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Heavy metals in leachate, impacted soils and natural soils of different landfills in Malaysia: An alarming threat

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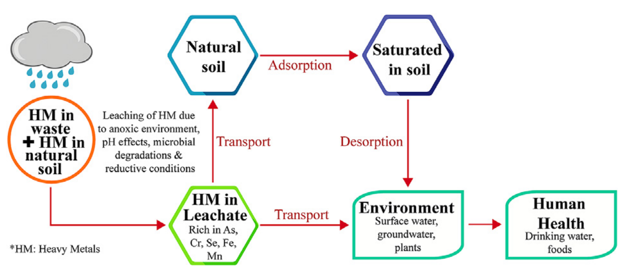
HIGHLIGHTS

- As, Cr, Mn, Se and Fe were high in raw leachate from both sanitary and non-sanitary landfills.
- Igeo, PI and IPI revealed that soil from non-sanitary landfills were polluted with metals especially by As, Cd, Pb and Cr.
- Heavy metals in landfill were not only possibly caused by wastes but also leaching from natural soils due to certain landfill conditions.
- As, Cd, and Cr contaminations in non-sanitary landfills poses alarming threat to the environment, ecosystem and public health.

GRAPHICAL ABSTRACT



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ABSTRACT

Landfills are a potential threat to human health and the environment, especially from the detrimental and toxic heavy metals. This study focuses on the assessment of heavy metals contamination in leachate and surface soils from different landfills in Malaysia. Maximum quality rating scale (QRS) values of As (787) and Cr (552) denotes progressive deterioration of leachate contamination in landfill. The impacted soils showed high heavy metal concentrations especially at non-sanitary unlined landfills, as compared to background values, and natural soil nearby the landfills. In addition, to examine the environmental impacts of the landfill area (soil) in more detail, specific indexes; geo-accumulation index (Igeo), pollution index (PI) and integrated pollution index (IPI) were determined. Maximum As (3.122) and Cd (2.633) for Igeo and As (34.037) and Cd (20.881) for PI revealed that the soil samples in non-sanitary landfills were moderate to strongly polluted. The difference in range of IPI values for sanitary (0.294 −0.322) and non-sanitary landfill soils (1.263−1.956) confirmed advanced decline of the soil quality in non-sanitary landfills. Arsenic concentrations were found to be statistically significant (ANOVA) for leachate and impacted soil in landfills investigated. It is also important to realize that rise in metal contents in landfill environments were not only caused by anthropogenic sources such as from the waste disposed, but also some other factors such as redox conditions, anoxic environments, pH, oxidation state

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of metals and microbial activities. Those conditions will actively promotes leaching of metals from waste and also natural soils in the landfill.

1. Introduction

In developing countries like Malaysia, landfilling is the most common method for waste disposal. Despite the fact that landfilling methods is commonly implemented, a great numbers of uncontrolled landfills without appropriate bottom liners, leachate collection or treatment system have been wide spread. As in December 2018, there are 146 operated landfills and 165 non-operated landfills in Malaysia, with only 18 of the operated landfills were classified as sanitary landfills (SWCorp, 2019). Non-sanitary landfills in Malaysia refers to waste disposal sites which is constructed or operated without a proper engineering plan and landfill bottom liner system (Fauziah and Agamuthu, 2012). These refer to controlled dumps that are unlined with proper liner system that is supposed to prevent leachate percolation into groundwater and soil, which would pose a serious pollution threat due to the migration of the pollutants in leachate. Open tipping sites also falls into same category which are considered as non-sanitary landfills where the liner system, the gas control system, the leachate collection and the treatment are not provided. Nevertheless, some of these non-sanitary landfills were upgraded and facilitate with leachate collection system and treatment during the closure procedures. Some of the open tipping sites were also upgraded and provided with road accessibility, designated tipping areas, weekly waste spreading, compaction and soil cover, however there are no gas control, leachate collection and also treatment available (Rahim et al., 2010).

Distribution of numerous pollutants especially due to the unorganized dumping of solid waste, poses a significant pressure on the environment as several pollutants are very toxic and dangerous to every form of life. Heavy metals such as arsenic (As), chromium (Cr) (VI), cadmium (Cd), mercury (Hg) and lead (Pb) are non-threshold pollutants that can exert toxic effects, even at minute concentrations (Jayanthi et al., 2016; Rahman and Singh, 2019). These pervasive metals may constitute a serious threat to the environment and human health not only because it is the most toxic contaminants and carcinogenic (Abu-Rukah and Abu-Aljarayesh, 2002) but also due to the fact that they do not degrade. Unlike organic matter in leachate which may reduce during methane production from the waste (Yusof et al., 2009), heavy metals can remain within the landfills for around 150 years if it leached at a rate of 400 mm/year (Adelopo et al., 2018). The toxic nature of heavy metals disturbs the natural biological balance and inhibits self-purification processes in the natural systems (Dahiya et al., 2006; Gworek et al., 2016; Öman and Junestedt, 2008; Talalaj, 2015). Besides the natural sources such as geological weathering and seepage, volcanic activities and forest fires, leaching of metals from garbage and solid waste dumps and landfill waste, as well as mining, industrial processing of ores and metals and manufacturing which involve the use of metals and its compounds also have caused excessive release of heavy metals in the environment (Gautam et al., 2016). Heavy metals may release to the environment through leachate production and migration from landfills and pose potential risks to the soil and groundwater, and subsequently to the surface water. Leachate production and mobility of heavy metals pollutants are also highly affected by the amount of rainfall received (Adamcová et al., 2017). These issues are evidents in landfills without proper lining materials or when the lining is punctured or leaky where raw leachate may seep and contaminate the soil (Agamuthu and Fauziah, 2010). To make things worse, some of the landfills were constructed in lower topographic areas to maximize the disposal capacity (Lisk, 1991), but as the consequences, higher the risk of groundwater pollution due to the contact of groundwater table and waste materials and leachate (Cozzarelli et al., 2011; Jorstad et al., 2004). In Malaysia itself, most of the closed and other non-sanitary landfill lacked of the landfill bottom liner system which is crucial to confine and collect leachate from polluting the environment (Fauziah and Agamuthu, 2012).

Most of the implemented treatment process of landfill leachate in Malaysia are focussed on organic compounds and ammonia removal due to the high concentration of the constituents. Therefore, less attention were given to the removal of heavy metals from landfill leachate (Aziz et al., 2004). Surprisingly, studies from Agamuthu and Fauziah (2010), Atta et al. (2015), Jayanthi et al. (2016), Taha et al. (2011), Nor Amani Filzah and Suhaimi (2010), Rahim et al. (2010), Sakawi et al. (2013), Samuding et al. (2012), Syahirah et al. (2013), Suratman et al. (2011), Syafalni et al. (2014), Yusoff et al. (2013) has revealed the impacts of heavy metal to the groundwater and soil in vicinity of operating and even in closed landfill sites in Malaysia. Studies in the other landfills around the globe also revealed the contamination of soil with heavy metals (Adelopo et al., 2018; Bouzayani et al., 2014; Gwenzi et al., 2016; Krčmar et al., 2018; Vaverková et al., 2018). National Hydraulic Research Institute of Malaysia (NAHRIM) also reported that mercury and arsenic contamination from landfills into groundwater were 9% and 27% respectively (Tawnie et al., 2016) and these numbers will continuously grow if immediate remedial and protection are not taken. Scarcity of studies regarding the heavy metal contamination in landfill leachate and soil specifically has resulted in less attention focussed on the removal of these pollutants. Thus, with indiscriminate distribution of uncontrolled landfills and dumpsites in Malaysia, it is important to realize that the landfill leachate which are untreated and loaded with heavy metals may endanger environment and affect the ecosystems. Uncontrolled widespread of these pollutants may not only affect the surrounding environment and ecosystems (Vaccari et al., 2018), but also increase the risks of numerous types of cancer to human health (Chervona et al., 2012).

Concentration of heavy metal in the leachate and leachate-affected soil were determined and the most significant heavy metal pollutants were identified using ANOVA analysis. The main objective of this study is the characterization of leachate and soil samples from sanitary and non-sanitary (unlined) landfills, in relation to their content of heavy metals. This study attempts to investigate the degree of heavy metals pollution in non-sanitary landfills (operational and non-operational) as compared to sanitary landfills, and emphasize the importance of barrier or lining system to reduce the strong impact on the contaminants distribution around the landfills. Besides, this work also aimed to elucidate the efficacy of present landfill leachate treatment in terms of heavy metals pollution. Contamination potentials in leachate were identified based on quality rating scales (QRS), while the impact of heavy metal pollution onto soil were measured using geoaccumulation index (Igeo) and pollution index (PI). To better understand the extent of soil pollution, control samples (natural soils from unaffected areas of the landfills) were analysed. The results of this site investigation may provide invaluable information to mitigate on-going contamination, and managing current and future waste management approaches.

2. Materials and methods

2.1. Description of study areas

Seven landfills were selected based on their status to represent different types of landfills which are sanitary landfills, closed landfills, and open dumping sites (Fig. 1). General conditions of the landfills are summarized in Table 1.

Two sanitary landfills, namely Sungai Udang (SG) and Ladang Tanah Merah (LTM) sanitary landfills are located at Melaka and Negeri Sembilan respectively. Sungai Udang landfill has the daily disposal capacity of 1200 tonnes of waste, and occupies a total land area of 64 acre (JPSPN, 2015). This landfill is located about 25 km to the north-west of Melaka town, on the flat area surrounded by an oil palm plantation with a forest reserve situated at north-west and a coastline which is about 5 km to the south. It starts receiving waste on 1st of April 2015. Ladang Tanah Merah landfill is surrounded by oil palm plantation, with a total project area of 120 ha. LTM is not only a sanitary landfill, but also a designated waste to energy plant which will produce power from handling solid waste disposal. This landfill started its operation in 2015 and receives waste from Port Dickson, Nilai, Seremban and Tampin due to the closure of three other landfills nearby which are Sua Betong landfill, Bukit Palong landfill, and Kuala Sawah landfill which have reached their maximum capacity. This landfill has a capacity of 800 tonnes per day it provides salvaging yard for segregation of combustible and recyclable wastes. Both SG and LTM landfills are level 4 sanitary landfill and well equipped with engineered facilities of leachate and landfill gas management systems. The waste cells are lined with geo-synthetic clay liner and HDPE membrane. Leachate management system for both landfills includes sequential batch reactor (SBR) process, and dissolved air floatation (DAF) system as primary treatments before subjected to chemical treatment for removal of heavy metals. In addition, LTM will also adopt fully anaerobic bioreactor system for leachate treatment due to its efficiency, low energy use, and green energy generation. Effluent from the treatment plants will comply with the Second Schedule (Acceptable Conditions for Discharge of Leachate), Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009, before being discharged to nearby waterway. Nevertheless, part of the treated leachate from LTM will be recirculated back to cell and used for washing and cleaning.

Bukit Palong landfill (BP) is a closed open-dumping site which located in Lukut, Negeri Sembilan. This landfill has been operating since 1995 before being closed in 2016 due to its location which is nearby riverside area (Sungai Menyala) and near residential area. During the operation, the landfill received about 480 tonnes of domestic and commercial wastes daily from surrounding area (JPSPN, 2015). This landfill was converted to an intergrated renewable energy park (Berhad, 2018), equipped with gas and leachate collections and treatment systems after the safe closure procedures. Nevertheless, the waste disposal areas (closed waste cells) were unlined with proper liner system.

