 2117 mg L^{-1} have been reported in previous studies by other researchers (Ghafari et al., 2010; Aziz et al., 2010). The high ammoniacal nitrogen content is the main cause of algal growth enhancement, eutrophication, biological treatment

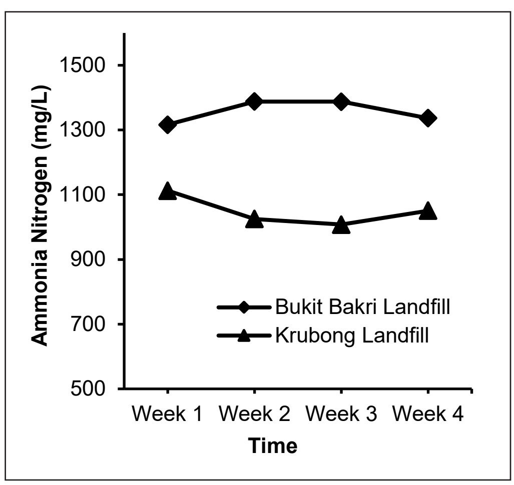

Figure 9. Ammonia Nitrogen value between BBLS and KLS

disruption and decreased dissolved oxygen (Keerio et al., 2022; Aziz et al., 2010). Consequently, its extreme toxicity, ammoniacal nitrogen poses a serious hazard to aquatic species (Bashir et al., 2010). Ammoniacal nitrogen concentrations typically vary from 10 to 800 mg L^{-1} for young landfills (<5 years old) and from 20 to 40 mg L^{-1} for mature landfills (> 10 years old), respectively.

Heavy Metal Concentration

Figure 10 shows the concentration of heavy metals and compares the concentrations of heavy metals in BBLS and KLS in leachate samples tested using ICPMS. Barium (Ba) represents the highest concentration value of heavy metals, with 362ppb for BBLS and 287ppb for KLS. Meanwhile, another heavy metal detected is Manganese (Mn) from both sites, with 277ppm in sample leachate from BBLS and 303 from KLS. The lowest heavy metals concentration in the leachate sample shows that Lead (Pb) with 14ppb and 16ppb were detected, respectively. In general, the concentration of heavy metals rises as the waste age increases, which raises the solubility of the metal. The stable leachate does have decreased heavy metal contents at this point (Kulikowska, 2008).

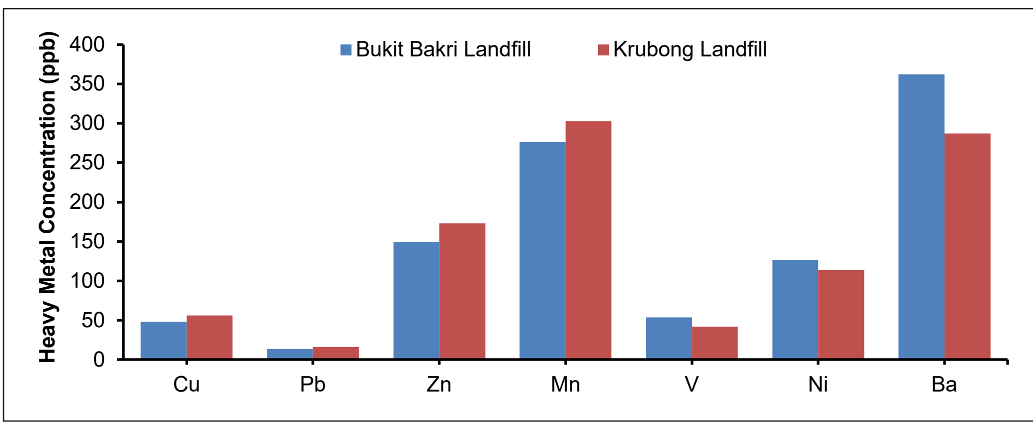

Figure 10. Heavy metal comparison between BBLS and KLS

Heavy Metal Concentration Composition of Soil

Figure 11 shows the soil heavy metals concentration composition from BBLS and KLS for this study findings. The result indicates that the soil from KLS exhibits the highest Barium (Ba) concentration at 409 ppm. Cesium (Cs) with 2 ppm was recorded as the lowest in soil sample BBLS. Meanwhile, soil samples from BBLS and KLS have a similar heavy metal concentration composition, Zirconium (Zr), with 209 ppm and 297 ppm. Most heavy metal concentrations in soil samples are BBLS and KLS, where certain chemical compounds have the lowest concentration value, for example, Cobalt (CO) with 4 ppm and 5 ppm.

