Leaching Behavior of Pb, Cd, and Cu from Domestic Solid Waste Over Three Types of Soil Columns Under Different Rainfall Loading

Marwan Haddad[1,*] and Qusai Al-Nuri[2]

[1]*Water and Environmental Studies Institute, An-Najah National University, Nablus, Palestine*

[2]*Faculty of Graduate Studies, An-Najah National University, Nablus, Palestine*

Abstract: Long-term raining over accumulated solid waste disposal dumps would result in heavy metal contamination in both soil and groundwater, specially when no separation of industrial waste is made in Nablus Area of Palestine. A column leaching experiments were conducted to study the leaching behavior of Pb, Cd, and Cu from domestic solid waste over three types of local soils, clay, sandy, and a mix of both in one, three and five 100 cm depth, soil packed in eleven plastic columns under different rainfall loading of one, five, and ten years of average annual rainfall. Experimental results showed that (1) The concentration of heavy metals in leachate passing through soil were highest out of sandy soil followed by sandy clay soil and the least was out of clay soil, (2) As the applied layer of solid waste over the soil in the columns increases, the concentration of heavy metals and organic matter increase, (3) As the amount of rainwater applied over solid waste increases, the concentration of heavy metals decreases in the leachate from all columns, (4) The concentration of heavy metals absorbed by clay soil was much higher than than those in the sandy and mixed clay-sandy soil indicating that clay soil is good for metal remediation or removal but not suitable for using the soil for agricultural production purposes, and (5) The TOC removal efficiencies were greater in clay and clay-sandy soil and significantly improve with time.

Keywords: Leaching behaviour, Domestic solid waste, Heavy metals, Soil columns, Rainfall loading.

1. INTRODUCTION

The disposal and management of domestic solid waste have become critical concerns in the context of environmental sustainability and public health. Major environmental problems have arisen at landfills because of the migration of leachate from the landfill site and the subsequent contamination of surrounding land and water. Whether leachate is to be collected and treated or be allowed to discharge to the soil, it is essential to have estimates of leachate flow and strength, and variation of these with time, as the site develops through closure and after closure [1, 2].

Heavy metals are found naturally on the Earth's crust since the Earth's formation. Due to the astounding increase of the use of heavy metals, it has resulted in an imminent surge of metallic substances in both the terrestrial environment and the aquatic environment [3].

In addition, a considerable amounts of heavy metals (*e.g.*, Pb, Cd, and Zn) from strong garbage removal, wastewater water system, pesticide application, and environmental data and documents can accumulated in surface soil and can possibly drain into groundwater [4]. Removing heavy metals from the soil is a truly troublesome issue since they are express extraordinarily intense tainting [5].

Future management options for solid wastes are likely to include land disposal. While the environmental ramifications of this option are now better understood, additional data is required to permit a thorough assessment of contaminant leachability from solid wastes [6].

The average daily generation of household solid waste in Palestine in 2015 was estimated at 2.9 kg (about 5.7 Kg per household): around 3.2 kg in the West Bank and 2.4 kg in Gaza Strip. The overall estimated quantity of solid waste generated daily was about 2551 tons [7]. As it is dumped on land for along time, solid waste is exposed to many conditions among which its exposure to natural rainfall, temperature, and fermentation.

Domestic solid waste in Nablus is collected from households, commercial markets and industrial factories without separation. This waste also include wrecked cars, metal materials, demolition and construction waste, gardens refuse, paper and paper boards, residential waste, commercial waste, industrial waste, and other waste materials. Industrial waste come from sweet factories, lathes and blacksmiths, shoes factories and workshops, textile factories, stone-cutting facilities and quarries, waste from hospitals and clinics, olive and vegetable oil factories, and ghee and

*Address correspondence to this author at the Water and Environmental Studies Institute, An-Najah National University, Nablus, Palestine;
Tel: +970 599 294952; E-mail: haddadm@najah.edu

E-ISSN: 2311-8741/24

detergents industry. The daily quantity of solid waste collected varies from 0.9-1.0 Kg per person.

Because in most areas in Palestine there is no separation in the collection of domestic and industrial solid waste, the composition of leachate from solid waste may contain various heavy metals and other toxic elements in addition to normal composition.

Leaving solid waste in open landfills and dumps and under sunlight and rain will lead with time to its decomposition and the leakage of leachate carrying toxic substances including heavy metals to soil and then to groundwater, which is the main source of water supply in Palestine.

