Assessment of Soil in the Vicinity of an Unengineered Landfill

Sumaiya Abdul Hameed Al Raisi

***Abstract*—Soil represents a major sink for metals that are released into the environment from various sources, including landfills. Some of these metals may be persistent due to their fairly mobile nature; whereas others are more mobile and have the potential to leach through soil profile at a higher rate, reaching the groundwater. Thus, a pollution problem arises when heavy metals are mobilized into soil solutions and transported to groundwater. Therefore, soil analysis is essential for identifying the characteristics of soil in a study area, relating it to leachate and leachate percolation, and defining the extent of contamination, if any. Due to the growing concern about the risk of groundwater contamination in landfills areas, especially in the widely used unengineered landfills, soil from three newly constructed boreholes in the vicinity of the Al Amirat unengineered landfill in Muscat was examined to determine the extent of soil contamination. The soil assessment indicated that soil samples in the vicinity of Al Amirat landfill do not pose any toxicity because they are not considered hazardous. However, since most metals are mobile within the soil profile, an effect on groundwater might occur in the long run if no action is taken to prevent it.**

***Index Terms*—Heavy metals, landfill, soil, TCLP.**

I. Introduction

One of the most significant environmental concerns is waste generation [1]. Waste management is an increasing environmental and health issue all over the world [2]. Landfills are used as a predominant method for waste disposal. They pose a significant threat to the environment since, during landfill operations, severe hazards, including gas and leachate, are produced, contaminating groundwater and soil if not properly managed [3], [4]. Leachate formation is currently one of the greatest problems that must be managed. When it gets in contact with the surrounding soil, surface, water, and groundwater, it can cause major pollution problems, having a detrimental effect on living organisms [5], [6]. Soil represents a major sink for metals that are released into the environment from a wide range of anthropogenic sources. Because of their fairly mobile nature, some of these metals could be persistent. Others are more mobile and have the potential to leach through the soil profile at a higher rate, reaching the groundwater [7]. Therefore, a pollution problem arises when heavy metals are mobilized into soil solutions and transported to groundwater. Therefore, soil analysis is essential for identifying the characteristics of soil in the study areas, relating them to leachate and leachate percolation, and defining the extent of contamination, if any. Due to the growing concern about the risk of groundwater contamination in landfill areas, especially the widely used unengineered landfills that lack leachate collection systems, the soil from three different points in the vicinity of Al Amirat unengineered landfill in Muscat was examined to evaluate the total and leachable heavy metal content and the extent of soil contamination.

II. Methodology

A. Al Amirat Landfill Site Description

Al Amirat's un-engineered landfill is located in the south-west of the city of Muscat as shown in Fig. 1. It lies at 655303 E and 2597522 N. It started operations in 1982, receiving waste from three different regions. It was partially closed in 2010 and only receives demolition waste that has been compacted and covered with layers of soil. Leachate started to flow and collect on lower parts of land on one side of the landfill, forming pools. The site is located in a broad valley and is surrounded by mountains and gravel plains with scattered trees. According to Muscat and Quriyat geological maps [8], the Al Amirat landfill is located on an area of alluvial fans and terraces and is bounded by metagreywacke and schist. A wadi moves 1 km away from the filling area across the other edge of the landfill-allocated land. Another wadi flows from the other edge of the landfill, following the majority of the leachate pools that formed behind the landfill in the wadi channel.

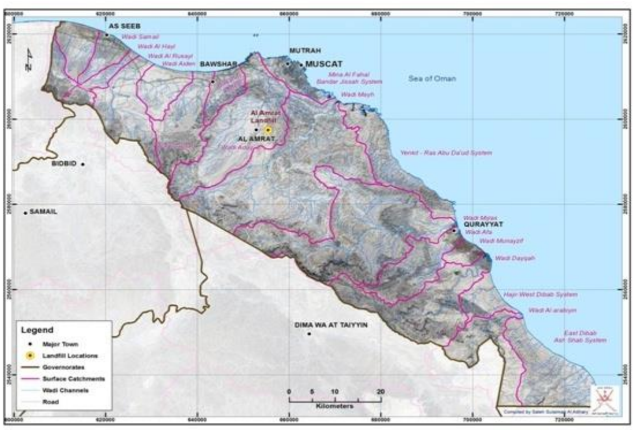

Fig. 1. The location of the Al Amirat unlined landfill.