Pajam landfill (PJ) has been operating from year 1993 as an open tipping site which receives about 380 tonnes domestic, commercial and industrial wastes from the districts of Nilai and Pajam, Negeri Sembilan. In 2016, this landfill was closed due to its location which was near residential areas and several other issues such as river water contamination (Sg. Pajam) (Zaini et al., 2010), causing odour pollution to its surrounding areas (Sakawi et al., 2011), and also few occasion of landfill fires (JPSPN, 2015). Upon its closure, this landfill was transformed into an integrated renewable energy park which was able to generate 8 MW of energy from landfill by-products like biomass and biogas (Berhad, 2018). This landfill was also facilitate with leachate collection and treatment system, as well as groundwater monitoring wells. Nonetheless, similar with the other closed landfills, though leachate is collected, existing waste disposal cells were still unlined thus the risk of leachate to seep into the soil and groundwater and leached out of the landfills were still high.

Ulu Maasop landfill is a non-sanitary landfill which located in Senaling, Kuala Pilah, and Tampin Negeri Sembilan respectively. Ulu Maasop landfill started its operation in 1982 and receives about 60 tonnes of domestic wastes per day (JPSPN, 2015). The first phase of the Ulu Maasop landfill has undergo safe closure procedures in 2013 (UMC). The other part of the landfill is still active and accept wastes from Kuala Pilah area (UMO). The site is an active open tipping before being upgraded to a controlled waste disposal site. However, there was no proper liner system for both active and closed cells at the landfill to prevent percolation of leachate into the groundwater and soil. In this landfill, the leachate generated were not only originated from the active waste cells, but also from the closed cell. As for the closed phase, leachate collection system has been installed and leachate generated were directed to a well. Nevertheless, leachate from the well were not directed to a leachate pond due to malfunction of the system. Leachate overflow from the well and fresh leachate from active dumpsites flowed directly into the storm water drainage without any treatment.

Kampung Keru landfill (KK) is located in a rural area near agricultural farmland, residential and oil palm plantation in Tampin, Negeri Sembilan. It has neither a bottom liner nor a leachate collection system, thus it is known as an uncontrolled landfill. The landfill was opened in 1988 and receives about 135 tonnes of wastes (basically domestic and agricultural wastes) (JPSPN, 2015). Untreated leachate from this landfill flow into tributary rivers nearby and also infiltrate into groundwater and affected agricultural and aquaculture activities.

2.2. Leachate and waste-impacted soil samplings

Leachate and soil samples were collected from landfills a few cycles from June 2016 to June 2018. Leachate samples from dump sites (Ulu Maasop and Kampung Keru) were collected and analysed periodically in three (3) years (2016, 2017, and 2018) to monitor closely the quality of leachate generated in both landfills. The leachate samples from sanitary and closed landfills (SG, LTM, BP and PJ) were collected from raw leachate collecting ponds, or leachate pumping chamber of the cells and at the discharge points of treated leachate. As for UMC, since no treatment plant is available, leachate were collected from a well and leachate runoff from the closed cell of the landfill. Meanwhile, leachate samples from the open dumping site (UMO and KK) were collected from drainage canal and leachate streams within the landfills. HDPE bottles that were used as collection bottles were rinsed with leachate before actual samples were taken. Leachate samples were stored for the analysis of general parameters and about 200 mL of the samples were acidified with concentrated nitric acid to a pH below 2.0 to prevent precipitation of heavy metals.

Soil from sanitary (S1 and S2) and closed landfills (C1 − C5) were collected at the landfills waste retaining soil-bund, while soil samples from open dump (D1 − D5) were from random locations which are affected by wastes and leachate. For comparison, soil samples were also taken from unaffected areas (by leachate and wastes) but still within the landfills (SN1 and SN2; CN1 − CN5; DN1

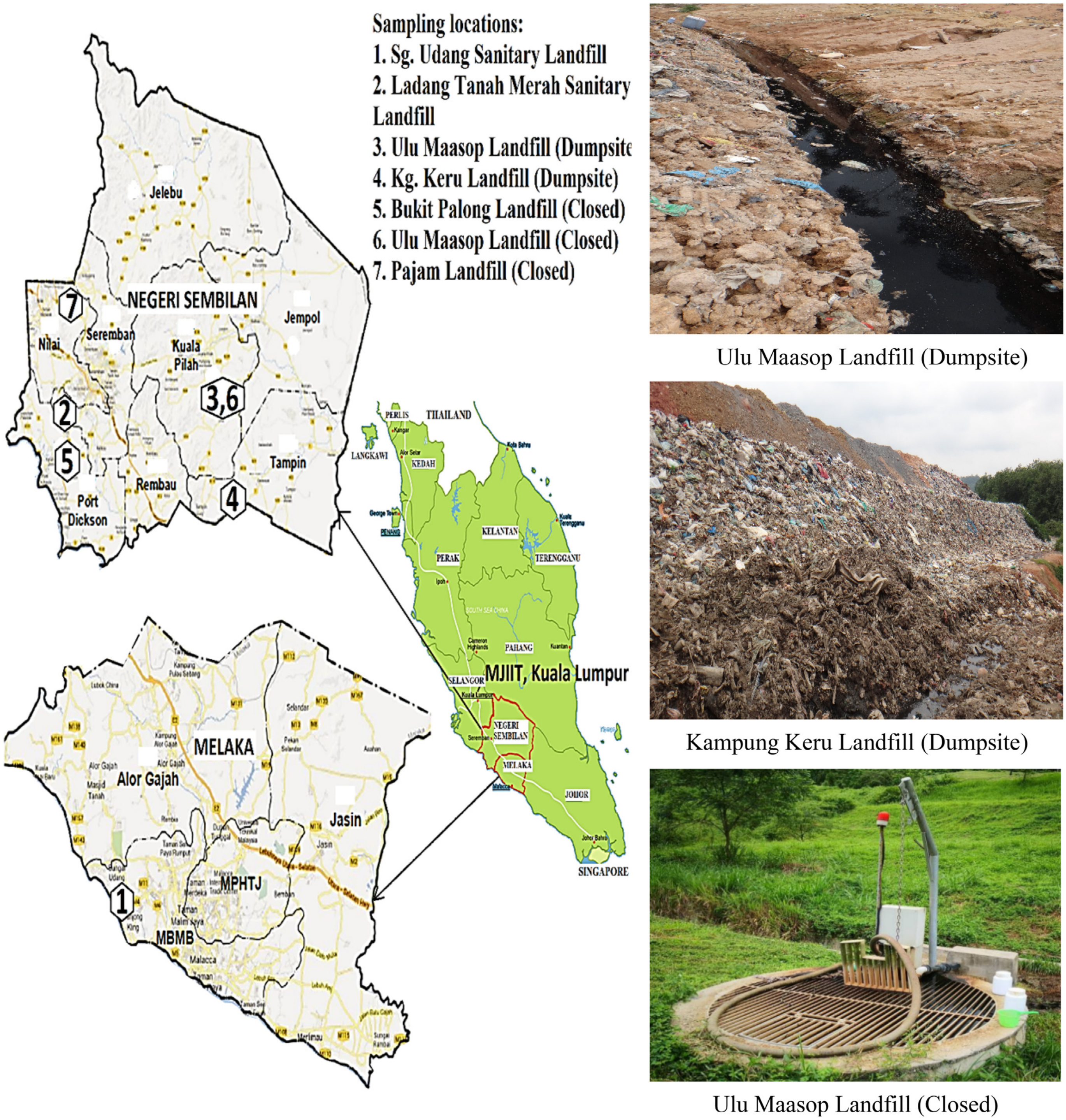

Fig. 1. Locations of study areas.

– DN5). This sample were referred as control samples to epitomize the quality of the native soils. The soil samples were collected at a depth of about 10–50 cm from soil surface using hand auger and hand trowel. The soil samples were kept in polyethylene bags and transported into the laboratory. After collection, the soil was dried at room temperature, ground and sifted through 2 mm sieve.

2.3. Analytical methods

The general parameters of landfill leachate; temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity and dissolved oxygen (DO) were measure in situ with portable multi-meter probe (HORIBA U-50 Series Multi-Parameter Water Quality Meter). The preserved leachate samples were filtered through 0.45 μm pore size polytetrafluoroethylene (PTFE) membrane syringe filter and analysed for heavy metals concentrations using Inductively Coupled Plasma – Optical Emission Spectrometry (ICP Optima 7300DV, PerkinElmer Instruments, USA). The dissolved metals contents in leachate were analysed according to Standard Methods for Examinations of Water and Wastewater (EPA 3120A)

Table 1
General conditions of the selected Malaysian landfills/dumpsites.

	Sg. Udang	Ladang Tanah Merah	Bukit Palong	Ulu Maasop[a]	Pajam	Kg. Keru
Landfills category	Sanitary	Sanitary	Non-sanitary (upgrade)	Non-sanitary (upgrade)	Non-sanitary (upgrade)	Non-sanitary
Age of landfills (years)[b]	2	2	22	36	24	30
Geographical coordinates	N 2.29926° E 101.1550°	N 2.66122° E 101.8173°	N 2.58330° E 101.8325°	N 2.68110° E 102.2509°	N 2.836265° E 101.8500°	N 2.488778° E 102.3015°
Status of landfills	New-active	New-active	Old-closed	Old-closed/active[a]	Old-closed	Old-active
Landfills area (m^2)	259 000	1 200 000	133 000	81 000	279 000	240 000
Average daily (tonnes)	1200	800	480	60	380	135
Bottom liners	Yes	Yes	No	No	No	No
Soil cover	Yes	Yes	Yes	No	Yes	No
Leachate collection	Yes	Yes	Yes	No	Yes	No
Leachate treatment	Yes	Yes	Yes	No	Yes	No
Distance to river	1 km	7 km	<0.5 km	<2 km	0.6 km	2 km

[a] Ulu Maasop landfill are divided into two phases, which are closed landfill and open dumpsite.
[b] Age and status of landfills were based on during the leachate and soil sampling.

(APHA, 2011). The soil samples were digested using the procedures described in Standard Methods for Examinations of Water and Wastewater (EPA 3051A) (APHA, 2011). Digestion was performed using nitric (HNO_3, 65%) and hydrochloric (HCl, 37%) acids (Sigma Aldrich) as these strong and concentrated mixture is capable of extracting inorganic metals. 0.5 g of sieved soil samples were placed into Teflon vessels. Then, 12 mL of aqua regia (1 part of HNO_3 + 3 parts of HCl) were added into the vessels. Digestion was performed with the pressurized microwave extraction in Multiwave 3000 Solv (Anton Paar) Microwave Reaction System. After digestion procedure and cooling, sample digests were filtered through 0.45 μm pore size polytetrafluoroethylene (PTFE) membrane syringe filter, then they were transferred in 50 mL flask and brought to volume using ultra-distilled water. Similar with landfill leachate samples, the digested soil were analysed using ICP-OES spectrometer in BIOREC Laboratory, Universiti Teknologi MARA. The analysis included the following metals; As, Cd, Cu, Cr, Ni, Zn, Mn, Fe, Pb, Se and Co. Heavy metal contents in leachate and soil were determined in triplicate for each sample and average values were reported. Besides analysis of replicates, the analysis also implements the use of standard operating procedures which include calibration with standards, analysis of reagent blanks, and recovery of spiked.

2.4. Statistical analysis

Statistical evaluation was analysed through analysis of variance (ANOVA) to evaluate the differences of heavy metal concentrations in leachate and impacted soil for different landfill sites investigated. The set of data for heavy metal concentrations were considered significant at $p < 0.05$, and F-value larger than F-critical value in the analysis.