Figure 11 shows a comparison of heavy metal concentration between BBLS and KLS with major elements that are contained in a soil sample. The result shows that the highest value of heavy metal concentration is Barium (Ba), with 409 ppm in the soil sample from KLS. Meanwhile, the sample soil from BBLS with a heavy metal concentration of Barium (Ba) is 32 ppm. The similar value of heavy metal concentration from both sample soil in KLS and BBLS is Chromium (Cr), with 56 ppm and 57 ppm. Other than that, the lowest value of heavy metals concentration is Cobalt (Co), with 5 ppm and 4 ppm from KLS and BBLS. The result from XRF also supported the result from ICPMS where certain chemical compounds, for example, Lead (Pb), Zinc (Zn), Manganese (Mn), Vadium (V), Nickel (Ni) and Barium (Ba), where the heavy metals exist in leachate sample.

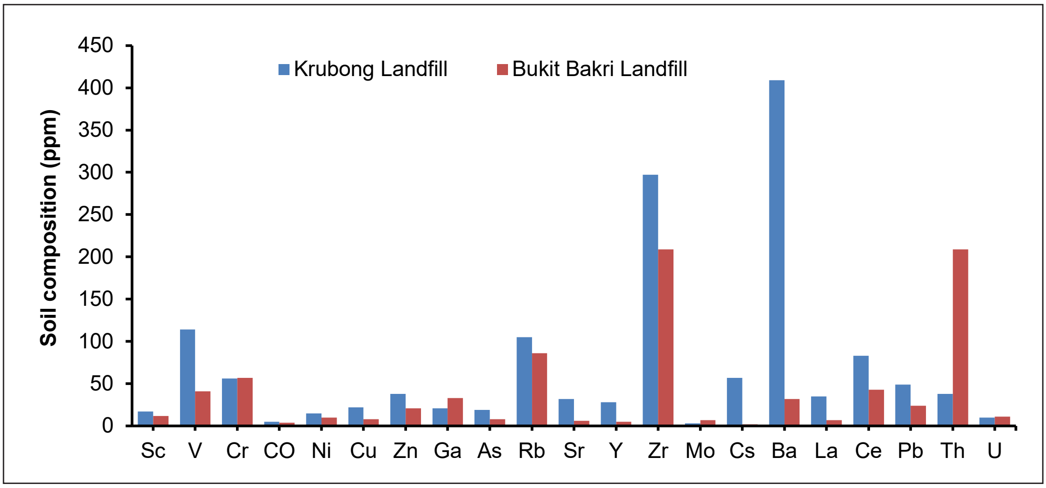

Figure 11. Comparison of heavy metals concentration between Bukit Bakri and KLS

CONCLUSION

The main objective of this study is to study the leachate and soil characteristics of BBLS (young landfill) and KLS (old landfill). Physical parameter characteristics were pH and temperature. The pH values in BBLS and KLS were almost the same, 9.08 and 8.84. Meanwhile, the temperature results from BBLS and KLS were almost the same, 30.06°C and 30.22°C.

The chemical parameters analysed includes COD, BOD, and ammonia nitrogen. The average COD values from BBLS were recorded at 11289 mg L^{-1}, and the COD value of KLS was recorded at 3695 mg L^{-1}. The BOD result was recorded at 3325 mg L^{-1} from BBLS and 1695 mg L^{-1} from KLS. Ammonia nitrogen results for BBLS and KLS were 1316–1337 mg L^{-1} and 1112-1051 mg L^{-1}, respectively.

For soil characteristics, the concentration of heavy metals in the sample from site KLS and BBLS was detected using XRF. The highest heavy metal concentration in sample KLS

Site is Barium (Ba) at 409 ppm, followed by Zirconium (Zr) at 297 ppm and Vanadium (V) at 114 ppm. The highest heavy metal concentration in sample BBLS Site is Zirconium (Zr), and Thorium (Th) was 209 ppm. Rubidium (Rb) was detected at 86 ppm, and Chromium (Cr) was detected at 57 ppm. For leachate results, the highest value of heavy metal concentration from BBLS and KLS is Barium with 32 ppb, and for KLS, Manganese (Mn) with 303 ppm. The result shows that Lead (Pb) represents the lowest value of heavy metal concentration in the leachate sample from BBLS with 14 ppm; for KLS, the lowest heavy metal concentration is also Lead (Pb) with a value of 16 ppm, respectively.

The result shows that seasonal variations, ages of waste, and location of waste where available moisture have significant effects on temperatures. This study demonstrates that the age of the leachate and soil significantly influences their composition. The biodegradable portion of organic contaminants in the leachate decreases with increasing landfill age. The overall conclusions and the result of the comparison show clearly that a landfill's age affects its characteristics. In comparison to older landfills, more organic waste is often present in newer landfills. In general, new landfills have higher quantities of contaminants than older ones. In order to find a better understanding of this study, it is suggested that this study be extended to investigate leachate and soil characteristics in more specific detail with consideration of more aspects.

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