B. Soil Analysis

Soil texture and heavy metal content were examined since soil analysis is required to assess the effect and extent of

Manuscript received March 9, 2022; revised April 25, 2022. This work was financially supported by Sultan Qaboos University, which is gratefully acknowledged.

S. A. Al Raisi was with Environment Authority, Oman (e-mail: sumaiyaalraisi@hotmail.com).

doi: 10.18178/ijesd.2022.13.5.1388

leachate contamination. In this study, three different boreholes were constructed in the vicinity of the Al Amirat landfill site: BH-A (4 m deep), BH-B (1 m deep), and BH-C (4 m deep). Soil samples were collected from different depths of the newly drilled boreholes (Table 1, Table 2, and Table 3) and also from control locations outside the landfill site (S1, S2, and S3).

Soil samples from every 0.25 m deep (BH-B) and 0.50 m (BH-A, BH-C) were analyzed to examine the total and leachable heavy metals content.

TABLE I: SOIL SAMPLES FROM THE FIRST BOREHOLE (BH-A)

Name	Depth (m)
BH-A(1)	0 - 0.5
BH-A(2)	0.5 – 1
BH-A(3)	1 – 1.5
BH-A(4)	1.5 – 2
BH-A(5)	2 – 2.5
BH-A(6)	2.5 – 3
BH-A(7)	3 – 3.5
BH-A(8)	3.5 – 4

TABLE II: SOIL SAMPLES FROM THE SECOND BOREHOLE (BH – B)

Name	Depth (m)
BH-B(1)	0 – 0.25
BH-B(2)	0.25 – 0.5
BH-B(3)	0.5 – 0.75
BH-B(4)	0.75 – 1

TABLE III: SOIL SAMPLES FROM THE THIRD BOREHOLE (BH – C)

Name	Depth (m)
BH-C(1)	0 – 0.5
BH-C(2)	0.5 – 1
BH-C(3)	1 – 1.5
BH-C(4)	1.5 – 2
BH-C(5)	2 – 2.5
BH-C(6)	2.5 – 3
BH-C(7)	3 – 3.5
BH-C(8)	3.5 – 4

C. *Soil Texture*

Soil texture is an essential soil characteristic. The percentage of sand, silt, and clay in soil determine its textural class. Soil texture determines the rate at which water dissipates through saturated soil [9]. The hydrometer method is the best method to determine the texture of any soil. The hydrometer method was used to identify the textural classes of soil samples [10].

D. *Soil Heavy Metals Analysis*

Soil total and leachable heavy metals content were examined. Soil total heavy metals were analyzed using an x-ray fluorescence spectrometry (XRF) model, the Axios Max PW4400. The soil leachable heavy metals content was identified in which samples were extracted according to the environmental protection agency (EPA) toxicity characteristic leaching procedure (TCLP) method 1311 [11].

III. RESULTS AND DISCUSSION

A. *Soil Analysis Results in BH-A*

1) *Total heavy metals concentrations*

The results of the analysis have shown that soil total concentrations of Cr, Cd, Ba, Pb, Co, Cu, and Hg were below the limits set by the EPA for both residential soil and home garden soil at all the depths within the borehole, while the concentration of Ni was above the limits only at the depth of 1.5–2 m. Ba and Rb were present in considerable concentrations. In general, the concentrations of most of the metals did not change much from 0 m deep to 4 m deep (Fig. 2). Any difference in metals concentrations with depth might be related to different soil properties at each depth and heavy metal mobility [12]. The properties of soil are very important in the attenuation of heavy metals in the environment in which heavy metal species undergo several possible fates, like adsorption/desorption reactions and precipitation/dissolution reactions [7].

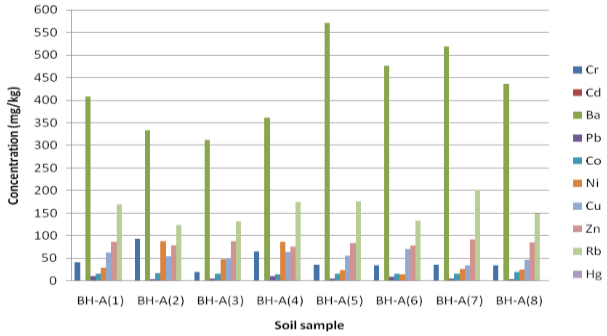

Fig. 2. Total heavy metals concentrations in soil samples.