2.5. Pollution assessment of heavy metals in leachate and waste/leachate-impacted soil

To determine the contamination potential of heavy metals in leachate, quality rating scales (QRS) (Ramakrishnaiah et al., 2009) values of each sampling points were calculated as per equation shown below:

$$q_i = \frac{C_i}{S_i} \times 100 \qquad (1)$$

Where;

q_i = Quality Rating Scale (%);
C_i = Concentration of heavy metal in leachate (mg/L); and.
S_i = Maximum permissible level of heavy metal (tolerance limit) in landfill leachate (mg/L) (EQA, 2009).

QRS were obtained by dividing heavy metal concentrations in leachate (and treated leachate) with the Standard − Acceptable Condition for Discharge of Leachate (EQA, 2009). The QRS values for heavy metal in leachate exceeding 100% represent poor quality of leachate, and immediate action should be taken if the values are more than 300%.

Environmental impact of heavy metal as well as the level of soils pollution can be determined using geo-accumulation index (Igeo) and pollution index (PI). The used of these indices also may help to evaluate the anthropogenic pollution as compared to natural element contents. Igeo is widely used to evaluate anthropogenic pollution as compared to the natural element content in soil (Kowalska et al., 2018; Müller, 1969). It is the assessment of soil contamination based on the ratio between the current metal contents in soil with the reference geochemical background for metals.

PI and IPI give an indication of the pollution risk to the environment (Tomlinson et al., 1980). Pollution index is given as a ratio between the content of each metal in the sample to the background values. Whilst integrated pollution index (IPI) reveals the degree of heavy metal toxicity and can be used to estimate the pollution status of heavy metals in a given area.

Classifications, range of values, and contamination levels of soil pollution indices applied are presented in Table 2. Igeo, PI, and IPI were determined using by the following equations:

$$\boldsymbol{Igeo} = \boldsymbol{log}_2 \frac{\boldsymbol{C_n}}{1.5 \times \boldsymbol{B_n}} \qquad (2)$$

$$\boldsymbol{Pollution}\ \text{index}(\boldsymbol{PI}) = \frac{\boldsymbol{C_n}}{\boldsymbol{B_n}} \qquad (3)$$

$$\boldsymbol{Integrated}\ \text{pollution index}(\boldsymbol{IPI}) = \sqrt[n]{\boldsymbol{PI}_1 \times \boldsymbol{PI}_2 \times \boldsymbol{PI}_3 \times \ldots \boldsymbol{PI_n}} \qquad (4)$$

Where C_n is the mean concentration of heavy metal in polluted soils, while B_n refers to geochemical background of average shale values or the average crustal abundance data as reference baselines (Rudnick and Gao, 2013), and n is the number of metals. Soil pollution indices were calculated using heavy metals composition from upper continental crust (lithogenic contents of heavy metals in soil) which values were not under the influence of pedogenic processes (Kowalska et al., 2018). The estimation of the trace element compositions of the upper continental crust by Rudnick and Gao (2013) were recommended based on the average values of surface exposures, sedimentary and loess data of previous studies (Rudnick and Gao, 2013). The factor 1.5 is referring to

Table 2
Soil pollution risk assessment of heavy metals.

Indices	Values	Class	Pollution risk
Geoaccumulation index, Igeo (Müller, 1969)	Igeo ≤ 0	0	Unpolluted
	0 < Igeo < 1	1	Unpolluted to moderately polluted
	1 < Igeo < 2	2	Moderately polluted
	2 < Igeo < 3	3	Moderately to strongly polluted
	3 < Igeo < 4	4	Strongly polluted
	4 < Igeo < 5	5	Strongly to extremely polluted
	5 < Igeo	6	Extremely polluted
Pollution index, PI (Tomlinson et al., 1980)	PI < 1	1	Unpolluted
	1 ≤ PI < 2	2	Slightly polluted
	2 ≤ PI < 3	3	Moderately polluted
	PI ≥ 3	4	Extremely polluted
Integrated pollution index, IPI (Tomlinson et al., 1980)	IPI ≤ 1	1	Unpolluted
	1 < IPI ≤ 2	2	Moderately polluted
	IPI > 2	3	Extremely polluted

background matrix correction factor introduced to minimize possible variations in background values due to lithospheric effects (Stoffers et al., 1986) as well as very small anthropogenic influences (Loska et al., 1997).

3. Results and discussion

3.1. Physical-chemical and heavy metals characteristics, and contamination potential in leachate from sanitary, closed and open dumping sites

The comparison of physical-chemical and heavy metals characteristics in raw leachate and treated leachate from sanitary, closed and open dumping site were shown in Table 3. Concentration of heavy metals were mentioned as average value for each particular sampling points. As for sanitary landfills (Sungai Udang, SG and Ladang Tanah Merah, LTM) and also closed landfills (Bukit Palong, BP and Pajam, PJ) where leachate treatment plant (LTP) were available, samples were collected from the raw leachate pond and at the discharge point of the LTP. In Pajam landfill, leachate sample was also collected from the surface drain which was located around waste cell which was still undergoing safe closure. Leachate samples were collected from different points/stream of leachate for Ulu Maasop (closed), UMC, Ulu Maasop (active), UMO and Kampung Keru, KK landfills since no proper collection for leachate nor treatment of leachate were available. Quality rating (QRS) values, to represent the pollution levels of heavy metals in landfill leachate (and treated leachate) were presented in Table 4.

Table 3
Physical-chemical and heavy metal characteristics of the landfills leachate.

Locations			pH	EC	TDS	DO	As	Cd	Cu	Cr	Ni	Zn	Mn	Fe	Pb	Se
Sanitary Landfills																
SG	SG1	Leachate pond	6.64	22.30	13 800	0.52	**0.0628**	0.0020	0.0205	**0.1712**	0.1963	0.2295	0.1697	2.7464	0.0065	0.0025
	SG2	Treatment	7.87	22.40	13 900	0.58	**0.0715**	0.0020	0.0094	**0.1457**	**0.2002**	0.1011	0.0814	0.8962	0.0043	0.0135
	SG3	Treatment	7.30	21.50	13 400	0.48	**0.0671**	0.0020	0.0095	**0.1418**	0.1983	0.1537	0.0614	0.8583	0.0003	0.0169
	SG4	Treatment	6.58	16.10	10 000	0.64	**0.0602**	0.0020	0.0257	**0.1216**	**0.2176**	0.1423	0.1527	1.3614	0.0001	0.0180
	SG5	Treatment	6.40	15.90	9800	0.67	0.0453	0.0024	0.0236	**0.1167**	**0.2125**	0.1228	0.1471	1.1112	ND	0.0244
	SG6	Discharge point	6.97	1.40	888	0.62	0.0081	0.0033	0.0036	0.0114	0.0202	0.0482	0.0203	0.3404	0.0079	0.0156
LTM	LTM1	Leachate pond 1	8.11	16.40	10 200	3.47	**0.0973**	0.0027	0.0055	**0.0898**	0.0569	0.1046	0.0403	2.3949	0.0058	**0.1522**
	LTM2	Leachate pond 2	8.50	4.47	2880	13.59	**0.0754**	0.0045	0.0002	0.0205	0.0266	0.0457	0.0457	0.2384	0.0128	**0.0539**
	LTM3	Discharge point	7.80	0.62	396	9.48	0.0128	0.0044	0.0032	0.0032	0.0035	0.1012	0.0697	3.4474	0.0109	**0.0513**
Closed Landfills																
BP	BP1	Leachate pond	**3.99**	6.74	4250	3.61	**0.1283**	0.0037	0.0198	**0.0831**	0.0531	0.1785	**0.7262**	**13.8220**	0.0120	0.0069
	BP2	Treatment	6.10	6.85	4320	1.09	**0.1258**	0.0042	0.0116	**0.0965**	0.0662	0.4391	**0.9760**	**14.6907**	0.0140	0.0068
	BP3	Discharge Point	**4.47**	8.84	5570	4.20	0.0097	0.0024	0.0372	**0.0667**	0.0699	1.4556	**3.6048**	**10.5148**	0.0078	0.0113
PJ	PJ1	Fresh leachate	8.74	17.90	11 100	0.90	0.0065	0.0080	0.0210	**0.1075**	0.1155	0.1540	0.1260	**5.7945**	0.0135	**0.0305**
	PJ2	Leachate pond	7.88	11.80	7290	2.48	0.0020	0.0070	0.0190	**0.0605**	0.0620	0.1125	0.1690	**7.6180**	0.0115	**0.0385**
	PJ3	Discharge point	7.25	9.81	6180	2.48	0.0100	0.0070	0.0090	0.0080	0.0170	0.1125	**0.4255**	0.0325	0.0060	0.0075
UMC	UMC1	Fresh leachate	6.85	17.60	10 500	3.51	**0.1339**	0.0078	0.0551	**0.1635**	0.1257	0.3782	**0.3809**	**16.2411**	0.0351	**0.0731**
	UMC2	Fresh leachate	6.05	10.60	5950	3.41	**0.1531**	0.0082	0.0598	**0.1641**	0.1323	0.3943	**0.4594**	**16.6064**	0.0433	**0.0694**
Open Dumping Sites																
UMO	UMO1	Fresh leachate	8.12	25.60	15 900	3.07	**0.2741**	0.0057	0.0409	**0.3305**	0.1511	0.8727	**0.5982**	**18.3039**	0.0553	**0.0243**
	UMO2	Fresh leachate	7.76	23.00	11 400	2.30	**0.2740**	0.0046	**0.2103**	**0.1740**	0.1160	0.6520	**0.3120**	**14.5600**	0.0000	**0.2510**
	UMO3	Fresh leachate	6.82	12.00	6690	4.97	**0.3936**	**0.0122**	0.0559	**0.2190**	0.1222	0.4088	**0.1177**	**8.6929**	0.0392	**0.1065**
KK	K1	Fresh leachate	7.70	33.90	20 800	4.11	**0.2942**	0.0041	0.0564	**0.2758**	**0.2151**	0.4202	**0.3167**	**20.0343**	0.0541	**0.0956**
	K2	Fresh leachate	**4.35**	24.60	15 300	4.20	**0.2014**	0.0061	**0.2754**	**0.2437**	**0.3037**	**3.2715**	**3.1536**	**133.4700**	**0.6908**	ND
	K3	Fresh leachate	8.59	13.57	6810	1.91	**0.0680**	ND	0.0840	**0.1000**	0.1140	0.6560	**0.3040**	**16.5940**	0.0120	ND
	K4	Fresh leachate	7.84	9.44	5720	0.91	**0.1162**	0.0077	0.1074	**0.0984**	0.0914	0.1784	**0.3282**	**10.1317**	0.0377	**0.2198**
	K5	Fresh leachate	6.34	6.36	3750	2.22	**0.1888**	0.0078	0.0507	**0.1019**	0.1006	0.1588	**0.2945**	**14.1871**	0.0339	**0.0808**
Leachate Discharge Standard*			6.0–9.0				0.0500	0.0100	0.2000	0.0500	0.2000	2.0000	0.2000	5.0000	0.1000	0.0200

Notes: Data for concentrations of heavy metals in leachate are expressed as means of three (3) replicates; EC - electrical conductivity; DO – dissolved oxygen; ND – not detected; All units in mg/L except for pH and E.C. (ms/cm); Leachate Discharge Standard - Acceptable Conditions for Discharge of Leachate, Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfills) Regulations 2009; Bold values indicate higher than standard values.

