Metals contamination on soil and surface water (earth drainage) due to leachate migration from Piyungan land

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Abstract. Decomposition of solid waste has the possibility of leached its heavy metal content into the leachate. Leachate flows into soil and surface water, causing possible leachate contamination onto the surrounding area. Monitoring of heavy metals contaminant is crucial to control the migration of leachate. This study focusses on the migration of leachate metals from the Piyungan landfill into the surrounding soil area and earth drainage. Triplicate soil and earth drainage samples were taken at ground level for each station to be analysed using the Inductively coupled plasma mass spectrometry (ICP-MS). Based on metals measurement in soil, there are two paths of leachate migration. Even though the concentrations of As, Ni, Cr and Mn were reduced from the landfill until the downstream, all sampling stations show a high concentration in the soil above the standard limit for a residential area. Besides, these metals also show the concentration above the standard limit for earth drainage. Soil contamination occurred ages ago before this study was conducted based on Cu, Ba, Li, V, Co, and Ti accumulated in soil based on high concentration detected. However, these metals show a low concentration in earth drainage during sampling work was conducted in this study. While Pb, Mg, Zn, Cd and Sr were not migrated due to low concentration in all sampling stations except the station nearest to the landfill area. In general, the metals contamination in soil and earth drainage from the landfill will be tended to the hazardous condition in future. In addition, surrounding the landfill area is a residential area with agricultural activities at downstream. Thus, the effect on residents and plants could contribute to the hazard of metals contamination.

1. Introduction
Landfilling is the most economical method for the disposal of solid waste if the land is abundantly available. Landfilling has been used in Indonesia for many years to manage the solid waste generated by its population. Almost every district in Indonesia has its own landfill. In Yogyakarta, an estimated 470 tonne of solid waste has been sent to Piyungan Landfill. The fraction of waste consists of 77% organic and 23% inorganic. Some recycle wastes collected and separated offsite and onsite. Yearly, Piyungan Landfill caters to 8% of solid waste increment [1].
Leachate is the drawback of landfilling. Leachate is considered a highly polluted liquid produced by the precipitation of runoff onto solid waste and flows down the layer of solid waste and carried along with the pollutant of the solid waste. The leachate characteristic depends on the decomposition process of the waste, and it can be classified as young, intermediate and old leachate. As its ages, the biodegradability of leachate reduced [2]. No matter what age of the leachate, it still considered highly polluted and required treatment before discharging.

Leachate is a liquid that tends to move downward from high elevation to low point because of gravity force. As landfill cover a very large area, leachate migration onto the surface and into groundwater is possible. Monitoring leachate movement and migration is important to reduced health effects to surrounding local resources users and the environment around Piyungan Landfill.

Heavy metals such as Cd, Cr, Cu, Pb, Ni, and Zn in leachate posed hazardous potential. These heavy metals in leachate attached to the materials flown into the soil through interaction mechanisms such as adsorption and complexation. Physical adsorption happens when the contaminants in the soil pore water (aqueous phase) are attracted to the soil constituents’ surfaces because of the net charges on the soil particles (attractive forces), while chemical adsorption happens because of the high-affinity. The complexation interaction mechanism occurred when the metallic cation reacts with an anion [3].

From observation with residents nearby Piyungan Landfill, well water (shallow and deep) and river are intensively used as potable water resources. Furthermore, daily activities such as farming, washing, and cleaning also use resources from the river water. Piyungan Landfill is located at a higher elevation compared to the surrounding residential area. The runoff mixed with leachate flow from landfill through surface soil and earth drainage. Ideally, it will be channel into the leachate treatment facility before discharging into the nearby river. However, since some of the drainages are made from earth drain, there is a possibility of the leachate to precipitate the ground and contaminate the groundwater sources. Furthermore, there is also a possibility of leachate channelled not into the leachate treatment facility because of breakage drain and drain naturally form by the leachate flow due to gravity force that contaminates the river water. Thus, the suitability of these water resources has raised concern due to the possibility of contamination of polluted matters from leachate.

The possible sources of leachate migration are through ground and surface area. An increased number of studies have been reported on the leachate pollution on surface and ground area [4] that sparks the needs of monitoring the leachate migration. Even though landfill construction follows the stringent standard, there will always be a possibility of non-compliance situation and un-effective monitoring that causing uncontrolled migration of leachate. Thus, this study focuses on the migration of heavy metals from Piyungan Landfill into the surrounding soil area and earth drainage.