2) *Leachable heavy metals concentrations*

The toxicity characteristic leaching procedure (TCLP) was also used to characterize soil to determine contaminant mobility in soil. Although this procedure was more labor-intensive and time-consuming than the total metals analysis, it was quite useful. This is because it recovers constituents that are easily soluble and not structurally contained in the samples [13]. Thus, determining the content of leachable heavy metals in soil is important in determining the extent of soil contamination [14] and the potential for groundwater contamination. Fig. 3 shows the amounts of heavy metals leached from different soil samples across the borehole depth.

The levels of Cd, Cr, Pb, and Hg were within the EPA's maximum concentration of toxicity characteristics. Thus, the soil samples within this borehole do not exhibit the characteristic of toxicity. The leachability of most of the heavy metals did not significantly change from 0 to 4 m of depth in the borehole. Most of the metals concentrations were below 0.9 mg/l. Cu and Zn concentrations were highest at the top (0–1 m) and the bottom of the borehole (3–4 m).

Comparing both total and leachable heavy metal concentrations, it has been found that the total concentrations of Zn, Cu, Rb, Cr, and Ba were the highest in the BH-A. The high concentrations of leachable Zn and Cu from the same borehole indicate that these metals have high mobility in the soils analyzed. Then, the low leachable concentration of Rb, Cr, Ni, and Ba, which were found in high concentrations in soil, indicates the high adsorption and low mobility of these metals in the soil of the BH-A borehole. The total and leachable heavy metals levels in this borehole were comparable with the results achieved in Thala Valley landfill soil samples in Antarctica [14], concentrations of soil samples in the vicinity of iron and steel works at Galati, Romania [15], and concentrations of soil samples around hazardous waste disposal sites in Hyderabad, India [16].

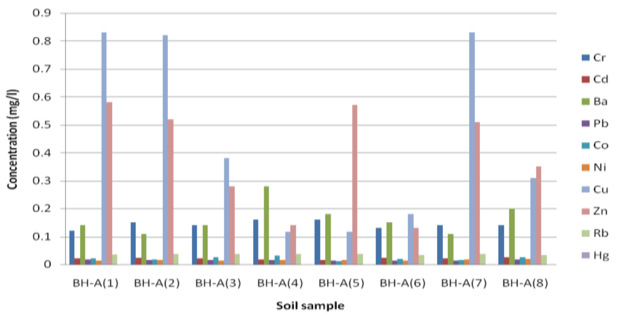

Fig. 3. Leachable heavy metals concentrations (TCLP).

B. Soil Analysis Results in BH-B

1) Total heavy metals content in soil samples

Fig. 3 shows that most heavy metals content in soil of BH-B which was drilled closer to the leachate pool was within EPA limits for both residential soil and home garden soil at all the depths within the borehole. Ba and Rb were present in high concentrations. Except for Ba and Cr, the heavy metals content did not change significantly within the borehole depths, as shown in Fig. 4. The concentration of heavy metals in BH-B at all the depths was in the following order: Ba > Cr > Rb > Zn > Ni > Cu > Pb > Co > Cd > Hg in ranges of (274.1–390.6) mg/l, (157.3–275.3) mg/l, (68.2–82.5) mg/l, (35.9–43.6) mg/l, (19.3–25.8) mg/l, (20.2–22.6) mg/l, (7.2–9.5) mg/l, (7.8–8.4) mg/l, (BDL–0.1) mg/l and below detection limits (BDL), respectively.

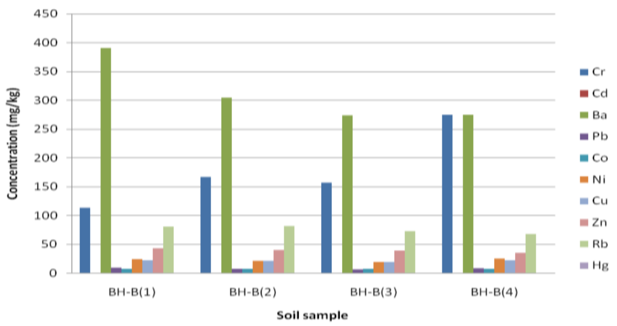

Fig. 4. Total heavy metals concentrations in soil samples.