Table 4
Quality rating of heavy metals in landfill leachate.

Sampling Locations		QRS_{AS}	QRS_{CD}	QRS_{CU}	QRS_{CR}	QRS_{NI}	QRS_{ZN}	QRS_{MN}	QRS_{FE}	QRS_{PB}	QRS_{SE}
Sanitary Landfills											
SG1	Leachate pond	126	20	10	342	99	11	85	55	7	13
SG2	Treatment	143	20	5	291	100	5	41	18	4	68
SG3	Treatment	134	20	5	284	99	8	31	17	0	85
SG4	Treatment	120	20	13	243	109	7	76	27	0	90
SG5	Treatment	91	24	12	233	106	6	74	22	-	122
SG6	Discharge point	16	33	2	23	10	2	10	7	8	78
LTM1	Leachate pond 1	195	27	3	180	28	5	20	48	6	761
LTM2	Leachate pond 2	151	45	0	41	13	2	21	5	13	270
LTM3	Discharge point	26	44	2	6	2	5	35	69	11	257
Closed Landfills											
BP1	Leachate pond	257	37	10	166	26	9	363	276	12	35
BP2	Treatment	252	42	6	193	33	22	488	294	14	34
BP3	Discharge Point	19	24	19	133	35	73	1802	210	8	57
PJ1	Fresh leachate	13	80	11	215	58	8	63	116	14	153
PJ2	Leachate pond	4	70	10	121	31	6	85	152	12	193
PJ3	Discharge point	20	70	5	16	9	6	213	1	6	38
UMC1	Fresh leachate	268	78	28	327	63	19	190	325	35	365
UMC2	Fresh leachate	306	82	30	328	66	20	230	332	43	347
Open Dumping Sites											
UMO1	Fresh leachate	548	57	20	661	76	44	299	366	55	122
UMO2	Fresh leachate	548	46	106	348	58	33	156	291		1255
UMO3	Fresh leachate	787	122	28	438	61	20	59	174	39	533
KK1	Fresh leachate	588	41	28	552	108	21	158	401	54	478
KK2	Fresh leachate	403	61	138	487	152	164	1577	2669	691	-
KK3	Fresh leachate	136	-	42	200	57	33	152	332	12	-
KK4	Fresh leachate	232	77	54	197	46	23	164	203	38	1099
KK5	Fresh leachate	378	76	25	204	50	8	147	284	34	404

3.1.1. *Sanitary landfills*

Less than six percent of the total disposal sites in Malaysia are classified as sanitary landfill which are facilitates with proper leachate collection and treatment, together with proper lining system underneath the waste cells and soil cover for soil and groundwater pollution protections, whilst the rest are typical actives or closed dumping grounds. Raw leachates from sanitary landfills in Malaysia normally undergo designated treatment which includes sequential batch reactor (SBR), dissolved air flotation (DAF) system, and also sand and activated carbon filter (Ishak et al., 2016; Jumaah et al., 2016). Similarly, specified treatment also applied in both SG and LTM leachate as described in the previous section (study areas).

Therefore, it can be seen that physical characteristics and heavy metal concentrations of treated leachate were much lower than raw leachate (leachate entering the treatment system) in both sanitary landfills where sampling were conducted. The pH in SG and LTM were in the range of 6.40–7.87 and 7.8 to 8.5 respectively. It is observed that the leachate samples had slightly high pH, showing an early sign of methanogenic phase (Rahim et al., 2010; Vasanthi et al., 2008) or an indicator of mature leachate (Jorstad et al., 2004), despite being young landfills (in term of the age of operations). Tchobanoglous et al. (1993) illustrated in his studies that for new landfills, normal pH values are 4.5–7.5 and for mature landfills, pH may varies from 6.6 to 7.5. Comparing SG and LTM, SG landfill has low DO levels and high conductivity (EC), whereas LTM leachate were in opposite conditions. TDS, which postulates a strong relationship with EC, were also observed to be in high values in SG landfill leachates which reflects high content of inorganic constituents (Al-Yaqout et al., 2005; Kurniawan et al., 2006; Naveen et al., 2017).

Elevated As and Cr levels were observed in raw leachate in both sanitary landfill sites (SG and LTM). Nevertheless, after leachate treatment, the levels of both pollutants were successfully reduced to permissible standard limit prior to discharge. The strength of contamination in leachate in sanitary landfills studied were found to be not very high. This is probably due to the effects of soil cover, which functions not only to reduce odour and inhibits rodents and flies, but will ultimately reduce moisture contents in the waste. The concentrations of Cd, Cu, Ni, Zn, Mn, Fe, and Pb in leachate for both sanitary landfills were observed to be below the stipulated standard. Nevertheless, it is observed that besides As and Cr, the concentration of Se in LTM was about 8 times higher than permissible limit of 0.02 mg/L and it was only reduced to 0.05 mg/L after the treatment. Elevation of As, Cr and Se levels are most probably associated agricultural activities and industrial processes. Wood wastes, from constructions and demolitions, utility posts, motorway fencing barriers, landscaping structures and wood products factories may also contribute to elevated of metals contents especially As, Cr and Cu due to the leaching of these metals from the wood which are normally treated with chromated copper arsenate (CCA) preservatives (Wong and Chin, 2016). The most serious risk occurs when the treated wood is burned. Nevertheless, both these parameters are often overlooked in most screening, monitoring and pollution control programs despite the widespread of environmental threat brought by these pollutants (Lemly, 2004).

Exceedance in As was also detected in Jeram sanitary landfill, with the value of 0.67 mg/L, 13 times higher than the stipulated standard. Besides As, Cr (0.65 mg/L), Zn (3.27 mg/L) and Ni (0.32 mg/L) were also among the triggering pollutants in this landfill (Ishak et al., 2016). Pb value as high as 3 mg/L was also reported by Aziz et al. (2010) in Pulau Burung sanitary landfill, about 30 times more than the stipulated standard. A study by Zamri et al. (2015) also revealed exceedance in the most of the metal concentrations analysed (Fe, Cd, Cu, Mn, Pb and As) in the leachate samples in Pulau Burung sanitary landfill. However, there were no available data on the quality of the discharge leachate (treated leachate). It is important to realize that overflow or malfunction of the leachate treatment systems should be avoid. Details characterizations of leachate were also needed to ensure efficiency of the treatment as biological treatments such as aerobic, anaerobic, sequencing batch reactor, aerated lagoons and activated sludge are more suitable for young leachate (Kurniawan et al., 2006). Whilst stabilized leachate, such as in Pulau Burung and Jeram sanitary landfills, shown with lower biodegradable compound (BOD/COD ratio of 0.11 and 0.06 respectively) (Aziz et al., 2010; Zamri et al., 2015), should be treated with extensive physico-chemical treatment for better removal of heavy metals and other persistent recalcitrant compounds (Kamaruddin et al., 2015; Renou et al., 2008).

In sanitary landfills, besides the issues of efficiency of leachate treatment, the risk of leachate emission to the adjacent area is inevitable due to the influence of surface runoff or heavy rainfall (Yusof et al., 2009). Attention should also be taken to monitor the failure risk of the landfill liner, as it may become brittle or leak due to natural deterioration (Fauziah et al., 2011). Thus, in order to avoid this inhibitory events, continuous monitoring at the point of discharge of leachate treatment plants and also nearby waterway should be perform.

3.1.2. Closed landfills

In this study, closed landfills studied were non-sanitary landfills. Two of it (BP and PJ) were controlled closed landfills while the other one (UMC) was uncontrolled closed landfill. All of these landfills has been was upgraded and facilitate with leachate collection system. Nevertheless, only BP and PJ landfills proceed with the treatment of collected leachate, whereas in UMC collected leachate were left untreated. These landfills are considered as old and mature landfills (as the age of landfill are more than 20 years). Leachate samples from BP landfill were collected from raw leachate pond in the leachate treatment plant, as well as the sampling for the treated leachate at the discharge point. Raw and treated leachate were also collected from the leachate treatment plant in PJ landfill. On the contrary, for UMC, leachate samples were collected at the well (pump station which was malfunctioned) and leachate stream which are flowing to the nearby monsoon drain located near the landfill.

In general, it can be observed that heavy metal concentrations in both landfills (BP and UMC) were slightly higher than those observed in sanitary landfills. The situation is contradictory with those commonly reported in the literature, where old landfills (mature landfills) normally have lower concentrations of inorganic constituents (Calli et al., 2005; Christensen et al., 2001b; Kjeldsen et al., 2002; Kulikowska and Klimiuk, 2008; Srivastava et al., 2005). Apart from the age of landfills, the fact that these landfills have already stop operating should lead to much lower concentrations of heavy metal, as there were no new wastes deposited to the landfill cells, but it was surprisingly higher, especially for several toxic metals such as As, Cr, Se, and inorganic macrocomponents such as Mn and Fe. The presence of heavy metal compounds could inhibit the biological process hence reducing the leachate treatment efficiency (Calabrò et al., 2018). In addition, the strong dark color as observed in the leachate collection pond may also be an indicator of inefficiency of the biological treatment, due to the retardation of microorganisms growth (Müller et al., 2015).

As, Mn and Fe shown to be predominant metals in raw leachate for BP landfill and leachate treatment provided has slightly reduced the impacts especially for As (from 0.1258 mg/L to 0.0097 mg/L) after treatment of leachate. However, due to the accumulation of Fe and Mn in raw leachate, shown with all the QRS values of more than 100, the treatment provided in BP landfill which is aeration (sequencing batch reactor, SBR) seemed insufficient to reduce the concentrations of both metals. Aeration technique is more suitable to remove some contaminants like phenolic compound, but not really efficient in treating heavy metals (Aziz et al., 2010; Yazici et al., 2012). Adsorbent supplemented SBR technique (Mojiri et al., 2012) or other physicochemical treatment might improve the treatment efficiency for stabilized leachate (Jumaah et al., 2016). From the monitoring, pH of samples in BP are acidic (3.99). Hence, attention should be given more on the leachate quality as it is well known that metal dissolution is enhanced at low pH (Kjeldsen et al., 2002). Another key point is, the older the landfill (methanogenic phase), the biodegradation treatment will be less efficient due to the lower biodegradable compound and higher refractory contents (Yuan et al., 2016), thus, decrease the efficiency of the treatment and may cause elevated level of heavy metals and metalloids in the leachate (Tenodi et al., 2020).

On the other hand, the condition is not the same for UMC as this landfill was merely closed, but uncontrolled. Leachate from closed waste cells were pumped and directed to a well, but left unattended and untreated. Poor quality of the leachate overflow from the pump and leachate runoff especially for As, Cr, Mn, Fe and Se appear to be potential risks as it was discharged into inland surface water without any treatment. Relatively high QRS values for heavy metals, especially for toxic metals such as As (268 and 306), Cr (327 and 328) and Se (365 and 347), as well as Mn (190 and 230) and Fe (325 and 332) may pose a significant threat to the environment and ecosystems especially as it were flowing directly to the waterway nearby the landfill. Similar conditions were reported for leachate concentration in other closed landfills in Malaysia, especially in Ampar Tenang landfill, with elevated in most heavy metal parameters (Cd, Ni, Cu, Pb and As) (Ashraf et al., 2013) and Air Hitam landfill, which As and Cd values exceeded the stipulated standard (Nur Fatin Dahlia and Ku Halim, 2013). These situations show that proper closure and post-closure environmental monitoring especially at non-sanitary landfills are crucial as to reduce detrimental impacts of leachate to the environment especially due to the facts that unlike organic contaminants, inorganic contaminant do not degrade (Adelopo et al., 2018).