Possibilities for predicting long-term hazards of metals are limited. Due to the complexity of the soil or sediment system and the variability of numerous influencing factors, the long-term prognosis on the mobilization of metals from soils or sediments is highly uncertain [8]. Because of the long-term involved, verification of model predictions from field observations is not possible. Despite the large uncertainties involved, predictions of metal mobility from laboratory leaching experiments allow a range of results to be obtained under plausible assumptions and thus may support decisions [9].

Chemical withholding and trapping has been considered as a promising soil remediation technique compared with conventional techniques, *e.g.*, excavation and off-site disposal [10, 11]. Heavy metal regathering or accumulation probably happens because of microbial activity, landfill, weathering, aging, acid deposition, and temperature fluctuation [12, 13].

Published data on the leachability of heavy metals from solid waste materials onto soil as assessed by dynamic leaching tests are scarce. In a previous contribution [14-17], the short-term leaching behavior of metal in surface soils derived from dredged materials was assessed using consecutive saturation extracts. Although metal concentrations in the saturation extracts of the oxidized soils were above levels found in pore-water of clean. Contaminants such as Pb, Cd, and Cu, commonly found in electronic waste, batteries, and household products, pose a substantial risk when released into the environment.

Understanding their leaching behavior under different scenarios is paramount for formulating effective waste management strategies and mitigating potential environmental hazards. This research builds upon existing literature on heavy metal leaching and extends its scope by exploring the intricate interplay between domestic solid waste, diverse soil compositions, and the dynamic factor of rainfall loading [18].

This article delves into a comprehensive laboratory investigation of the leaching behavior and patterns of three prominent heavy metals—lead (Pb), cadmium (Cd), and copper (Cu)—from domestic solid waste. The study focuses on assessing the dynamic interactions between these heavy metals and three distinct types of soil columns subjected to varying rainfall loading conditions.

2. MATERIALS AND METHODS

2.1. Experimental Site

This research was performed mainly by laboratory work, all laboratory work was done at the Water and Environmental Studies Institute laboratories and Experimental station at An-Najah National University located East of Nablus city, Palestine. Nablus city is located in the northern part of the Palestinian Territory. Ambient temperature in Nablus ranges 6.2-13.1 oC in winter and 19.5-29.4 oC in summer. Average annual rainfall in Nnablus is 663.6 mm and mostly fall between December and March [19].

2.2. Leaching Experiment Variables

Three leaching experimental variables were tested:

- Time: rain water application-variable
- Solid waste intensity or thickness variable
- Soil type variable

2.2.1. Rain Water Application

Nablus municipal water supply which is from ground water was used as the source for rain water application. Taking the average annual rainfall for the Nablus area of 663.6 mm (see Table **1** below) and the cross sectional area of the 6” PVC pipe we came to the amount of 681 ml as the dose for one year application. This water volume was applied as spray to the column and was homogeneously distributed in twenty doses one dose every three days with a total application period of sixty days. Four categories of rain water application were used: one (681 ml or o.124 m^3/m^2-day), three (2043 ml or 0.0373 m^3/m^2-day), five (3405 ml or 0.0621 m^3/m^2-day), and ten (6810 ml or 0.124 m^3/m^2-day) application every three days interval.

Table 1: Intensity and Distribution of Rainfall for the Average Year

Month	Amount of rain water (mm)
January	160
February	156
March	110
April	40
May	34
June	3
July	0
August	0
Septemper	0
October	17
November	76
December	67
Total Annual	663

Data Source [20]

2.2.2. Solid Waste

Solid waste was collected from six containers around the city, 10 Kg from each container. The collected waste was brought to the experimental site, then mixed together before weighing and placing in the experimental columns. Three levels were tested one layer, three layers, and five layers of solid waste. Each layer consisted of 3.5 kg of solid waste or about 33 cm of column height. A sample from the mixed solid was was collected and brought to the laboratory for content analysis. Results of solid waste material composition or content are listed in Table **2** below. It is clear that the majority of solid waste content is organic matter. Also chemical analysis were conducted on a mixed sample and the results are listed in Table 2. Noticeable that SO_4, TOC, Cu, and Cd are high in the sample.