2) Leachable heavy metals concentrations in soil samples

The levels of Cd, Cr, Pb, and Hg were within EPA's maximum toxicity concentration characteristics. Therefore, the soil samples within this borehole do not exhibit toxicity characteristics. Except for Ba, Cu, and Zn, the leachability of most of the heavy metals did not significantly change from 0 to 1 m depth of the borehole. All the metals concentrations were below 0.6 mg/l.

When comparing the total heavy metal content of the soil samples within the borehole with the leachable content, it has been found that the highest heavy metal concentration (Ba) was also the most mobile heavy metal within the soil profile, indicating the high mobility of Ba in the BH-B borehole.

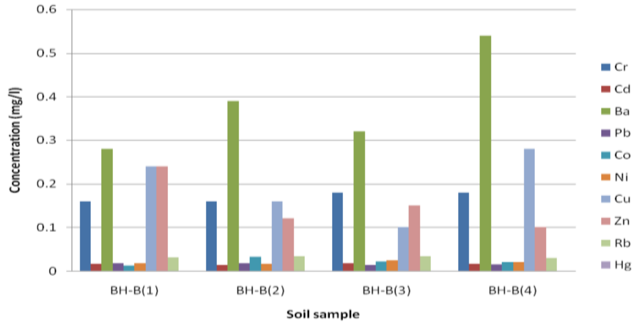

Fig. 5. Leachable heavy metals concentrations in soil samples.

C. Soil Analysis Results of BH-C

1) Total heavy metals concentrations in soil samples

The soil total concentrations of Cr, Cd, Ba, Pb, Co, Ni, Cu, and Hg were below the limits set by the EPA for both residential soil and home garden soil at all the depths within the borehole (BH-C). Ba and Rb were present in considerable concentrations. The concentration of most of the metals shown in Fig. 5 did not change much from 0 m depth to 4 m depth. The exceptions were Cr, Ba, Ni, Cu, and Rb. Ba, Rb, Zn, and Pb in which their concentrations were higher at the deepest point in the drilled borehole (3.5 – 4m), while the levels of Cr and Ni were highest at 0.5 – 1 m depth.

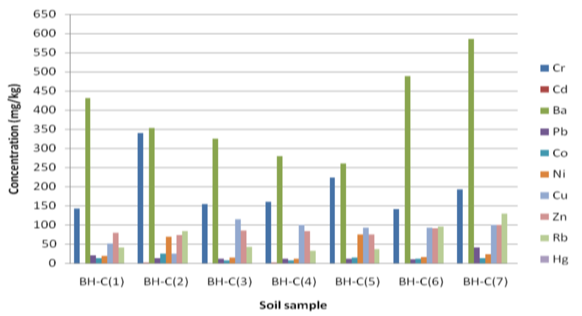

Fig. 6. Total heavy metals concentrations in soil samples.

2) Leachable heavy metals concentrations in soil samples

The levels of Cd, Cr, Pb, and Hg were within the EPA's maximum concentration of toxicity characteristics. Thus, the soil samples within this borehole do not exhibit the characteristic of toxicity. The highest concentrations of Cu, Zn, and Cr were found at a depth of 2.5 to 2 m, while the highest level of Ba was found at a depth of 0 to 0.5 m. The values for the rest of the heavy metals did not significantly change across the 4 m deep borehole. The leachable heavy metal levels were in the order of Ba > Cu > Zn > Cr > Rb, followed by comparable concentrations of Pb, Co, and Ni.

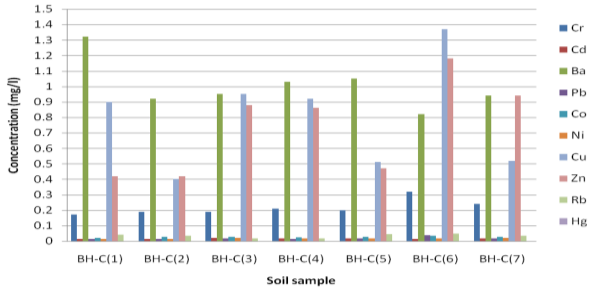

Fig. 7. Leachable heavy metals concentrations in soil samples.

When comparing both total and leachable heavy metal concentrations, it has been found that the leachable concentrations were higher for Ba, Cu, Zn, and Cr. The same heavy metals were the highest for total heavy metals analysis, indicating that these metals have high mobility in the soil samples analyzed.