In contrast with BP and UMC landfills leachate, the concentration of metals from PJ landfill were observed to be fairly low, possibly due to humic subtances produced by the degradation of the waste or sorption of metals onto the clay mineral in the soil (Mwiganga and Kansiime, 2005). However, unlike the closure of sanitary landfills, this non-sanitary landfill is facing issues such as almost all of the closed wastes cells in this landfill are unlined. Though the whole areas (waste cells) were covered with geomembrane to prevent precipitation into the waste layer, it might only reduce probably around 40 percent of leachate generated (Fauziah and Agamuthu, 2010). This is because large percentage of the wastes dumped in the landfills in developing countries like Malaysia were organic wastes which may produce high volume of leachate (Jayanthi et al., 2016; Moh and Abd Manaf, 2017). Thus, monitoring of surrounding water bodies such as stream and groundwater were crucial in vicinity of unlined landfills even if it were closed.

3.1.3. Dumping sites

Both open dumping sites (KK and UMO) showed significant potential risk due to the discharge of higher concentrations of most of the metals throughout the study areas. Heavy metals investigation in both open dumpsites showed that the concentration of As, Cr, Mn, Fe and Se were highly above the stipulated standard for leachate discharge. This suggest a very serious threat to the environment due to the nature of uncontrolled dumping sites which lack of proper liners and collection system where raw leachate will laterally seep into and contaminate the soil and also groundwater. Dumping of waste directly on the earth surface may lead to formation of anoxic or reducing condition in the underlying aquifer due to redox shift caused by high organic contents in leachate plume and cessation of oxygen diffusion in the aquifer. The microbial decomposition of organic matter may have attributed to mobilization of iron and arsenic (Zheng et al., 2004). Arsenic and several other heavy metal pollutants might be very toxic and dangerous to every form of life, even at minute concentrations (Jayanthi et al., 2016). In Malaysia, most of its older landfills do not have a barrier system/liner nor the leachate collection system to restrict the dispersal of leachate into the soil and groundwater.

Generally, non-sanitary landfill sites in this study (BP, PJ, UMC, UMO and KK) were considered as old landfills. Based on the characterizations of leachate studies conducted by Hussein et al. (2019) in Ulu Maasop, Kampung Keru and Pajam (UMC, UMO, KK and PJ), it has been observed that landfill leachate in these landfills were in methanogenic phase. During this phase, volatile fatty acids which normally high in leachate in earlier phase (acidic phase) will be degraded by methanogenic bacteria and reduce the organic strength of the leachate, leading to higher pH, as mostly observed in the aged landfills in these studies (Ehrig, 1984; Kulikowska and Klimiuk, 2008; Kurniawan et al., 2006; Ziyang et al., 2009). Thus, even with continuous wastes being dumped in the landfills (in UMO and KK), the leachates were not in acidogenic condition due to greater ratio of old and stabilized leachates (Demirbilek et al., 2013).

It was reported previously that the concentrations of inorganic macro-components (Fe and Mn) and other heavy metals were generally lower in this phase (methanogenic phase) which is due to higher pH and enhance sorption and precipitation of metals (Christensen et al., 2001a; Ehrig, 1983; Kjeldsen et al., 2002; Kulikowska and Klimiuk, 2008). Nevertheless, heavy metals such as As, Hg and Co were not dealt in this context as it were considered rare metals in leachate. Contradictory to the norm of old and mature landfills, results observed in this study indicates that most metals, especially toxic metals such as As, Cr and Se were found to be in high concentrations. QRS for As were all above 500 in UMO and within 136−588 in KK landfill. Besides, maximum QRS of 661 for Cr and 1255 for Se were also observed in UMO landfill. Similarly, significantly high concentrations of Cr, Mn, Fe and Se were observed in KK landfill with QRS values as high as 552, 1577, 2669 and 1099 respectively. As for these active dumpsites (UMO and KK), these situations were probably due to continuous discharges of fresh waste into these landfills. KK2 leachate for instance, which has merely exceedance in most heavy metals analysed, were sampled at leachate stream flowing into nearby tributaries river located nearby the dumpsite. Elevated concentrations of As, Cr, Fe, Mn and Pb in this leachate stream might pose extreme hazards to the receiving stream and ecosystems.

The main origin of heavy metals in leachate were glasses, metals, pesticides, fertilizers, paints, construction and demolition debris (Jambeck et al., 2008; Weber et al., 2002), and CCA-treated wood (or preservative for timber) (Jambeck et al., 2007; Jones et al., 2019; Karnchanawong and Veerakajohnsak, 2010; Townsend et al., 2004; Wong and Chin, 2016) destined to the landfills. High concentration of Cr in the leachates could be attributed due to the dumps of household batteries, colored polyethylene bottles, discarded plastic materials and empty paint containers, also wastes from tannery and electroplating industries (Karnchanawong and Limpiteeprakan, 2009).

In Malaysia, heavy metals contamination from dumpsites is not a new issue. Similar situation was also observed in leachate in Ampar Tenang (Selangor) landfill where high concentration of heavy metals (Cd, Ni, Cu, Pb, and As) were observed. Elevated concentrations of As, Pb, Cu, Ni, and Cd were also observed in the groundwater sampling points in vicinity of the landfill (Ashraf et al., 2013). Aziz et al. (2010) also reported significant Pb, Cu and Ni concentrations in their studies in Kulim (Kedah) and Kuala Sepetang (Perak) landfills. Zin et al. (2013) recorded high values of Cd and other parameters in leachate from Matang (Perak) and Kuala Sembeling (Kedah) landfills. High amount of Fe, Ni and Mn also observed in Matang (Perak) and Beriah (Perak) landfills leachate (Syafalni et al., 2014). Nor Nazrieza et al. (2015) in their studies reported significant amount of Pb, Cu and Cd in leachate from Panchang Bedena (Selangor) and Batang Padang (Perak) landfills. Leachate in Beris Lalang (Kelantan) landfill also shown exceedance of standard discharge limits for Cr, Cu and Pb. Not only the leachate, results from groundwater sampling in vicinity of Beris Lalang landfill also revealed high concentrations of As and Pb, which would probably risk the workers of the landfills which has been using the groundwater as their water resources (Fadhullah et al., 2019).

3.2. Comparisons of heavy metals in soils from sanitary landfills, closed landfills and dumping sites

The levels of heavy metals in the impacted soil revealed variation in metal levels between point of samplings and also different types of landfills. It is also differs according to the landfill conditions, lined or unlined. This is because sanitary landfills will normally be equipped with leachate collection systems and proper landfill liner while for non-sanitary landfills, wastes were normally dumped directly on the ground surface, thus the soil may be heavily impacted by the wastes and leachate produced. In this study, surface soils were collected at waste retaining soil-bund around the landfill cells and at random locations which are affected by wastes and leachate. This is to estimate the load of heavy metals in the impacted soil, the potential risk it poses to human health and surrounding ecosystems. On the other hand, samples of natural soil were collected in vicinity of landfill areas not affected by wastes or leachate locations. The heavy metal properties (mean values of each parameters) of the waste impacted soils and natural soil at the landfills area are presented in Table 5, along with the background values of the heavy metals (Rudnick and Gao, 2013). Fig. 2 shows

Table 5
Heavy metals in soil impacted by waste/leachate for sanitary landfill and non-sanitary landfills (closed and actives dumpsites).

	Sanitary landfill (from soil bund)		Closed landfills (soil from waste affected area)					Dumpsites (soil from waste affected area)					Background level (Rudnick and Gao, 2013)	Dutch Soil Protection Act (2009)	
	S1	S2	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5		Target values	Intervention values
As	3.88	15.92	**21.87**	**22.47**	**31.86**	**34.82**	**163.38**	**153.21**	**66.68**	**49.78**	**41.07**	**74.45**	4.80	29	76
Cd	ND	**0.10**	**0.27**	**0.26**	**0.56**	**0.71**	**1.72**	**1.36**	**0.47**	ND	**1.33**	**1.88**	0.09	0.80	13
Cu	11.86	11.51	19.83	**28.23**	**32.01**	**31.56**	7.73	**48.05**	7.63	**61.63**	4.43	0.40	28	36	190
Cr	36.80	28.84	33.30	71.04	83.65	**303.91**	34.27	**346.82**	**95.63**	**101.84**	8.38	12.36	92	100	380
Ni	3.18	0.58	4.91	6.91	12.16	15.63	9.34	15.34	14.50	12.16	1.17	1.98	47	35	100
Zn	29.12	12.31	29.21	42.09	**68.90**	**79.06**	54.81	65.21	**71.30**	61.25	**96.70**	**86.86**	67	140	720
Pb	6.93	5.73	11.81	12.65	**19.01**	**30.05**	**27.02**	**23.02**	10.91	**46.79**	**171.72**	**17.77**	17	85	530
Mn	48.18	10.73	182.50	190.59	336.28	301.08	133.96	92.82	29.35	176.97	**693.13**	178.82	438.59		
Fe	25 237	16 942	23 525	24 975	32 991	**53 755**	33 721	**58 123**	36 158	**55 733**	20 190	26 329	39 175		

Notes: Data for concentrations of heavy metals in soil are expressed as means of three (3) replicates for each samples; ND – not detected; All units in mg/kg; Bold values indicate higher than background levels.

the comparisons between heavy metals in sanitary and non-sanitary landfills, and also between waste/leachate impacted soil and natural soil. This figure explains the differences in heavy metal contents in between impacted and natural soil in each landfills. Soil samples were collected to represent each conditions for sanitary landfill, closed landfill and dumpsite. Average values for each sampling points were plotted in the graph.

From the results, for sanitary landfill, it can be seen that there are not much differences between the metal contents in the soil from waste retaining soil-bunds with the natural soil. This is probably due to the fact that it was a sanitary landfill and equipped with leachate collection system and landfill liner, avoiding the leachate to seep and adsorb to the nearby soil and also to the groundwater. Nevertheless, most of the heavy metals analysed in non-sanitary landfills (closed and actives dumping sites), especially As, exceeds the background values. Similar conclusion can be made comparing the level of heavy metals of the soil samples with Dutch Protection Act (2009). The exception is Ni, showing none of the samples exceeding the standard or background values. The highest concentration of As observed (163.38 mg/kg), detected in sample C5 and 153.21 mg/kg, in sample D1. Apparently, both of the samples are collected from unlined landfills. Other samples on the other hand, showed to have enriched with most of the heavy metals analysed (As, Cd, Cu, Cr, Zn, Pb and Fe). This situation implies that heavy metals pollution has locally occurred in the soil within the landfills, especially for non-sanitary landfills. As for the closed landfills, though the sites are inactive and as part of the rehabilitation process, leachate collection systems were installed beneath the landfill cells to collect landfill leachate. However, it can be seen that the pollution emitted from the landfill still continues, especially due to the absence of landfill lining system which may results in seepage and infiltration of leachate from the waste into the soil and groundwater. The situation was even worst in active dumpsites where neither leachate collections nor lining systems are available to reduce the migration and attenuation of leachate to the environment. Soil covers are also beneficial as it may reduce the amount of precipitation into the waste and hence minimize the production of leachate (Gworek et al., 2016). However, the dumpsites studied did not implement the application of protective daily soil cover, which then, will poses higher risk to the environment.