Table 2: Percentages of Specific Weight Values for Solid Waste

Composition	Percentage
Food Residues	72.4
Paper and Cartoon	19.3
Plastics	2.7
Class	2.3
Metal Cans	1.8
Clothes	0.9
Leaves,Wood, & Other	0.6
Water Content	20.4

2.2.3. Soil Type

Three types of soil were used and tested in this experiment:-

1- Clay soil (Burqa soil):- this soil selected from Burqa village about 15 km north of Nablus and is brown rendzinas type of soil. A major sanitary landfill was constructed there after studying the soil in the site to be clay and suitable. A total of 500 Kg of soil collected from that site, to be used in the column experiment.

2- Sand soil from Gaza Strip soil or about 200 Kg were collected and brought to the experimental site in Nablus to be used in the column experiment.

3- Mixed soil: This soil mix was made mixed between clay soil and sand soil with percentage 1:10 gm clay to sand.

Table **3** below includes results of chemical analysis of raw solid waste, clay, and sandy soil.

Table 3: Chemical Analysis of Raw Solid Waste, Clay, and Sandy Soil

Parameter	Solid Waste	Clay	Sandy
PH	8.22	8.02	7.92
EC (ds/m)	1.61	0.444	0.777
CO_3 (mg/l)	1143	126	18
HCO_3 (mg/l)	10133	1006.5	494.1
NO_3 (mg/l)	100	23	6
SO_4 (mg/l)	835.4	23	2
TOC (mg/l)	13500	0.0	0.0
COD (mg/l)	51724	0.0	0.0
Pb (ppm)	0.0	191.9534	15.9872
Cd (ppm)	143.1	530.83	16.3763
Cu (ppm)	1583	100	75

The measured solid waste values above (see Table **3**) are higher than typical solid waste composition and represent a strong in organic content solid waste. Same apply for the concentrations of heavy metals, specially Cd and Cu, compared to published values for solid waste [21]. Similar for soil, both soils have higher levels of metals than allowable [22].

2.3. Experimental Setup and Design of Experiments

Column experiments are well-suited to determining the concentrations of heavy metals that can be released using a relatively small solid waste and soil layers, and which also corresponds to shorter time periods. The design of a typical column leach experiment apparatus is illustrated in Figure **1**.

Eleven experimental columns were constructed. Each column consisted of five parts free board, solid waste layer, soil layer, gravel layer, and leachate collection funnel. Figure **1** is an illustration of the experimental column. Columns were made of 6” PVC plastic. A diffuser was placed between the solid waste layer and rain water application. Also two metal mesh sheets were installed separating solid waste layer from soil and soil layer from leachate collection funnel (see Figure **1**).

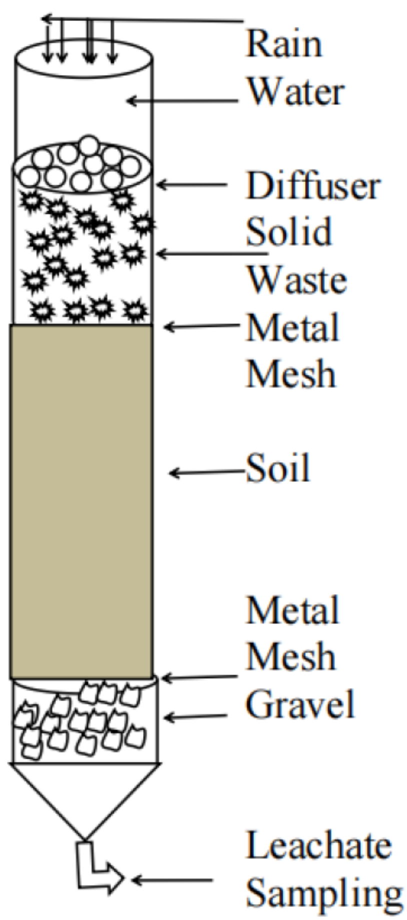

Figure 1: Schematic of experimental column.

Gravel layer with particles about 2 cm in size with a height of 20 cm, was placed under the soil layer acting as a filter and for allowing air circulation through the column. After the gravel layer, a funnel was placed to collect the drained leachate.

A 100 cm deep soil layer was about 29kg for sandy to 31kg for clay soil Kg in weight. Soil samples were taken from three positions in the soil layer at 33, 66, and 100 cm depth.

The characteristic of each experimental column including solid waste loading, rain water application rate, soil type, and column total depth or height are listed and detailed in Table **4** below. The experiment was conducted over a duration of seventy days. Leachate was collected from the funnel at the bottom of the experimental column every three days. Also rain water application was done every three days.