When the leachable heavy metals content of all the constructed boreholes was examined (Fig. 8), it was found that the soil leachable heavy metals concentrations were higher in the BH-C borehole than in the BH-A and BH-B boreholes. BH-A and BH-B were constructed in the vicinity of landfill leachate pools, while BH-C was constructed about 1 km away from the leachate pools at the edge of the wadi that passes through the leachate pools. The landfill site's soil type was found to be sandy clay loam, which exhibits low permeability. The color of the soil in the boreholes has not changed. Moreover, it was observed that soil was forming a strong crust at the areas of contact with leachate, reducing its dissipation to lower soil layers. Therefore, the high leachable heavy metals levels in BH-C are because of the infiltration of leachate which moves with the wadi flow during rainfall.

The concentrations of total heavy metals within and in the vicinity of Al Amirat landfill were found to be higher than the concentrations detected in Bousher landfill, except for Ni [17].

The topsoil total heavy metals concentrations of all the boreholes were compared with soil from around hazardous waste disposal sites located in the north-western part of Hyderabad (India) [16]. It has been found that Cr, Cu, Ni, Pb, and Zn values were lower in BH-A and BH-B, while Cr and Cu concentrations were higher in BH-C than in the soil of hazardous waste disposal sites located in Hyderabad. Furthermore, soil samples' leachable heavy metals concentrations in all boreholes were less than the leachable heavy metals concentrations of soil at waste disposal sites in Antarctica [14].

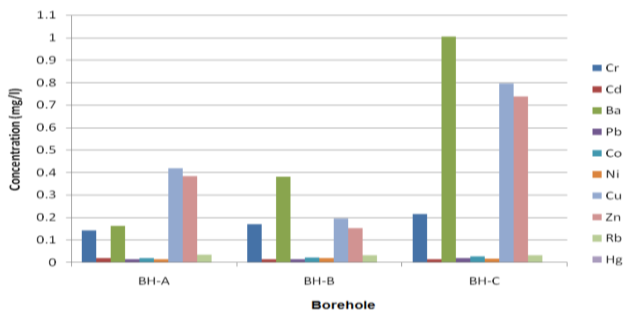

Fig. 8. Average leachable heavy metals content in the boreholes.

The heavy metal concentrations in the collected soil samples were found in considerable concentrations. However, these pollutants will continuously be migrated and attenuated through the soil strata, and after a certain period, they might contaminate the groundwater system if no action is taken to prevent this [12].

D. Control Samples Analysis

Control soil samples were collected from areas away from the landfill site. The results of the total heavy metals concentration in control soil samples were compared with the top layer samples of all boreholes as shown in Fig. 9.

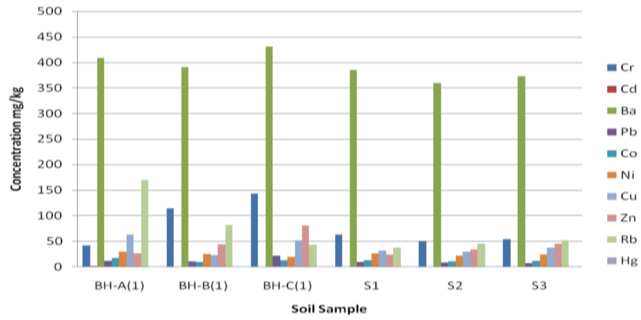

Fig. 9. Total heavy metals concentrations in borehole and control soil samples.

The results show that the total heavy metal content of control soils was less than the content of samples in the landfill vicinity. Moreover, Fig. 10 indicated that the leachable concentration of heavy metals in control samples was less than the leachable concentration of heavy metals in samples located near the landfill site, indicating that any contamination in the samples around the borehole and on the downstream side of the landfill is caused by the landfill because the heavy metals detected in the landfill leachate were also detected in the soil samples and considerable concentrations as leaching of the soluble components of the soil samples occur. Therefore, anthropogenic releases give rise to higher concentrations of metals relative to the normal background values. The same conclusion was made by [15] in which soil heavy metals levels in some locations exceeded the alert levels in Romania.

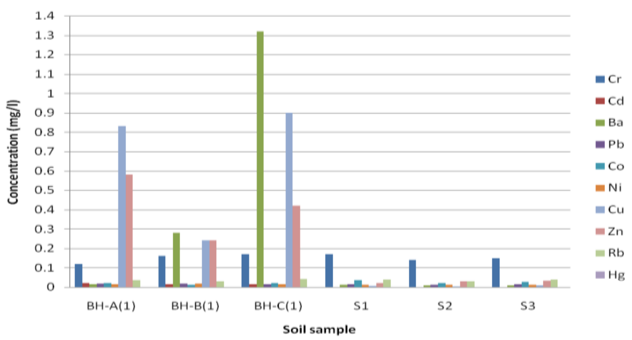

Fig. 10. Leachable heavy metals concentrations in borehole and control soil samples.