2. Methodology

2.1. Details on Sampling Station
Sampling point positions considered the direction of leachate migration through surface runoff from landfill to the earth drainage until to the mainstream (Opak river) and also to the surrounding housing village nearby. There were 11 soil samples and 3 water samples taken from the site. One sample point (SC1) was used as the control point for soil, where the chosen position indicated was not affected by the leachate. The type of samples taken, distance and their positions are presented in Table 1. The direction of the earth drainage channel, located at the downstream of the landfill until the Main Stream Opak river was represented by sample ID of SS1, SS3, SS11, SS10 and SS9.

2.2. Soil Sampling Procedure
Sampling for each station was collected three times as the average of the data. The soil samples were taken in the open space area without soil interrupted by human activity. Target soil sampling was as deep as 30 cm from the surface, so that hand auger was a suitable tool for collecting soil samples. Soil samples were collected randomly by using a hand auger tool. Soil samples were placed into the HDPE plastic bag and were labelled according to their respective locations. Soil sampling were taken in dry weather conditions. Thus, the concentration of metals in the soil sample is not disturbed. All the
samples taken were left at room temperature without the presence of moisture by using a tight container.

| ID | SC1 | SS1 | SS2 | SS3 | SS4 | SS5 | SS6 | SS7 | SS8 | SS9 | SS10 | SS11 | LP1 | L6 | L14 |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|-----|----|-----|
| SC1| 0.00| 91.21| 148.86| 328.59| 284.96| 369.28| 715.20| 459.61| 422.89| 1362.46| 1086.17| 661.55| 196.95| 154.26| 128.08|
| SS1| 91.21| 0.00| 143.39| 370.06| 231.32| 281.51| 638.13| 368.40| 332.77| 1390.82| 1128.13| 709.13| 113.30| 154.73| 107.35|
| SS2| 148.86| 143.39| 0.00| 238.65| 157.93| 308.56| 605.36| 426.57| 414.16| 1248.04| 990.02| 576.22| 238.54| 13.15| 37.48|
| SS3| 328.59| 370.06| 238.65| 0.00| 327.27| 521.02| 732.48| 648.10| 646.13| 1034.85| 759.46| 339.21| 475.15| 225.50| 274.88|
| SS4| 284.96| 231.32| 157.93| 327.27| 0.00| 199.72| 447.83| 329.87| 344.25| 1245.41| 1019.99| 634.21| 264.78| 160.01| 163.22|
| SS5| 369.28| 281.51| 308.56| 521.02| 199.72| 0.00| 376.34| 130.27| 157.70| 1427.45| 1215.12| 833.93| 225.27| 319.56| 286.92|
| SS6| 715.20| 638.13| 605.36| 732.48| 447.83| 376.34| 0.00| 389.24| 463.76| 1376.80| 1246.80| 955.47| 600.86| 610.05| 601.88|
| SS7| 459.61| 368.40| 426.57| 648.10| 329.87| 130.27| 389.24| 0.00| 75.27| 1550.89| 1344.20| 964.06| 279.23| 438.41| 400.03|
| SS8| 422.89| 327.37| 414.16| 646.13| 344.25| 157.70| 463.76| 75.27| 0.00| 1583.46| 1364.23| 972.38| 231.02| 426.88| 383.27|
| SS9| 1362.46| 1390.82| 1248.04| 1034.85| 1245.41| 1427.45| 1376.80| 1550.89| 1583.46| 0.00| 335.48| 727.70| 1481.00| 1236.25| 1285.16|
| SS10| 1086.17| 1128.13| 990.02| 759.46| 1019.99| 1215.12| 1246.80| 1344.20| 1364.23| 335.48| 0.00| 426.72| 1228.38| 977.32| 1027.46|
| SS11| 661.55| 709.13| 576.22| 339.21| 634.21| 833.93| 955.47| 964.06| 972.38| 727.70| 426.72| 0.00| 814.00| 563.17| 613.08|
| LP1| 196.95| 113.30| 238.54| 475.15| 264.78| 225.27| 600.86| 279.23| 231.02| 1481.00| 1228.38| 814.00| 0.00| 251.39| 201.25|
| L6| 154.26| 154.73| 13.15| 225.50| 163.22| 319.56| 611.05| 438.51| 426.88| 1236.25| 977.32| 563.17| 251.39| 0.00| 50.16|
| L14| 128.08| 107.35| 37.48| 274.88| 160.01| 286.92| 601.88| 400.03| 383.27| 1285.16| 1027.46| 613.08| 201.25| 50.16| 0.00|