Furthermore, the elevation of As, Cr, Cu, Cd, and Pb in landfills leachate and soil might be attributed from the anthropogenic activities around the landfills such as the used of fertilizers, arsenical pesticides, used batteries, leaded gasoline, petroleum, chemicals and electronics manufacturing, tire and cement factory, woods and steel works as well as municipal runoffs and atmospheric deposition (Ahmed et al., 2016; Ali et al., 2016; Fu et al., 2014; Singare et al., 2012). Elevated Pb concentrations in non-sanitary landfills might be attributed by leaded gasoline or waste bottles, petroleum and municipal runoffs from the surrounding areas (Mohiuddin et al., 2012; Shikazono et al., 2012), as well as from electronics wastes, tires, steelworks and constructions and demolition wastes. Level of As shown to be dominating compared to other metals in all sampling sites. High As concentrations in soil were also observed in previous studies in Kelana Jaya landfill (Fauziah and Agamuthu, 2010), closed landfill in Kubang Badak (Table 6) (Nor Amani Filzah and Suhaimi, 2010) and also in Ampar Tenang landfill (Mohd Adnan et al., 2013).

Another surprising factor is that the metals contents in natural soils in vicinity of landfills are also quite high at several point of sampling (Fig. 2), such as Cr, Pb and As. Some heavy metal concentrations in natural soil were found to be above defined background values. However, though metal contents of these soils are high, they are much lower than from waste/leachate affected soils. It is important to realize that heavy metals are also naturally occurring trace elements and rarely toxic (Wuana and Okieimen, 2011). It is unlikely that the metals dissolved, leached and mobile into the environments under normal conditions. Nevertheless, it can be triggered throughout consecutive reductive conditions (Ghosh (Nath) et al., 2019; Martiñá-Prieto et al., 2018), and anaerobic bio-disintegrations (Keshta, 2016). These situations might result in metals trapped in the natural soil to leach out. Methanogenic condition of landfill leachate will also lead to reductive dissolution of iron due to the reduction of oxygen content (Demirbilek et al., 2013). Soils which are impacted by high organic landfill leachate plumes may also release the metals, especially As into the surrounding environment (DeLemos et al., 2006; Ford et al., 2011). Moreover, elevated Fe and Mn in leachate also plays an important role in heavy metals sink in soil as they may act as the catalyst. Presence of As, Cr, Cu and other metals in soil were intricately connected with persistence of iron and manganese oxides (Gharibreza et al., 2013). Redox shifts due to high organic compounds in leachate may also lead to dissolve of Fe and Mn in the natural soil (Yan et al., 2016). Arsenic, which are normally abundance in soil and wastes, might leach to the waterway in certain factors such as ion displacement, desorption of As at surrounding pH more than 8.5, reduction of readily As (V) metals from wastes into leachate to As (III) through microbial reduction and also mineral dissolutions Fe and Mn oxides (Fendorf et al., 2010). Besides, transition from aerobic phase to anaerobic phase of landfill

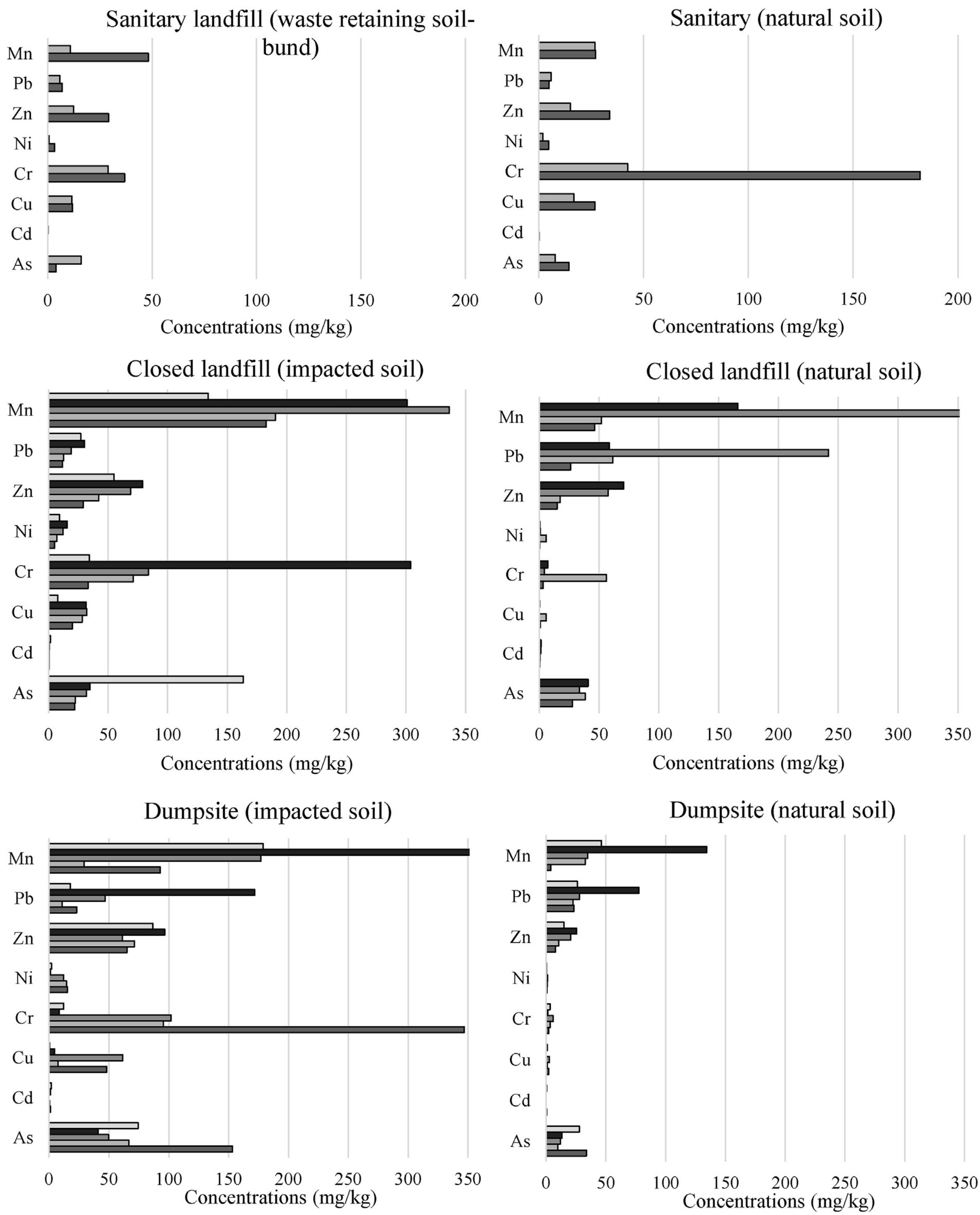

Fig. 2. Comparison of heavy metals concentrations between sanitary and non-sanitary, and waste/leachate impacted soils and natural soil in vicinity of landfills. Comments on Fig. 4. Each bar represents average value (heavy metal concentration) of the soil sample collected.

leachate may also liberate As from dominant solids minerals such as alluvial soil and pyrite. Continuous discharge of arsenic compounds from the solid wastes dumped in these landfills and anaerobic conditions in the waste pile, more of the As (III) would be preferably formed. This anaerobic condition in waste piles may also triggered competing biogeochemical processes in the leachate, resulting in rise of more toxic As (III) species (Yusof et al., 1999).

3.2.1. Soil pollution indicators

The geo-accumulation index (Igeo) is a tool to measure the extent of contaminations in soil with regards to the background values of the polluting metals in soil (Table 7). According to the Igeo

Table 6
Heavy metals in soils in vicinity of disposal sites as of other studies in Malaysia.

Landfills	Fe	Cd	Ni	Cu	Mn	Pb	As	Zn	Cr	References
Background values	39 175	0.09	47	28	438.59	17	4.8	67	92	Rudnick and Gao, (2013)
Target values*		0.8	35	36		85	29	140		
Intervention values*		13	100	190		530	76	720		
Seri Petaling		**0.92–1.07**	2.2–2.89	1.83–6.49		3.42–7.67		3.97–20.44	5.71–12.61	Ahmed and Sulaiman, (2001)
Dengkil	312.25		4.35	2.21	11.35	12.78		12.97	11.51	Bahaa-Eldin et al. (2008)
NSL(A) - Langat Basin	930	**4.61**	0.8	**43.2**	19.7	**20.1**		13.9		Norkhadijah et al. (2015)
NSL(B) - Langat Basin	1260	**2.69**	1.55	**37.9**	76.5	**37.5**		17.8		
NSL(C) - Langat Basin	582	**2.57**	0.8	20.5	90.8	**17.9**		6.47		
NSL(D) - Langat Basin	299	**4.39**	0.28	13.7	32.9	**37.9**		14.8		
Kubang Badak				**201.6**	262.5	**89.25**	**26.9**	**666.05**	**136.85**	Nor Amani Filzah and Suhaimi, (2010)
Kelana Jaya		0–**0.6**	0.3–5.0	2.3–17.3		2.7–**148.0**	**8.8–64.5**	7.7–**129.8**	0.5–14.1	Fauziah et al. (2010)
Ampar Tenang	**48 208**			**344.76**	292.83	**189.76**	**274.64**	**1857.19**		Syahirah et al., 2013

Notes: NSL - Non-sanitary landfill; *Target values and Intervention values – Dutch Soil Protection Act, 2009; All units in mg/kg; Bold values indicate higher than background levels.

Table 7
Geoaccumulation indices (Igeo) values of soil in landfills.

Parameters	As	Cd	Cu	Cr	Ni	Zn	Pb	Mn	Fe
Sanitary landfill (soil-bunds)									
S1	-0.619		-1.264	-1.322	-3.099	-1.239	-1.302	-2.614	-0.845
S2	0.794	-0.325	-1.295	-1.565	-4.802	-2.100	-1.493	-4.116	-1.244
Non-sanitary - Closed landfill (waste impacted soil)									
C1	1.111	0.705	-0.750	-1.422	-2.665	-1.236	-0.770	-1.282	-0.915
C2	1.138	0.664	-0.397	-0.664	-2.322	-0.870	-0.701	-1.239	-0.856
C3	1.487	1.416	-0.272	-0.501	-1.758	-0.377	-0.293	-0.671	-0.577
C4	1.576	1.654	-0.286	0.789	-1.506	-0.240	0.164	-0.782	-0.089
C5	3.122	2.542	-1.693	-1.393	-2.022	-0.606	0.058	-1.591	-0.555
Non-sanitary - Dumpsite (waste-impacted soil)									
D1	3.058	2.307	0.134	0.922	-1.525	-0.433	-0.102	-1.958	-0.011
D2	2.226	1.250	-1.706	-0.367	-1.581	-0.343	-0.849	-3.110	-0.486
D3	1.934		0.384	-0.304	-1.758	-0.495	0.607	-1.313	-0.053
D4	1.741	2.286	-2.248	-2.801	-4.102	-0.039	1.907	0.052	-1.068
D5	2.336	2.633	-4.662	-2.413	-3.570	-0.146	-0.361	-1.303	-0.803

calculated, soils impacted with waste/leachate in non-sanitary landfills are moderately to strongly polluted (Igeo >2), especially for As, Cd and Pb levels in the soil. The Igeo accumualation for As and Cd in non-sanitary landfills indicated heavier pollution than samples from sanitary landfills, given the maximum values of 3.122 (As) and 2.633 (Cd). Apart from that, the Igeo values for Cu, Cr, Pb and Mn in these non-sanitary landfills also may rise some concern and thus, need further monitoring.