Because the leachable heavy metals concentrations were below the leachable maximum contamination levels around and downstream of the landfill area, the soil samples do not pose any toxicity since they are not considered hazardous. However, since most of the metals show mobility within the soil column and the concentration, of some metals increases in the deepest points of some boreholes (BH-A, BH-C), an effect on environment might occur in the long run.

By comparing the total and leachable concentrations of each heavy metal in each borehole, it was found that the leachable concentrations of heavy metals at some depths have followed the total heavy metals concentrations trend (Fig. 11–12), while it did not at other depths depending on the soil sample analyzed (Fig. 13–14). The difference in soil heavy metals mobility among different samples has been also observed by [14] in Thala Valley soil samples near waste disposal sites.

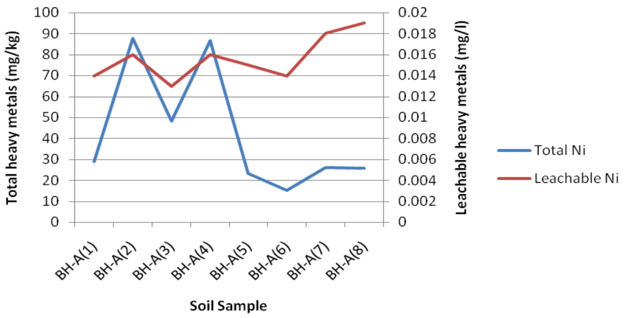

Fig. 11. Total and leachable heavy metals concentrations of Ni in BH-A.

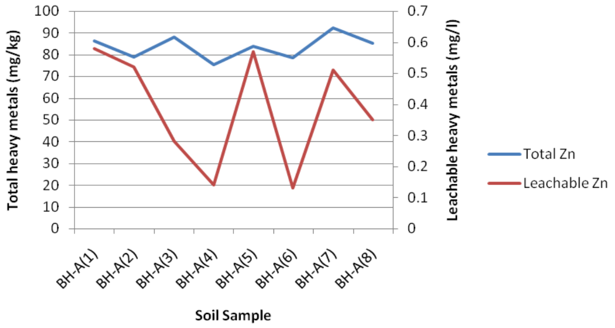

Fig. 12. Total and leachable heavy metals concentrations of Zn in BH-A

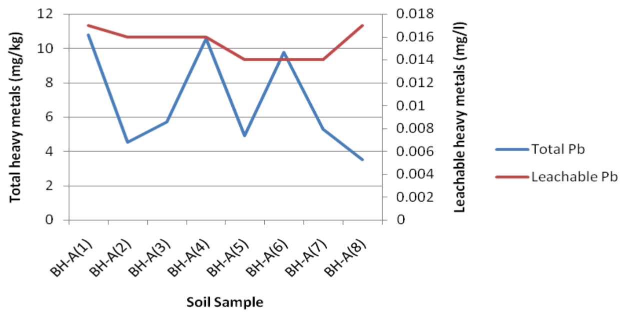

Fig. 13. Total and leachable heavy metals concentrations of Pb in BH-A.

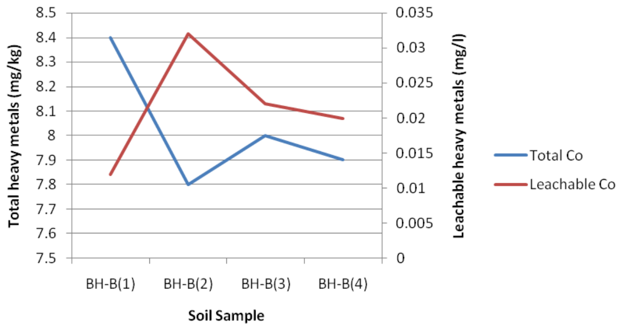

Fig. 14. Total and leachable heavy metals concentrations of Co in BH-B.