(Note: SS=Soil, LP=Leachate Pond, L=Surface Water/Drain)

2.3. Digestion Process and Metals Analysis for Soil Sample

Sample preparation was carried out before the sample was analysed for metal concentration using ICP-MS. During the drying process, soil samples were broken down into smaller pieces to accelerate the drying sample process and then were placed in an oven with a temperature of 105°C for 24 hours. After the drying process, the soil samples were inserted into the blender machine to be crushed into a fine piece. Then, the ground sample was sieved using a sieve size 63um [5]. The sieving process is performed to obtain a uniform size of soil samples for the preparation digestion process.

Soil samples were digested by referring to Method 3050B of Acid Digestion of Sediments, Sludges and Soils. For sample digestion, samples were weighed 1 g (dry weight) and then the soil samples were transferred into the 250 mL of digestion vessel. 10 mL of 1:1 nitric acid was added into the digestion vessel that contains the soil sample and covers with refluxing devices. The sample was heat around 95 °C ± 5°C and reflux for 10 to 15 minutes (without boiling). After the sample cool, 5 mL of concentrated HNO3 was added and was reflux for 30 minutes. The solution was heated by using the refluxing device to allow the solution to evaporate nearly to 5 mL.

After completing the digestion process, the sample was cooled, 2 mL of distilled water and 3 mL of 30% Hydrogen Peroxide (H2O2) was added. Then, the samples were diluted to 100 mL with distilled water or ultrapure water. All the digestion samples have been through the filtration process by using Whatman No. 41 filter paper. All samples were ready for analysing using Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) to determine the concentration of metals.

2.4. Surface sampling procedure

The surface water sampling was done according to Shaylinda et al. [1]. Surface water sample for earth drain was collected from L6 and L14 sampling stations. Grab samples were taken by using a 1 L polyethylene or glass bottle. The water samples were filled to the total volume of the container, and a cap was sealed; thus, no air space can remain inside the bottle. The bottles were first washed thoroughly using Decon 90 detergent and dried. Before sampling, the bottles were rinsed with the water sample. After taking water samples, acid nitric was added to the samples until pH 2 and kept below 4°C by using an ice storage box. The bottles were labelled by stating the name and location of the site, date, and collection time.
3. Results and discussion

This section is divided into two subsections based on the comparison of parameters concentrations with several standards. In the first subsection, concentrations of metals detected in soil and earth drainage were higher than the standards limit. Whereas in the second subsection, only soil shows a high concentration of metals.

3.1. Soil and earth drainage contamination

The presence of metals in the soil sample indicates significant soil contamination by leachate migration from the Piyungan landfill. In this section, As, Ni, Cr and Mn, which have a similar position in the periodic table, shows the concentrations in soil and earth drainage above the standards limit. By referring to the 1st path in Figure 1, a high concentration of As was detected at SS1 (74.1 mg/kg), located nearest and downstream to the landfill. From SS1, the concentrations were reduced gradually to downstream 24.6 mg/kg, 17.5 mg/kg, 20.8 mg/kg and 18.7 mg/kg. The last station SS9 (18.7 mg/kg), the concentration was almost similar control section CSI (18.5 mg/kg). In addition, high concentrations of As were also detected through the earth drain at L6 (0.051 mg/L) and L14 (0.046 mg/L), which were above the raw water standard (0.01 mg/L). Both stations were located after the leachate treatment plant. Sampling from these stations shows the leachate migration after the leachate treatment pond until the Opak River. The spreading of metals from the treated leachate was through the earth drain and along the soil surface. Even though the concentrations were reduced, the concentrations were above the standard limit for the residential area by referring to Contaminated Land Management and Control Guidelines No. 1: Malaysian Recommended Site Screening Levels for Contaminated Land [6]. This standard was referred from the site screening level of the United States Environmental Protection Agency (USEPA).

The trend of As migration for the 1st path was like Ni, Cr and Mn, which shows the concentrations of metals were reduced from SS1 until SS9, as shown in Figure 2. Mostly, metals concentration at SS9 was almost similar control section CSI except for Ni. Besides earth drain at L6 and L14, the concentrations of Ni, Cr and Mn also showed a similar trend with As as shown in Figure 3, which above the raw water standard. These reductions show that metals were reduced through the path before they reached the Opak River. Probably, Ni requires a longer path to reach the concentration in the control section. However, the downstream of station SS9 is the Opak River. Thus, the river probably is contaminated with a high concentration of Ni. In addition, several agricultural activities were observed at station SS9 and probably due to reduced use of soil liming in agricultural activities, decrease the soil pH. With reduce soil pH, the mobility and solubility of Ni increase [7]. Thus, it is highly recommended to conduct soil pH in that area and measuring Ni concentration in the Opak River.