3.4. Laboratory Analysis

Two types of laboratory measurements were concerned; chemical analysis of water and leachate and physical and chemical analysis of soil. For water and leachate analysis all measurements were performed according to standard methods for examination of water and wastewater [23]. All physical and chemical analysis of soil and solid waste were conducted according to methods listed in "Methods of Soil Analysis” [24].

3. RESULTS AND DISCUSSION

Many analysis were conducted on the collected leachate including pH, EC, CO_3, HCO_3, SO_4, NO_3, TOC, COD, and heavy metals (Cd, Cu, and Pb). For this paper and for size and subject limitation, leachate volume, TOC, and heavy metals will be presented and discussed.

3.1. Heavy Metal Concentrations in the Leachate

Leaching of Cu, Pb, and Cd from the eleven columns are listed in Table **5**. Results of analyzed heavy metals reveled an increase in Cd, Cu, and no readings for Pb. Effluent Cu from all columns increased from 100 and 75 for clay an sandy soil to about 585 mg/l during the collection of leachate either after 29 or 58 days since the start of the experiment. This was noticeable for columns with different solid waste loading, different rain water application, and different soil. This may mean that the Cu leached from the solid waste did not exceed the absorption capacity of the soils used.

As listed in Table **5**, leachate after 29, and 58 days and from all columns did not include Pb. An indication that neither the soils nor thee solid waste had Pb in it.

Table 4: Description and Characteristics of Column Experiments

Description	Depth [cm]	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Free Board	20											
Solid Waste Layer												
One	1 x 33	X	X	X	X	X	X			X	X	X
Three	3 x 33							X				
Five	5 x 33								X			
Soil Type												
Clay	100	X	X	X								
Sandy	100				X	X	X	X	X			
Mixed	100									X	X	X
Rainwater Intensity												
One Year		X			X					X		
Three Years								X	X			
Five Years			X			X					X	
Ten Years				X			X					X
Total column depth [cm]		**153**	**153**	**153**	**153**	**153**	**153**	**213**	**275**	**153**	**153**	**153**

Notes:
One year precipitation loading = 681 ml every three days for a duration of sixty days; One solid waste layer = 3.5 Kg of mixed domestic solid waste from Nablus dump site or about 33 cm depth in the column; Column = Six inch in diameter PVC pipe; Clay Soil = Burqa type clay soil about 15 km north west of Nablus; Sandy Soil = Sand soil from Gaza area; Mixed Soil = 1:10 clay to sand soil.

Table 5: Concentration of Cd, Cu, and Pb in Leachate after 29 and 58 Days, ppm

Column Number	Cd		Cu		Pb	
	Time Collected, days		Time Collected, days		Time Collected, days	
	29	58	29	58	29	58
Col.(1)	3.764	27.28	586	586	0.0	0.0
Col.(2)	2.137	5.22	587	586	0.0	0.0
Col.(3)	0.919	0.995	586	585	0.0	0.0
Col.(4)	5.813	48.735	588	586	0.0	0.0
Col.(5)	5.231	10.214	586	589	0.0	0.0
Col.(6)	3.598	5.49	588	586	0.0	0.0
Col.(7)	28.1	97.81	585	585	0.0	0.0
Col.(8)	73.652	105.15	585	588	0.0	0.0
Col.(9)	3.893	7.365	587	587	0.0	0.0
Col.(10)	7.01	16.94	588	586	0.0	0.0
Col.(11)	7.895	0.774	586	586	0.0	0.0

Cd concentration in leachate after 29 and 58 days since the start of the experiment were illustrate in Figure **2**. The highest Cd concentration were found in columns 8, 7, and 4. These concentrations correspond to columns packed with clay soil. Also, these concentrations correspond to columns packed with solid waste loading of five layers, three layers and one layer, consequently and with rain water application of five years, three years, and one year, consequently. Which means that:

- Clay soil and under the same experimental conditions leach more Cd than sand soil.