The mobility of heavy metals in the different soil samples analyzed was variable. The mobility and adsorption of heavy metals in soil are influenced by different factors. Understanding the factors governing heavy metals migration in the soil is therefore important for predicting metal environmental impacts. Maintaining the pH of the soil solution neutral to slightly alkaline conditions, for example, shows the low mobility of all heavy metals. Also, the presence of soil organic matter plays an important role in heavy metals adsorption. Soil organic matter may immobilize heavy metals. Furthermore, soil texture affects metal mobility in soil. Texture reflects the particle size distribution of the soil and thus the content of fine particles like clay, which are well-known adsorption surfaces for heavy metals in soils. When compared with sandy soil, clay soil retains a high amount of metals [7]. Moreover, precipitation is frequently connected with neutral to alkaline soil conditions as well as clayey soil. As the soil analyzed in this study was alkaline and clayey, some heavy metals might be precipitated and adsorbed since differences in pH, clay mineralogy, and clay content contribute to differences in heavy metals adsorption [18].

Other factors like temperature and competing ions also play important roles in heavy metals mobility [7]. For example, Zn that does not form highly stable complexes with organic matter is not as greatly affected by the presence of dissolved organic matter in the soil [19].

The extent of movement of heavy metals in the soil system is related to the chemistry of the soil and the specific properties of the metal. Soil properties such as pH, redox potential, surface area, cation exchange capacity, organic matter content, clay content, etc. have been correlated to cationic metal retention. In addition to soil properties, the type of metal, its concentration, and the presence of competing ions must be considered [19].

Because of the wide range of soil characteristics and various forms by which metals can be added to soil, evaluating the extent of metal retention by soil is site and soil specific [20]. Heavy metals mobility from different studies showed different mobility of heavy metals. The relative mobility of the metals concluded by [21] followed: Cd > Zn > Cu > Ni, while the mobility of heavy metals concluded by [22] followed the Pb > Zn > Cu > Ni > Cd order in contaminated soils of Southern Nigeria.

Soil systems are dynamic and are thus constantly changing. Changes in the soil environment over time, such as the degradation of the organic waste matrix, changes in pH, redox potential, or soil solution composition, due to various processes or natural weathering processes, may also enhance metal mobility. The extent of vertical contamination is related to the soil solution and the chemistry of the soil matrix's surface [19]. Temperature, for example, has a significant effect on metal availability. Soil extracts from 25^{o}C treatment had greater concentrations of Cd, Ni, and Zn than those at 15^{o}C. It has been concluded that this may be attributed to the organic matter, which decomposes more rapidly at 25^{o}C [23].

In addition, heavy metals tend to migrate and percolate through the soil strata. Moreover, these pollutants tend to bio-magnify and induce a long-term adverse impact on the environment if no action is taken to prevent them, and might contaminate the groundwater system after a certain period [12].

In conclusion, soil assessment has indicated that soil samples in the vicinity of Al Amirat landfill do not pose any toxicity as it is not considered hazardous, but since most of the metals show mobility within the soil profile, an effect on environment might occur in the long run if no action is taken to prevent it.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] S. Leao, I. Bishop, and D. Evans, "Spatial-temporal model for demand and allocation of waste landfills in growing urban regions," *Computers, Environment and Urban System*, vol. 28, 2004, pp. 353-385.

[2] United Nations Environment Program (UNEP), *Sanitary Landfill*, UNEP, 2005, Ch. XIV.

[3] J. Pichtel, *Waste Management Practices*, Taylor & Francis Group, USA, 2005.

[4] H. Modin, "Modern landfill leachates — Quality and treatment," PhD dissertation, Lund Univ., 2012.

[5] A. O. Adeolu, O. V. Ada, A. A. Gbenga, and O. A. Adebayo, "Assessment of groundwater contamination by leachate near a municipal solid waste landfill," *African Journal of Environmental Science and Technology*, vol. 5, no. 11, pp. 933-940, 2011.

[6] M. Chien and M. Liu, "Ecological risk assessment on a cadmium contaminated soil landfill: A preliminary evaluation based on toxicity tests on local species and site-specific information," *Science of the Total Environment*, vol. 359, pp. 120-129, 2005.

[7] T. Sherene, "Mobility and transport of heavy metals in polluted soil environment," *Biological Forum*, vol. 2, no. 2, pp. 112-121, 2010.

[8] Ministry of Petroleum and Minerals (MPM), *Geological Map of Muscat; sheet NF*, pp. 40-4A, 1986.

[9] B. Wayne, Q. Ketterings, S. Antes, S. Page, J. Russell-Anelli, R. Rao, and S. DeGloria, *Soil Texture*, Cornell University, 2007.