![Figure 1. Distribution of As from the Piyungan Landfill.](image-url)
Besides the 1st path, As was also migrating from SS5 until SS6 (from 51 mg/kg to 24.1 mg/kg), which indicates the 2nd path in Figure 1. There is no leachate pond found in these locations during site observation. Both locations were housing areas where mostly, residents’ daily work was collecting recycled trash from the landfill, as shown in Figure 4. However, other metals, namely Ni, Mn and Cr, do not show a similar trend with As for the 2nd path. It means that the contamination of Ni, Mn and Cr does not migrate into the 2nd path. However, concentrations of Mn and Cr were above the allowable limit for residential soil.

These high concentrations can cause cancer and skin lesions if residents live near the landfill expose for a long-term duration. Also, exposure to the high concentration of these metals can be associated with diabetes, cardiovascular disease or manganism disease [8]. Besides of direct effect on human, the plant also can absorb these metals in soil. Some plants can absorb and move these metals from roots to leaves, which will indirectly adversely impact human health through the digestion process [9].

SS8 (15.4 mg/kg), SS7 (17.85 mg/kg) and SS4 (15.3 mg/kg) shows the As concentrations mostly like CSI. Thus, probably no migration of leachate in the soil surface in these sampling locations. The trend for As was also similar to Mn. However, Ni and Cr show high concentrations at SS8. SS8 is located upstream of the landfill. The concentrations of Ni and Cr may increase mainly through anthropogenic deposition, e.g., atmospheric deposition from the waste burning of e-waste observed during sampling work [10].

Among all metals, Mn is the highest concentration detected in the soil, which constant with the result of a study conducted by Kanmani & Gandhimathi [11]. Based on the study, sources of Mn in that site were due to disposal of bottle caps, blades, and pharmaceuticals, galvanising, paints, pigments, insecticides and cosmetics, along with garbage. Like Piyungan landfill, the high composition of these waste was also dumped in that area. By referring to Alam et al. [9], the geoaccumulation index (Igeo) for Mn was from 2.6 to 5.5 range for the 1st path, which shows moderately polluted to very strong polluted. Meanwhile, the 2nd path shows the Igeo was from 2.8 to 3.4 range, which shows the strongly polluted. This index is suitable to quantify the metals contamination in the soil, and the result in this study shows that the area was highly contaminated with Mn.

Based on Table 2, Mn and Cr were detected at a similar concentration from the earth drainage (L6 and L14). However, there is a huge difference by comparing to Mn and Cr concentration in soil. This large difference may be due to the difference in precipitation of Mn and Cr in soil. Precipitation is a key mechanism of retaining metals in soil. Soil precipitation occurs during chemical reactions when a nutrient or chemical in the soil solution (water around soil particles) transforms into a solid [12]. Thus, based on the result in this study, Mn was accumulated in the soil, whereas not for Cr.

**Table 2**: Comparison between earth drain and soil contamination with Mn and Cr.

| Sampling stations | Earth drain (mg/L) | Soil (mg/kg) |
|-------------------|--------------------|--------------|
|                   | L6     | L14     | SS3     | SS5     |
| Mn                | 0.888  | 1.099  | 1.26E+04| 9.29E+03|
| Cr                | 0.991  | 1.129  | 1.45E+02| 1.69E+02|

3.2. Soil contamination without effect on earth drainage

In this section, high concentrations of detected four metals (Li, V, Co, Ti) in the soil for all sampling stations were above the standard limit for the residential area by referring to Contaminated Land Management and Control Guidelines as shown in Table 3 and 4. However, these metals show low concentrations in earth drainage (L6 and L14). By comparing soil and surface water (in this considered as earth drainage), soil can be considered the best indicator of environmental hazard due to contamination from leachate migration. Soil with high holding capacity has the capability to accumulate the metals, whereas earth drainage is flowing the metals from the upstream until the downstream [13]. Probably, during sampling in August 2019, these metals concentrations in earth
drainage were in low concentrations. However, due to the high concentration in soil, these metals were in high concentrations for a very long time before this study was conducted.