The calculated pollution indices (PI) and integrated pollution indices (IPI) are summarized in Table 8. Different from Igeo, PI is the ratio between the content of each metal to the background values, where the higher the values demonstrates progressive deterioration of contamination in the soil. Leachate/wastes impacted soil in non-sanitary landfills revealed a significant contamination by arsenic and cadmium ($PI \geq 3$). Almost all samples of soil in these landfills gained higher than severe levels for As and Cd. Cu, Cr, Zn, Pb and Fe were observed to be moderately polluted, with Cr and Pb reaching extremely polluted level in some of the samples collected. This is merely the impacts of non-existence of landfill liners and also not even a leachate collection systems available especially in open dumpsites. Nevertheless, when all metals were taken into accounts as in IPI calculated, it can be concluded that non-sanitary landfills studied (closed and dumpsites) were moderately polluted by heavy metals ($1 < IPI \leq 2$).

This situation implies that non-sanitary landfill environments are exposed to source of pollution from waste and landfills leachate. Not only in operated landfills, but also long after the closure of a landfill, the leaching and discharge of metals will continue.

Table 8
Pollution indices (PI) and integrated pollution indices (IPI) of soil in landfills.

Parameters	As	Cd	Cu	Cr	Ni	Zn	Pb	Mn	Fe	IPI
Sanitary landfill (soil-bunds)										
S1	0.808		0.424	0.400	0.068	0.435	0.408	0.110	0.644	0.322
S2	3.317	1.084	0.411	0.313	0.012	0.184	0.337	0.024	0.432	0.294
Non-sanitary - Closed landfill (waste impacted soil)										
C1	4.555	3.035	0.708	0.362	0.104	0.436	0.695	0.416	0.601	0.672
C2	4.681	2.913	1.008	0.772	0.147	0.628	0.744	0.435	0.638	0.837
C3	6.636	6.180	1.143	0.909	0.259	1.028	1.118	0.767	0.842	1.263
C4	7.254	7.840	1.127	3.303	0.333	1.180	1.768	0.686	1.372	1.729
C5	34.037	19.062	0.276	0.372	0.199	0.818	1.589	0.305	0.861	1.183
Non-sanitary - Dumpsite (waste-impacted soil)										
D1	31.919	15.061	1.716	3.770	0.326	0.973	1.354	0.212	1.484	1.956
D2	13.893	5.234	0.272	1.039	0.309	1.064	0.642	0.067	0.923	0.864
D3	10.372		2.201	1.107	0.259	0.914	2.752	0.403	1.423	1.324
D4	8.557	14.748	0.158	0.091	0.025	1.443	10.101	1.580	0.515	0.933
D5	15.511	20.881	0.014	0.134	0.042	1.296	1.045	0.408	0.672	0.597

*Darker shading represents higher pollution risk

Furthermore, calculated soil pollution indices (Igeo, PI and IPI) also suggest that heavy metals contamination in landfill studied, especially for non-sanitary landfills were mainly from anthropogenic sources emanated from wastes disposed, rather than from natural sources (lithological sources) in soils. It is important to realize soil contaminated with heavy metals from anthropogenic source such as in unprotected landfills were more mobile and bioavailable than the lithogenic ones (Kaasalainen and Yli-Halla, 2003; Kuo et al., 1983).

3.3. Statistical summary for heavy metal concentrations in leachate and impacted soil of in different landfill sites

To evaluate the significance of the difference between mean values of each metal studied in leachate and soil for every landfill, one-way ANOVA was used. The independent variable was difference landfill sites, while the dependent variable was the concentration of the substances. Result of ANOVA test for the leachate and impacted soil of different landfills is presented in Table 9. The statistical analysis showed significant differences ($P < 0.05$) and (F-value > F-critical) for As, Cd, Cu, Cr and Ni for leachate and As, Cd, Ni, Zn and Mn for impacted soil between landfill studied. Comparison for statistical differences at probability $P < 0.05$ proved that differences occur in the mean values of metal concentrations among all landfill sites. Hence, on the basis of statistical analysis, it can be concluded that some of heavy metals concentrations largely depends on the landfill types, conditions, ages, and waste compositions as elaborated in the section previously and further discussed in the section below.

3.4. Fate and threats of heavy metals in leachate, impacted soil, and natural soil in non-sanitary landfills

Fig. 3 shows the concentrations of heavy metals in leachate, impacted soil as well as natural soil collected in the same dumpsite (Kampung Keru landfill). This figure aims to demonstrate how landfill leachate may have affected the soil quality in landfill environment. In this study, elevated heavy metals contents in impacted soil analysed in the landfill proved that soil in the area were burdened by the pollutants. High concentrations of As, Cu, Cr, Ni, Mn, Fe, and Pb in leachate have shown to be directly impact the quality of soil in vicinity of the landfills when compared to the quality of the natural soil which are unaffected by waste or leachate. These can be seen clearly when considering the facts that natural soil (unaffected soils) in the dumpsite show lower level of heavy metals as compared to the impacted soil. The impacts of metal pollution in this study shows that disposal of solid waste directly onto an unprotected natural soil formation shall be prohibited. Besides, leachate which are not contained, collected nor treated might not only contaminate the soil, but also groundwater,

Table 9
The result of analysis of variance (ANOVA) for different landfill sites.

Landfils Leachate										
	As	Cd	Cu	Cr	Ni	Zn	Mn	Fe	Pb	Se
F	11.20	3.98	2.77	4.02	3.08	1.05	1.88	1.26	0.81	1.84
Sig. (P)	0.00	0.01	0.04	0.01	0.03	0.43	0.14	0.32	0.57	0.15
Impacted Soil										
	As	Cd	Cu	Cr	Ni	Zn	Mn	Fe	Pb	
F	22.50	8.75	1.16	0.34	3.40	15.40	3.17	1.91	2.94	
Sig. (P)	0.00	0.00	0.34	0.34	0.03	0.00	0.04	0.15	0.05	

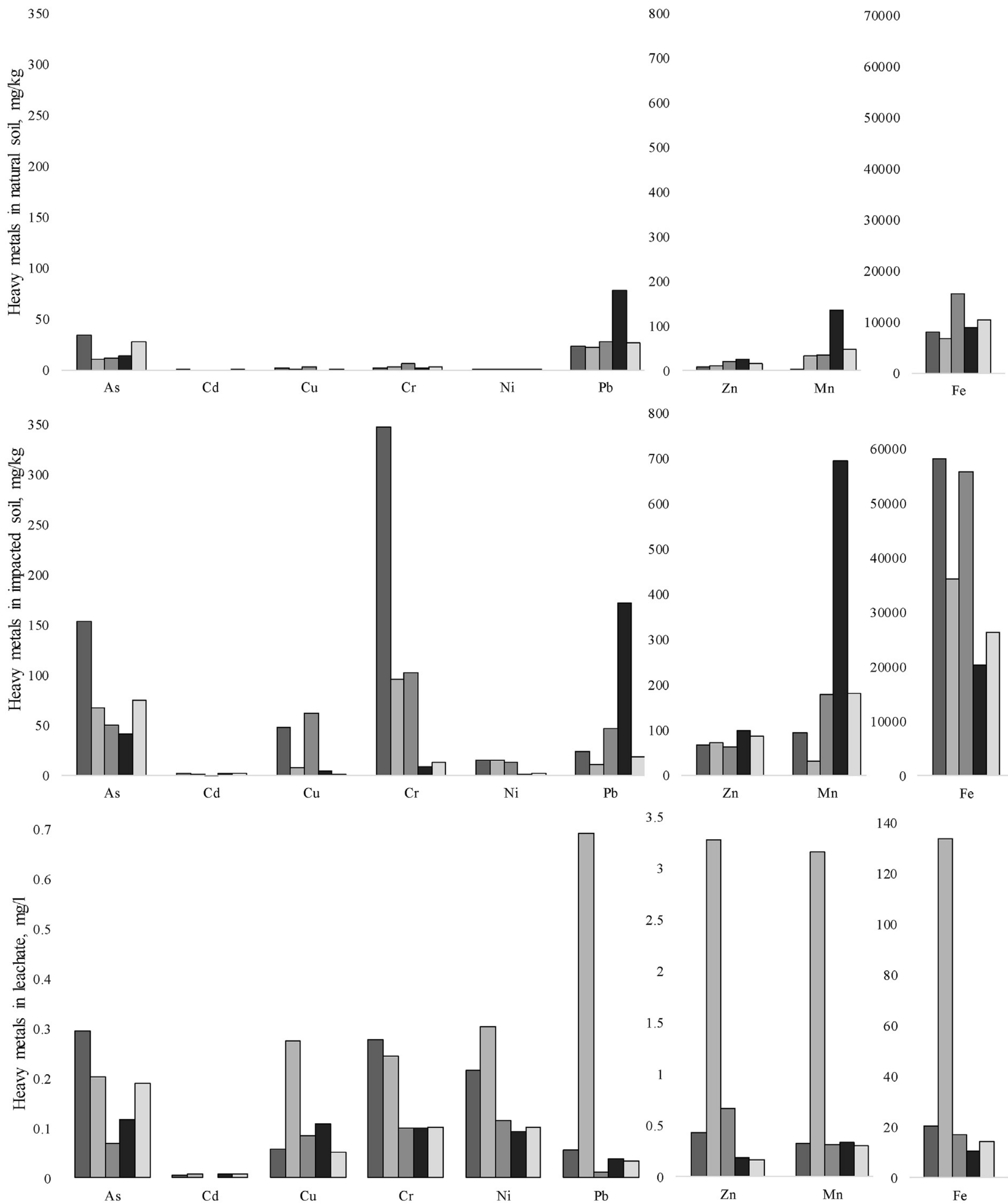

Fig. 3. Variations in levels of heavy metals in natural soil, impacted soil and leachate from the same dumpsite (Kampung Keru Landfill).

plants, fishes, and other surrounding ecosystems. Deteriorations of groundwater quality in landfills area due to leachate pollution are evident globally, not exceptional in Malaysia (see Table 10). Elevated concentrations in most of the metals proved that the contamination plume has migrated further away from the site. Various studies also covered on the impacts of leachate pollution especially in terms of heavy metals toxicity onto fishes and plants which might pose significant threat to food security (Adamcová et al., 2017; Alkassasbeh et al., 2009; Daria et al., 2020; Emenike et al., 2011; Gworek et al., 2016; Ishak et al., 2016; Okedeyi et al., 2014; Vaverková et al., 2018).

Fig. 4 denotes the fate of metals transport in landfill environments. Heavy metals in leachate observed were probably emanated through leaching from indiscriminate dumping of waste with high metal contents by precipitation. Waste compositions, waste age, and amount and quality of water percolating in the wastes may also exhibits the release of heavy metals in the leachate (Talalaj, 2015). In addition, factors such as leaching of heavy metals from natural

Table 10
Heavy metals in groundwater in vicinity of disposal sites as of other studies in Malaysia.