[10] M. R. Carter and E. G. Gregorich, *Soil Sampling and Methods of Analysis*, Taylor & Francis Group, USA, 2008.

[11] Environmental Protection Agency (EPA), *EPA Toxicity Characteristic Leaching Procedure (TCLP)*, EPA, 1992.

[12] S. Kanmani and R. Gandhimathi, "Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site," *Applied Water Science*, vol. 3, no. 1, pp. 193-205, 2012.

[13] D. Marcos, P. Jason, G. Humberto, C. Alba, C. Gustavo, C. Alfredo, D. Alberto, and G. Jorge, "Comparison of ICP-OES and XRF performance for Pb and As analysis in environmental soil samples from Chihuahua City, Mexico," *Physical Review & Research International*, vol. 1, no. 2, pp. 29-44, 2011.

[14] S. C. Stark, L. Snape, N. J. Graham, J. C. Brennan, and D. B. Gore, "Assessment of metal contamination using X-ray fluorescence spectrometry and the toxicity characteristic leaching procedure (TCLP) during remediation of a waste disposal site in Antarctica," *Journal of Environmental Monitoring*, vol. 10, no. 1, pp. 60-70, 2008.

[15] A. Ene, A. Bosneaga, and G. Rom, "Determination of heavy metals in soil using XRF technique," *Journal of Physics*, vol. 55 no. 9, pp. 815-820, 2010.

[16] V. Partha, N. Murthya, and P. Saxenab, "Assessment of heavy metal contamination in soil around hazardous waste disposal sites in Hyderabad city (India): Natural and anthropogenic implications," *Journal of Environmental Research and Management*, vol. 2, no. 2, pp. 027-034, 2011.

[17] S. Al Touqi, "Assessment of waste dumping sites and groundwater quality in Oman," MSc thesis, Sultan Qaboos University (SQU), Oman, 2008.

[18] U. Chuangcham, W. Wirojanagud, P. Charusiri, W. Milne-Home, and R. Lertsirivorakul, "Assessment of heavy metals from landfill leachate contaminated to Soil: A case study of Kham Bon Landfill, Khon Kaen Province, NE Thailand," *Journal of Applied Sciences*, vol. 8, no. 8, pp. 1383-1394, 2008.

[19] J. McLean and B. Bledsoe, *Behavior of Metals in Soils*, EPA, 1992.

[20] F. Obiri-Nyarko, A. A. Duah, A. Y. Karkari, W. A. Agyekum, E. Mano, R. Tagoe, "Assessment of heavy metal contamination in soils at the Kpone landfill site, Ghana: Implication for ecological and health risk assessment," *Chemosphere*, p. 282, 2021.

[21] M. Hickey and J. Kittrick, "Chemical partitioning of cadmium, copper, nickel, and zinc in soils and sediments containing high levels of heavy metals," *Journal of Environmental Quality*, vol. 13, no. 3, pp. 372-376, 1984.

[22] A. Olajire, E. Ayodele, G. O. Oyedirdan, and E. Oluyemi, "Levels and speciation of heavy metals in soils of industrial southern Nigeria," *Environmental Monitoring and Assessment*, vol. 85, no. 2, pp. 135-155, 2003.

[23] M. L. A. Silveria, L. R. F. Alleoni, and L. R. G. Guilherme, "Biosolids and heavy metals in soils," *Scientia Agricola*, vol. 60, no. 4, 793-806, 2003.

Sumaiya A. Al Raisi is from Muscat, Sultanate of Oman. She has an experience in environmental control and management as well as in solid and hazardous waste management. Her BSc, MSc and PhD (scholarship) were achieved from Sultan Qaboos University (Oman) in the field of environmental science. She has worked on a first of a kind project in Oman concerning unlined landfills, leachate and their potential impacts on ground water and environment.

She has gained her experience from working in the environment authority of Oman as well as a teaching assistant in the college of science in the same university. She has participated in different workshops, meetings, courses and conferences related to environment and waste management in particular, e.g. US EPA training on principles of environmental impact assessment, US EPA training on principles of environmental impact assessment review, waste management, Basel convention, conference on sustainable development, international and regional environmental convention and protocols workshop, workshop on illegal transboundary movement of hazardous waste, etc.

Dr. Al Raisi is interested in doing scientific research concerning environmental management.