- As we increase solid waste loading, Cd in leachate increases.
- As we apply more rain water Cd in leachate increases.
- The highest the combined rate of application of rain water and solid waste, the highest the concentration of Cd in the leachate and vice versa. The rate after 58 days, if we look at Figure **1** above is almost linear.
- As the solid waste loading increase from one to three, to five layers (columns 6, 7, and 8), the Cd increased.
- Cadmium in leachate of clay and sandy-clay mixed soil was less that that for sandy soil columns indicating the power of clay in absorbing and/or adsorbing cadmium ions.
- For one year rain water application, Cd in leachate for clay Column 1)and mixed soil (column 9) was less than that in leachate from sandy soil (column 4).
- The high concentration of cadmium and copper in the leachate of all experiments indicate that cadmium and copper are of great mobility and assimilability. This result for cadmium agree with those found by Zhuang *et al*. 2014 [25]
- No lead was observed in the leachate of all experiments indicate either its absence in the solid waste or very little and being totally absorbed by the soil.
- The increase in cadmium in leachate is an increase in leachate toxicity. This agree with results obtained by Hu, *et al*. 2014 [26].
- The leachability of heavy metals from domestic solid waste through various types of soils (experimental columns 1-11) indicated the need for adopting strict solid waste management and control measures to limit ground water pollution.
- The leachability of cadmium and copper is significantly affected by multivariate experimental factors associated with local conditions, i., e., solid waste loading, rain water intensity, and type of soil.
- Results listed in Table are compatible and solid waste analysis (Table).
- Results indicate that domestic solid waste have both a higher heavy metals content and heavy metals leachability.

3.2. Total Organic Carbon (TOC) in Leachate

Table **6** and Figure **3** include monitored TOC in leachate out of the eleven columns after 15, 29, 44, and 58 days since the start of the leaching experiments. Results showed that:

- In all columns leachate TOC was in decreasing trend with time indicating its accumulation in soil.

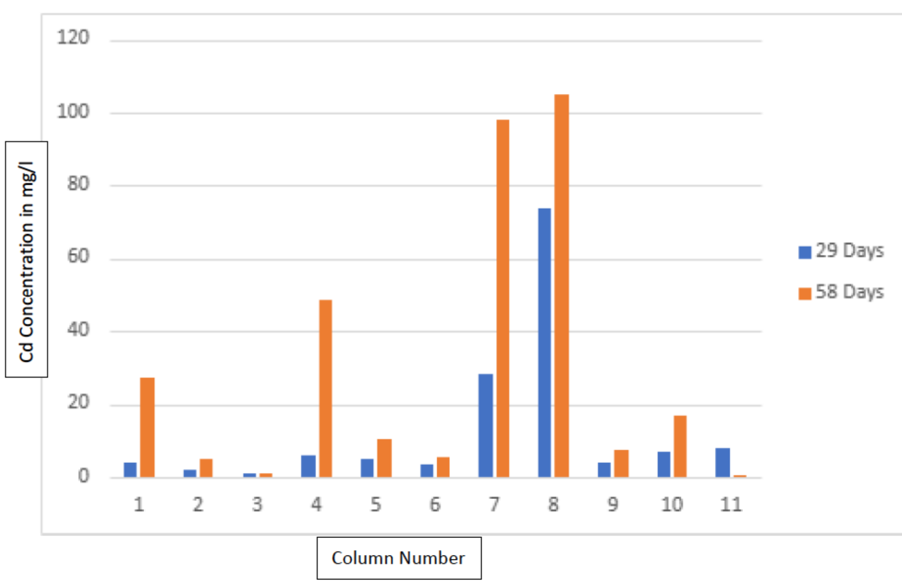

Figure 2: Concentrations of Cd in Leachate after 29 and 58 days.

- Columns with sandy soil (columns 4-8), TOC in leachate was increasing with increasing solid waste loading.
- Columns with sandy soil (columns 7-9) and clay soil (columns 1-3), TOC in leachate was increasing with decreasing time. TOC was the highest at 15 days after the start of experiment and the lowest after 58 days.
- Columns with mixed soil (columns 9, 10, and 11) followed the general decreasing trend but the TOC values in leachate after 58 days were the minimal among all experiments.This may be as a result of clay particles absorbing more TOC with time.

Table 6: Concentration of TOC of Leachate (mg/l)

Column Number	15	29	44	58
Column 1	300	1150	3080	453
Column 2	10920	3980	1120	1120
Column 3	1680	1356	560	390
Column 4	7800	8400	840	700
Column 5	5600	3200	600	1020
Column 6	5740	560	300	540
Column 7	10500	9320	5880	1150
Column 8	26880	10500	8300	1200
Column 9	4900	9800	780	85
Column 10	2240	1045	550	70
Column 11	1680	540	300	110

3.3. Total Volume of Leachate Collected

Leachate was collected from the eleven columns from a hose placed at the funnel placed at the bottom of each column. The measurements of total volume of leachate collected for clay soil for one year, five years, and ten years rain water application is given in Table **7**. The measurements of total volume of leachate for sandy, and mixed (clay-sandy) soil for the three time periods are given in Tables **8** and **9**.