Landfills	Fe	Cd	Ni	Cu	Mn	Pb	As	Zn	Cr*	References
WHO Standard	0.300	0.003	0.07	2.0	0.5	0.01	0.01	3.0	0.05	
INWQS Class II*	0.300	0.003	0.02	1.0	0.1	0.01	0.01	3.0		
Drinking Water Standards Malaysia	0.300	0.003	0.02	1.0	0.1	0.01	0.01	3.0	0.05	
Taman Beringin	**0.410**	ND	0.016	0.026	0.06	**0.042**	ND	0.13		Atta et al. (2015)
Gemenceh Landfill	0.200 **−215**	<0.010 −0.100	<0.100	<0.100 −0.700	<0.100- **230**	<0.010- **1.260**		<0.100 −0.900	<0.010-**1**	Suratman, (2003)
Disposal site in Taiping	**2.800**	**0.013**				**0.232**		**3.391**	**0.018**	Samuding et al. (2012)
Ampar Tenang (2005)	**0.400 −2.410**	0−**0.098**	0.004 **−0.674**	0.023 −0.771	0−0.070	**0.021 −1.179**	0−0.002	0.050 −0.288	0−0.039	(Mohd Raihan Taha et al., 2011)
Ampar Tenang	**1.030 −1.040**	**0.058 −0.095**	**0.023 −0.028**	0.2−0.203	0.011 −0.02	**1.179 −1.181**	0−0.0009	0.130 −0.180		
Bukit Tagar	0.017 −0.559	0.001 −0.005		0.002 −0.026	0.001 −0.087		0.005	0.005 −0.074	0.001 −0.005	
Ampar Tenang	**1.560 −1.800**	**0.019 −0.023**	**0.439 −0.647**	0.370 −0.390	0.040 −0.060	**0.042 −0.090**	**0.060 −0.090**	0.334 −0.397	0.009 −0.017	Yusoff et al. (2013)
Ampar Tenang	**0.970 −2.820**	0.002 **−0.067**	0.006 **−0.325**	0.212 −0.993	0.040 −0.080	**0.075 −1.057**	0−0.002	0.015 −0.770	0.004 −0.037	Rahim et al. (2010)
Beris Lalang				0.02−0.04		**0.060 −0.080**	0.005 **−0.020**	1.0−2.0	0.02−0.03	Fadhullah et al. (2019)
Seri Petaling	0.270 **−0.470**			0.003 −0.012				0.014 −0.015	0.002 −0.01	Ahmed and Sulaiman, (2001)

Notes: All units in mg/L.

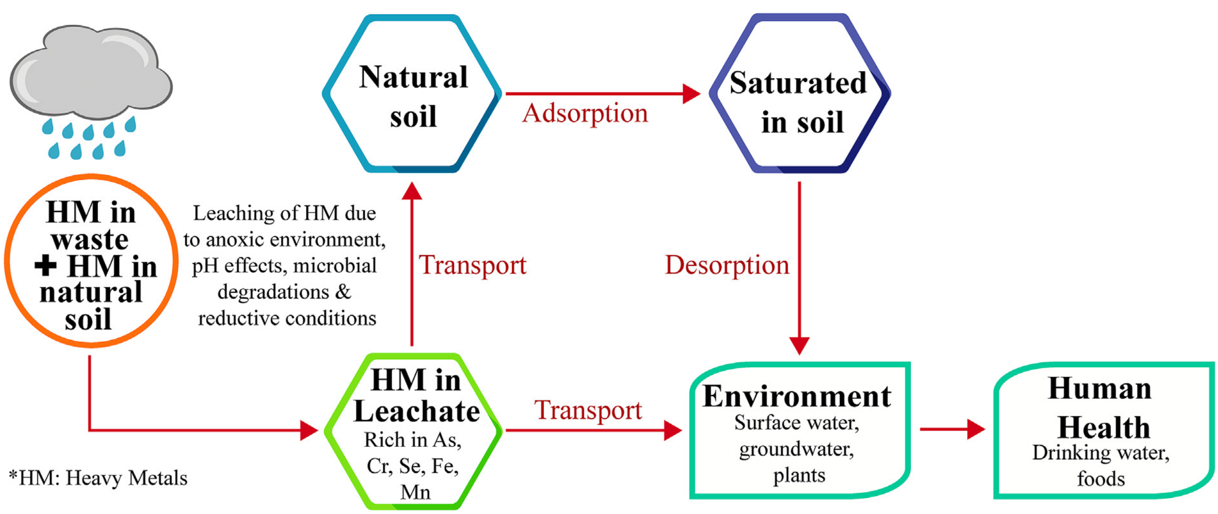

Fig. 4. Flow of heavy metals fate in non-sanitary landfills (unlined and no leachate collection systems).

soil where the waste were dumps due to pH, anoxic condition in the waste cells, and microbial degradations will also contribute to the rise of heavy metals in leachate (Krüger et al., 2012; Talalaj, 2015) and thus, conveys a strong polluting load to the absorbing soil (Kanmani and Gandhimathi, 2013; Szymański and Janowska, 2016; Yusoff et al., 2013; Zhan et al., 2014). The sorption process will normally occur during the movement of leachate and diffusion into the soil (Ololade et al., 2019). This phenomenon is known as soil purification process. Heavy metal contaminants in leachate also attenuate in the soil by various processes which either slow or transform them (de Godoy Leme and Miguel, 2018). Nevertheless, movement of pollutants in soil environment were not only involved adsorption and ion exchange, but also desorption. At certain level when the soils are saturated with metal contents, or under certain circumstances such as pH effects or ion competitions, metals will desorb from the soil solid surfaces. After various cycles of leaching, adsorption and desorption processes, the remaining heavy metal pollutants in the leachate will migrate at considerable distance, to the water courses such as river and into the groundwater.

Toxicity levels held by these heavy metals especially in open dumps and poorly managed landfills may pose a great risk to the water courses around the landfills, plants and ecosystems and also to the public health (Vaverková et al., 2018). Exposure to toxic metals such as As, Cd and Pb, can lead to multiple effects such as hypertension, problems in gastrointestinal systems, decreased growth and induces carcinogenesis of organs like lungs, kidney, bladder and skins (Dooyema et al., 2012; Kamunda et al., 2016; Udiba et al., 2019). Selenium (Se) for instance, though it is considered as essential nutrient, but ingestion at high concentrations above 0.055 mg/L might cause damage to the nerves system. Metals such as As and Zn were also the most potent health risk hazards in terms of cancer risk factor, besides Cd which could damage the reproductive system and DNA, and also cause deficit in learning, cognition, behavior and neuromotor skills in children (Chen et al., 2015). The implication of heavy metals in soil in the other hands may concerns agricultural production systems (Magaji, 2012), as well as food security (Ololade et al., 2019).

4. Conclusions

Arsenic is the most abundant heavy metals in the landfill sites investigated both in leachate and impacted soil. Statistical analysis (ANOVA) results indicating the presence of significant differences in the concentrations of As, Cd, Cu, Cr, and Ni in leachate among the landfill sites. Whereas for impacted soil, concentrations of As, Cd, Ni, Zn and Mn were statistically different for each landfills. Elevated in concentrations of toxic metals especially As in landfills leachate and soils (especially in non-sanitary landfills), may be the point of interest of why such scenario are happening in both sanitary and non-sanitary landfills in Malaysia. The presence of toxic metals in landfills leachate threaten the quality of the soils and plants in vicinity of the landfill sites and also may pollute significantly both surface and groundwater.

Leachate in the sanitary landfills (SG and LTM) and two of the closed landfills (BP and PJ) investigated were treated before being discharged. Nevertheless, it is important to regularly monitor the quality of the discharged leachate to ensure the efficiency and suitability of the treatments provided. The leachate of the observed landfills tendencies towards stabilization and significant heavy metals concentrations may indicate the needs of extensive treatment besides the conventional biological treatment such as sequential batch reactor (SBR) system. The research findings also show that unlike sanitary landfills, wastes disposed at non-sanitary landfills in Malaysia were not properly managed, releasing leachate loaded with toxic metals that are transferred to impacted soils. This issue is worsen in open dumping sites (UMC, UMO and KK) where leachate collection and treatment were non-existence. In the studied dumpsites, maximum QRS of As ranging from 136 to 787 and Cr, from 197 to 661 were observed. High concentrations of these toxic metals in leachate in non-sanitary landfills revealed very carcinogenic lifetime risk due to the fact that the leachate may migrate predominantly into the soil, and mobile freely into the groundwater.

In the presented work, the content of heavy metals in waste/leachate impacted soil in landfills were monitored. In addition, metals contents in natural soil collected in vicinity of the landfills sites were also analysed, as control (comparison samples). These results obtained from this study suggests that soil impacted by waste/leachate in non-sanitary landfills are heavily burdened with heavy metals content. As was found to be relatively high in both leachate and impacted soil from these landfills. The Igeo values suggest that soil impacted by wastes/leachate in closed and active dumpsites seems to have moderate to heavily polluted by As and Cd (Igeo >2). Employing the results of the soil pollution index (PI), it is proved that soil impacted by waste/leachate in non-sanitary landfills were moderately to heavily polluted with metals especially As (4.555−31.919), Cd (2.913−20.881), Pb (0.642−10.101). Meanwhile, the integrated pollution index (IPI) values in these sites was greater than 1 (IPI > 1), implying that the soils were polluted with studied heavy metals. Contrary results were observed in soil at sanitary landfills (IPI < 1) as these landfills were equipped with proper lining systems which could protect the surrounding soil from waste and leachate. Therefore, as for non-sanitary landfills, it is crucial for a clean-up process and set an insulated barrier under the waste areas. Efforts should also be taken to check the nature of refuse dumped, as well as continuous monitoring for possible impacts, in order to avoid disastrous environmental impacts in the future.

Dumping wastes in unlined landfills, where leachate was neither confined nor collected, merely not a good idea. Leachate from unlined and uncontrolled landfills can easily escape and interact with the surrounding soils. It is important to realize that heavy metals are also naturally occurring trace elements in natural soil. Therefore, as soil layers were saturated due to the leachate flow, it might attribute to dissolution of soil minerals. Partitioning of heavy metals into aqueous phase due to desorption, change in pH values, and mineral dissolution may lead to devastating impact on water quality. As and Cr for instance, which were quite abundant in natural soil, may release from soil either by dissolution or diffusion out of the solid phase. Factors triggering these phenomenon as in landfills were during the transition to more anaerobic conditions of the landfills, from oxidising to reducing conditions, and also redox shift due to high organic contents in leachate. Furthermore, some other factors such as microbial activities in anaerobic environment in landfills could also influence metals mobilization in the environment.

Arsenic has been pointed out as one of the dominant hazardous potential inorganic contaminant in landfills leachate studies. Almost all raw leachate monitored in both sanitary and non-sanitary landfills contain high level of As. Nevertheless, it is important to realize that the study of landfill leachate which include the monitoring of As are scarce. In Malaysia itself, only few studies covered the monitoring of As in landfill leachate, and surprisingly, most of it reported a significant concentrations. In this study, it can be concluded that the possible sources of elevated heavy metals especially As in leachate include leaching from waste disposed in the landfills or reductive dissolution of soils and sediments which were exposed to landfill leachate. Pollution of arsenic is a great concern as this element was both potent and discrete, and even considered as ‘poison of king of poisons’. Therefore, it is clear from this study that the problems of non-sanitary landfills must be prioritized and solved. Segregation of waste disposed in landfills must also be practice, as well as replacing the open dumpsites by sanitary landfills to avoid such long-term pollution. A systematic environmental monitoring and precautionary action should also be imposed to avoid future complications.

Credit roles

Munirah Hussein, Conceptualization; Methodology; Investigation; Formal analysis; Writing - original draft; Visualisation, Kenichi Yoneda, Validation; Writing - review & editing, Zuhaida Mohd-Zaki, Writing - review & editing, Amnorzahira Amir, Resources; Writing - review & editing, Nor'Azizi Othman, Supervision.

Declaration of competing interest

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