Figure 2. Distribution of (a) As, (b) Ni, (c) Mn and (d) Cr in soil.

Figure 3. Distribution of (a) As, (b) Ni, (c) Mn and (d) Cr in earth drainage.
Several sampling stations shows Cu and Ba concentrations were above the allowable limit for a residential area. By referring to Alam et al. [9], Igeo for Cu was in the range from 2.4 to 5.8, which indicate moderately to very strong polluted. Cu is one of the metals that less immobile in the soil, which mostly adsorb Cu have always detected for Mn Oxides [14]. Meanwhile, a high concentration of Ba may be a marker for anthropogenic activity, which this metal commonly uses in manufactured material such as paint, glass, brick and other materials. Besides, a high concentration of Ba may influence a high concentration in the plant. MaBridge et al. [15] stated that Ba in vegetables was much higher than other metals, although Ba in soil was lower.

For Pb, Mg, Zn, Cd and Sr, the nearest sampling station to the landfill area (SS1) shows the high concentration above the allowable limit for a residential area. This result shows that these metals were successfully removed during the treatment in the leachate pond. These metals were also detected in low concentrations below the allowable limit for leachate discharge standard [1].

### Table 3. Metals concentrations in soil

| Metals | SS1    | SS2     | SS3    | SS5    | SS6    | SS7    | Residential Soil |
|--------|--------|---------|--------|--------|--------|--------|-----------------|
| Li     | 683.704| 83.471  | 84.776 | 136.862| 87.411 | 109.843| 16              |
| V      | 8267.382| 1175.216| 1407.629| 1421.945| 1202.876| 1414.273| 39              |
| Co     | 1333.846| 149.252 | 179.164| 179.264| 231.263| 181.034| 2.3             |
| Tl     | 5.383  | 0.763   | 1.365  | 1.51   | 1.093  | 0.793  | 0.08            |
| Cu     | 3.87E+03| 4.74E+02| 2.94E+02| 1.25E+03| 2.79E+02| 4.06E+02| 3.10E+02       |
| Ba     | 1.08E+04| 1.59E+03| 2.47E+03| 8.04E+02| 3.27E+03| 2.03E+03| 1.50E+03       |
| Pb     | 2.70E+03| 1.31E+02| 1.55E+02| 9.15E+02| 1.04E+02| 1.01E+02| 4.00E+02       |
| Mg     | 6.15E+05| 1.02E+05| 1.92E+05| 9.79E+04| 1.31E+05| 3.80E+05| 3.80E+05       |
| Zn     | 3.88E+03| 6.13E+02| 4.94E+02| 7.71E+02| 4.47E+02| 5.46E+02| 2.30E+03       |
| Cd     | 22.99  | 1.642   | 4.36   | 2.66   | 1.445  | 1.724  | 7.1             |
| Sr     | 7.13E+03| 9.41E+02| 6.60E+02| 1.02E+03| 1.33E+03| 6.81E+02| 4.70E+03       |
Table 4. Metals concentrations in soil (Cont...)

| Metals | SS8  | SS9  | SS10 | SS11 | SSG  | CSI  | Residential Soil |
|--------|------|------|------|------|------|------|------------------|
| Li     | 75.287 | 91.942 | 88.579 | 104.91 | 58.117 | 148.202 | 16 |
| V      | 688.983 | 1120.852 | 1291.333 | 1446.281 | 794.606 | 732.3 | 39 |
| Co     | 93.311 | 121.184 | 161.552 | 197.451 | 105.492 | 191.434 | 2.3 |
| Ti     | 0.654   | 0.868   | 1.368   | 1.015   | 1.077   | 1.082   | 0.08 |
| Cu     | 4.30E+02 | 4.53E+02 | 3.75E+02 | 3.84E+02 | 2.56E+02 | 2.70E+02 | 3.10E+02 |
| Ba     | 1.28E+03 | 1.39E+03 | 2.21E+03 | 2.13E+03 | 1.93E+03 | 1.46E+03 | 1.50E+03 |
| Pb     | 1.49E+02 | 3.23E+02 | 1.98E+02 | 2.34E+02 | 1.15E+02 | 6.50E+01 | 4.00E+02 |
| Mg     | 6.89E+04 | 8.58E+04 | 6.31E+04 | 8.92E+04 | 3.82E+04 | 1.24E+05 | 3.80E+05 |
| Zn     | 8.36E+02 | 9.05E+02 | 9.39E+02 | 6.39E+02 | 4.37E+02 | 4.20E+02 | 2.30E+03 |
| Cd     | 4.578   | 2.989   | 4.683   | 3.024   | 1.45    | 1.739   | 7.1 |
| Sr     | 1.44E+03 | 1.13E+03 | 8.88E+02 | 6.55E+02 | 1.23E+03 | 9.65E+02 | 4.70E+03 |