It was found that the total volume collected after 58 days were about the same as applied while for clay soil the total volume collected was 15-22% less than total applied volume. However, this trend of percent of water volume recovered for clay soil was different and decreasing from 82% to 74%, to 63% consequently at half period application (29 days) for 1, 5, and 10 year application. This might be due to that soil pores at half time were subject to filling with water while at the end of the experimental period they were all filled with applied water.

For sandy soil, percent of water volume recovered at the end of experiment (58 days) was close for the three periods (94-98%) and similarly at half period (81%-86%).

For sandy-clay soil, percent of water volume recovered at the end of experiment (58 days) was close for the three periods (88-97%). At half period results are different (75%-98%).

The difference between total applied and total collected is possibly due to the transport characteristics of the various soils. However, it is clear that mixing of

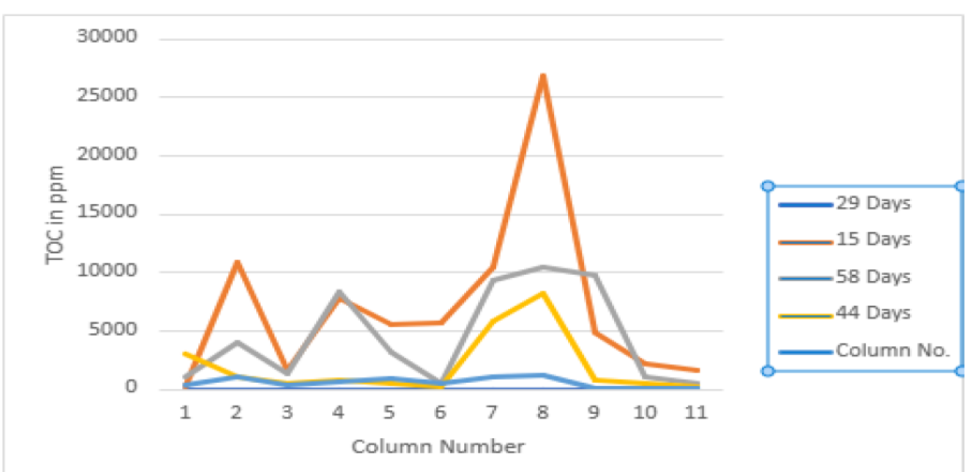

Figure 3: Change of TOC levels in leachate with column and time click on it so dots disappear.

the clay and sandy soil did improve the percent of water recovered.

4. CONCLUDING REMARKS

Based on the results obtained the following concluding remarks were observed:

Table 7: Total Volume of Collected Leachate for Clay Soil

Time (day)	One Year		Five Years		Ten Years	
	Total Applied	Total Collected	Total Applied	Total Collected	Total Applied	Total Collected
0	681.25	0.0	3406	0.0	6812.5	0
4	1362.5	538	6812	1420	13625	3620
8	2043.75	1148	10218	4635	20437.5	7720
11	2725	1848	13624	8235	27250	12920
15	3406.25	2638	17030	12035	34062.5	18820
19	4087.5	3188	20436	15135	40875	24470
22	4768.75	3788	23842	17405	47687.5	28320
25	5450	4488	27243	19625	54500	34120
29	6131.2	5038	30654	22785	61312.5	39120
32	6812.5	5458	34060	25685	68125	44070
36	7493.7	5978	37466	28855	74937.5	49770
39	8175.0	6128	40872	31015	81750	56370
43	8856.2	6658	44278	34165	88562.5	61870
47	9537.5	6878	47684	37165	95375	68170
50	10218.7	7638	51090	40565	102187.5	75270
53	10900	7938	54496	43025	109000	81770
58	10900	8128	54496	46775	109000	87720

Table 8: Total Volume of Collected Leachate for Sandy Soil

Time (day)	One Year		Five Years		Ten Years	
	Total Applied	Total Collected	Total Applied	Total Collected	Total Applied	Total Collected
0	681.25	0	3406	0.0	6812.5	0
4	1362.5	410	6812	1620	13625	4700
8	2043.75	1025	10218	4970	20437.5	10800
11	2725	1635	13624	8520	27250	17000
15	3406.25	2425	17030	12090	34062.5	23600
19	4087.5	3025	20436	15640	40875	29870
22	4768.75	3705	23842	18980	47687.5	36000
25	5450	4425	27243	21510	54500	43230
29	6131.25	5170	30654	24890	61312.5	50580
32	6812.5	5860	34060	28310	68125	57380
36	7493.75	6590	37466	31530	74937.5	63550
39	8175	7190	40872	34230	81750	69850
43	8856.25	8040	44278	38180	88562.5	77290
47	9537.5	8770	47684	41580	95375	84290
50	10218.7	9480	51090	45070	102187.5	91190
53	10900	9930	54496	47670	109000	98140
58	10900	10670	54496	51470	109000	104740

Table 9: Total Volume of Collected Leachate for Mixed Sandy-Clay Soil

Time (day)	One Year		Five Years		Ten Years	
	Total Applied	Total Collected	Total Applied	Total Collected	Total Applied	Total Collected
0	681.25	0	3406	0.0	6812.5	0
4	1362.5	270	6812	1200	13625	3990
8	2043.75	1010	10218	4190	20437.5	10190
11	2725	1835	13624	7840	27250	16840
15	3406.25	2625	17030	11140	34062.5	22440
19	4087.5	3285	20436	14650	40875	28690
22	4768.75	3895	23842	17720	47687.5	35790
25	5450	4555	27243	20140	54500	42840
29	6131.25	5255	30654	23100	61312.5	50340
32	6812.5	5985	34060	26450	68125	57350
36	7493.75	6625	37466	29680	74937.5	63460
39	8175	7080	40872	32770	81750	70160
43	8856.25	7915	44278	35740	88562.5	77160
47	9537.5	8615	47684	38510	95375	83860
50	10218.7	9265	51090	41980	102187.5	90810
53	10900	9675	54496	44680	109000	97560
58	10900	10375	54496	48330	109000	103760

- Domestic solid waste after rain water application caused an accumulation of heavy metals (Cd, and Cu) in leachate from various types of soils,
- Cadmium and copper are of great mobility and assimilability
- The leachability of cadmium and copper is significantly affected by multivariate experimental factors associated with local conditions, i., e., solid waste loading, rain water intensity, and type of soil.
- Domestic solid waste used have both a higher heavy metals content and heavy metals leachability.
- Adopting strict control measures for domestic solid waste disposal management in obligatory to protect ground water pollution.
- Mixing of the clay and sandy soil did improve water flow through the column and the percent of water recovered.
- Clay soil proved to have great tendency absorbing and/or adsorbing cadmium ions and therefore good in cadmium removal.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

REFERENCES

[1] Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z., & Zhu, Y. G. (2008). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environmental Pollution, 152(3): 686-692. https://doi.org/10.1016/j.envpol.2007.06.056

[2] Oyelami, A. O., Gbadebo, A. M., & Bankole, O. S. (2016). Impact of landfill leachate on groundwater quality: A case study of Ibadan, Nigeria. Groundwater for Sustainable Development, 2: 122-131.

[3] Jessica Briffa, Emmanuel Sinagra, Renald Blundell. Heavy metals in the environment: fate, transport, toxicity and remediation technologies Thermodynamic profiling of pollutants View project Materials for Solid oxide fuel cells View project Heavy Metals in the Environment: Fate. Heliyon 2020; 6(9): 2020, https://doi.org/10.1016/j.heliyon.2020.e04691

[4] Niu L, Yang F, Xu C, Yang H, Liu W (2013) Status of metal accumulation in farmland soils across China: from distribution to risk assessment. Environ Pollut 176: 55-62 https://doi.org/10.1016/j.envpol.2013.01.019

[5] B. J. Alloway and D. C. Ayres, "Chemical Principles of Environmental Pollution," 2nd Edition, Blackie Academic & Professional (Chapman & Hall), London, 1997, pp. 205-211.

[6] Bridle T.R., Cote, P.L., Constable T.W., and Fraser, J.L, (1987). Evaluation of Heavy Metal Leachability from Solid Wastes. Water Science & Technology 19(5): 1029-1036. https://doi.org/10.2166/wst.1987.0280

[7] Palestinian Central Bureau of Statistics,PCBS, 2015. Results Household Environmental Survey, 2015. - PCBS. Ramallah, Palestine. Found in: PCBS | PCBS: Results Household Environmental Survey, 2015.

[8] Salomons, W. (1995) Environmental Impact of Metals Derived from Minerals Activities: Processes, Predictions, Prevention. Journal of Geochemical Exploration, 25, 125-132.