4. Conclusion
There are 15 metals that were measured in soil and earth drainage to assess the effect of leachate migration from the Piyungan landfill. Based on the result, the metals contamination was migrated from the landfill into two paths based on the high concentration of As (74.131 mg/kg), Ni (734.9 mg/kg), Cr (4528.313 mg/kg) and Mn (5703.69 mg/kg) in soil and earth drainage. Meanwhile, Cu, Ba, Li, V, Co and Ti shows high concentrations only in soil, not in earth drainage. Due to the high holding capacity of the soil, these metals probably were accumulated in the soil ages ago before this study was conducted. Pb, Mg, Zn, Cd and Sr were not migrated due to low concentration in all sampling stations except the station nearest to the landfill area.

5. References
[1] Shaylinda N M Z, Amani N F M K, Mohd-Salleh S N A and Shahar M S 2020 Investigation of heavy metals pollution in Piyungan Landfill underground and surface water IOP Conference Series: Earth and Environmental Science 498(1) 012080
[2] Zailani L M and Zin N S M 2018 Characterisation of Leachate at Simpang Renggam Landfill Site, Johor Malaysia Journal of Physics: Conference Series 1049(1) 012040
[3] Paria S and Yuet P K 2006 Solidification–stabilisation of organic and inorganic contaminants using portland cement: a literature review, Environ. Rev. 14(4) 217-255
[4] Akoteyon I S, Mbata U A and Olalude G A 2011 Investigation of heavy metal contamination in groundwater around landfill site in a typical sub-urban settlement in Alimosho, Lagos-Nigeria, Journal of Applied Sciences in Environmental Sanitation 6(2)
[5] Geana E I, Iordache A M, Voica C, Culea M and Ionete R E 2011 Comparison of three digestion methods for heavy metals determination in soils and sediments materials by ICP-MS technique, Asian J. Chem. 23(12) 5213
[6] Department of Environment (DOE), Malaysia 2009 Contaminated Land Management and Control Guidelines No. 1: Malaysian recommended site screening levels for contaminated land (Kuala Lumpur: Department of Environment, Ministry of Natural Resources and Environment, Malaysia)
[7] Iyaka Y A 2011 Nickel in soils: a review of its distribution and impacts Sci. Res. Essays 6(33) 6774-6777
[8] Morais S, Costa F G and Pereira M D L 2012 Heavy metals and human health. Environmental health–emerging issues and practice 10 227-246
[9] Alam R, Ahmed Z and Howladar M F 2020 Evaluation of heavy metal contamination in water, soil and plant around the open landfill site Mogla Bazar in Sylhet, Bangladesh, *Groundw. Sustain. Dev* **10** 100311

[10] Luo C, Liu C, Wang Y, Liu X, Li F, Zhang G and Li X 2011 Heavy metal contamination in soils and vegetables near an e-waste processing site, south China, *J. Hazard. Mater.* **186**(1) 481-490

[11] Kanmani S and Gandhimathi R 2013 Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site, *Appl. Water Sci.* **3**(1) 193-205

[12] Kasassi A, Rakimbei P, Karagiannisidis A, Zabaniotou A, Tsiouvaras K, Nastis A and Tzafeiropoulou K 2008 Soil contamination by heavy metals: Measurements from a closed unlined landfill *Bioresour. Technol* **99**(18) 8578-8584

[13] Kamil N A F M and Abdul-Talib S 2010 Hazards due to Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals at the closed Kubang Badak landfill, Selangor *Int. Conf. on Science and Social Research (CSSR 2010)* (Kuala Lumpur)

[14] Arfania H and Asadzadeh F 2015 Mobility of heavy metals after spiking in relation to sediment and metal properties: leaching column study, *J. Soils Sediments* **15**(11) 2311-2322

[15] McBride M B, Shayler H A, Spliethoff H M, Mitchell R G, Marquez-Bravo L G, Ferenz G S and Bachman S 2014 Concentrations of lead, cadmium and barium in urban garden-grown vegetables: the impact of soil variables, *Environ. Pollut.* **194** 254-261

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