[9] Trapp, Stefan and Michael Matthies (1998). "Chemodynamics and Environmental Modeling." (1998). Published by Springer. pp. 37-48. https://doi.org/10.1007/978-3-642-80429-8_4

[10] Komárek M, Vaněk A, Ettler V (2013) Chemical stabilization of metals and arsenic in contaminated soils using oxides-a review. Environ Pollut 172: 9-22. https://doi.org/10.1016/j.envpol.2012.07.045

[11] Valipour M, Shahbazi K, Khanmirzaei A (2016) Chemical immobilization of lead, cadmium, copper and nickel in contaminated soils by phosphate amendments. Clean - Soil Air Water 44: 572-578. https://doi.org/10.1002/clen.201300827

[12] Chen G, Zeng G, Du C, Huang D, Lin T, Liang W, Shen G (2010). Transfer of heavy metals from compost to red soil and ground water under simulated rainfall conditions. J Hazard Mater 181: 211-216 https://doi.org/10.1016/j.jhazmat.2010.04.118

[13] Beesley L, Moreno-Jiménez E, Clemente R, Lepp N, Dickinson N (2009). Mobility of arsenic, cadmium and zinc in a multi-element contaminated soil profile assessed by in-situ soil pore water sampling, column leaching and sequential extraction. Environ Pollut 158:155-160. https://doi.org/10.1016/j.envpol.2009.07.021

[14] Mizerna, K., and Król, A., (2023). The importance of time and other determinants in the assessment of heavy metals release during solid waste management. Scientific Reports 13(1), January 2023. https://doi.org/10.1038/s41598-023-28926-0

[15] Bo Yan, Da-Mao Xu, Tao Chen, Zi-Ang Yan, Li-Li Li, Ming-Hui Wang, (1998). Leachability characteristic of heavy metals and associated health risk study in typical copper mining-impacted sediments, Chemosphere, Volume 239, 2020. https://doi.org/10.1016/j.chemosphere.2019.124748

[16] E. Voudrias, B TSANIKLIDI, (1998). Leachability of heavy metals in Greek fly ash from coal combustion. May 1998. Environment International 24(4): 477-486 https://doi.org/10.1016/S0160-4120(98)00027-0

[17] Smith, A. E., & Brown, J. M. (2018). Heavy metal leaching from electronic waste: A review. Environmental Pollution, 242, 1930-1946.

[18] Wang, Q., Wang, Y., Ji, Y., & Du, Y. (2020). Leaching behavior of cadmium and copper from spent lithium-ion batteries in municipal solid waste landfills. Journal of Hazardous Materials, 392, 122318.

[19] Applied Research Institute of Jerusalem, ARIJ, (1996). Environmental Profile for the West Bank, Volume five, Nablus District. Bethlehem, Palestine, October, 1996.

[20] Ibid, Applied Research Institute of Jerusalem, ARIJ, (1996).

[21] Paulo J., D., (2013). "Municipal Solid Waste Management: Processing Energy Recovery, Global Examples". Published by: Springer, 2013.

[22] Crommentuijn, T., Polder, M. D, and Van de Plassche, E. J., (1997). Maximum Permissible Concentrations and Negligible Concentrations for Metals, Taking Background Concentrations into Account (RIVM Report 601501001) Bilthoven, Netherlands (1997).

[23] American Public Health Association, APHA, American Water Works Association, AWWA, and Water Environment Federation WEF, (2017). Standard Methods for the Examination of Water and Wastewater, 23nd edition. Washington DC. Found in: standard methods.org.

[24] D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston, M. E. Sumner, Eds (1996). "Methods of Soil Analysis. Published by: Soil Science Society of America, 1996. https://doi.org/10.2136/sssabookser5.3

[25] Zhuang P, Lu HP, Li ZA, Zou B, McBride MB (2014) Multiple Exposure and Effects Assessment of Heavy Metals in the Population near Mining Area in South China. Plos One 9(4): e94484. https://doi.org/10.1371/journal.pone.0094484

[26] Hu Y, Norton GJ, Duan G, Huang Y, Liu Y (2014) Effect of selenium fertilization on the accumulation of cadmium and lead in rice plants. Plant Soil 384: 131-140. https://doi.org/10.1007/s11104-014-2189-3

Received on 15-01-2024 Accepted on 20-03-2024 Published on 17-04-2024

DOI: https://doi.org/10.12974/2311-8741.2024.12.01