Pak. J. Agri. Sci., Vol. 56(2), 275-282; 2019
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/19.7538
http://www.pakjas.com.pk

MOBILITY AND DISTRIBUTION OF LEAD IN SOILS TREATED WITH MUNICIPAL SOLID WASTE ASH

Abdulaziz G Alghamdi*, Adel Ghoneim* and Saud S Al-Oud

Department of Soil Sciences, College of Food and Agricultural Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Kingdom of Saudi Arabia

***Corresponding authors e-mail: aghoneim@ksu.edu.sa; agghamdi@ksu.edu.sa**

Lead (Pb) is an inorganic conservative pollutant poses a risk to soils and water resources. Quantifying the potential hazard impacts of Pb in soils needs further circumstances about its mobility and retention as well. The objective of this study was to evaluate the effects of municipal solid waste ash (MSWA) on mobility and distribution of Pb in two types of soil textures. The extent of Pb mobilization in soils amended with different application rates of MSWA has been quantified by soil columns experiment under steady state conditions. Transport of Pb was studied in soil columns by applying Pb solution of 150 mg/L at the rate of 0.09 cm/min for loamy sand soil and 0.035 cm/min for sandy loam soil. The mathematical model- HYDRUS-2D was used to describe this transport. The results indicated that Pb concentrations were extremely low in the leaching solutions collected from soil columns over time regardless of the application rates of MSWA. Application of MSWA increased the recovery of Pb in both soils achieving superiority in loamy sand soil. The Pb distributed in the soil columns ranged between soil leaching solutions and sorbed phase, of which the greater portion was in the sorbed phase. Lead move slowly through soils columns and the distance of movement was about 5 cm to the soil surface and then the concentrations decreased down the soil columns and later disappeared beyond a depth of to 7 cm. Mass balance calculations of Pb according to the HYDRUS-2D mathematical model resulted in values that were similar to those of the experimental data (error $\leq 5\%$). A soil quality indicator is considered as a key element of sustainable agriculture and hence soil quality plays an important role in deciding the MSWA methods.
Keywords: Alkaline soil, column leaching, municipal solid waste ash, Pb mobility.

INTRODUCTION

Waste generation and subsequent accumulation generated by increased urbanization and industrialization, coupled with rising standards of living is one of the major problems confronting our present generations (Dela Cruz *et al*., 2010). Solid wastes arise from human and animal activities, including the heterogeneous mass of garbage from the urban communities, as well as the more homogeneous accumulations comprising countless different materials (paper, metals, plastic and glass), construction wastes, industrial process wastes, pathological wastes, and hazardous wastes (Mohapatra, 2006). Current global MSW generation levels are approximately 1.30 billion tonnes/year, and are expected to increase to approximately 2.20 billion tonnes/ year by 2025 (Shekdar, 2009).

In Riyadh city, the Kingdom of Saudi Arabia (KSA), the total MSW generation has increased to more than 12 million ton per year and the per capita of MSW is about 1.50-1.80 kg /person/ day (Al–Oud and Ghoneim, 2018). MSW produced is disposed on land without taking any specific precaution. There are many open dumps causing soil pollution which makes soil unsuitable for irrigation purposes and reduces crop yield.

The common method of MSW disposal in Riyadh city is dumping it into the soils or incineration because these are the cheapest methods. Incineration is a common technique for MSW disposal as it reduces its mass and volume by 70 and 90%, respectively (Klein *et al*., 2001). The soils contaminated by municipal solid waste ash (MSWA) application areas causes' potential groundwater pollution especially with heavy metals (Zhang *et al*., 2012). Moreover, leachate from MSWA dumpsites affects the distribution and mobilization of potential toxic metals (PTMs) in such soils (Saritha *et al*., 2014; Mahmoud and Ghoneim, 2016). Heavy metal contamination due to MSW applications has received much attention lately because of concerns regarding uptake by plants. Its accumulation in the soil constitutes a long-term environmental hazard as it could leach from the soils and re-entry the food chain or contaminate the ground and surface water (Ghoneim, 2002; Kaschl *et al*., 2002). Lead is most commonly found in MSWA (Steinnes, 2013; Elbana *et al*., 2014). The exhaust gases generated from petrol engines which represent about 80% of the total lead in air are considered the main sources of Pb contamination globally and particularly in the KSA. The Cd and Cu metals reduced the release and recovery of Pb in alkaline soils (Elbana, 2013). In this investigation the affinity of PTMs took the following sequence, Pb>Cu>Cd. The stabilization of Pb-contaminated soils using immobilizing amendments such as municipal solid waste ash (MWSA) is remediation procedure practical for reducing Pb mobility in soils (Chaudhari and Tare, 2008). Stabilization of Pb in soils can be achieved by Pb adsorption, complexion, and precipitating. HYDRUS-2D model is considered one of the most robust models that can predict solute transport, heat and water in one, two and/or three dimensions (Simunek *et al*., 2009). The MSWA, which has unique chemical characteristics, may affect Pb mobility and distribution in soils. However, there is limited information about the fate of Pb from MSWA dumpsites in soils of arid and semi-arid regions. In addition, modeling the solute transport in such regions particularly by HYDRUS-2D has also less attention so far. Therefore, the objective of this study was to quantify the Pb transport and distribution in two different types of soils-amended with different application rates of MSWA.

MATERIALS AND METHODS

***Municipal solid waste sampling and chemical analysis*:** All the chemicals used in this study were of analytical reagent (AR) grade and supplied by Ranbaxy chemicals Ltd., Chennai, India. Municipal solid waste samples were collected from four different dumping sites of Dierab city, KSA (N 27° 30′, E 41° 43′). The municipal solid waste (MSW) samples were incinerated at 800°C in a kiln that allowed the generated gases to pass through a water bath thereby preventing air pollution. The resultant municipal solid waste ash (MSWA) was screened through a 0.30 mm sieve to remove unburnt MSW like ceramics and broken glasses. The ash was further ground to particle sizes less than 0.063 mm using a micro-milling machine. The resultant MSWA was analyzed for total $CaCO_3$ content according to Wright (1959). Cation exchange capacity (CEC) was determined according to Sumner and Miller (1996). Total Cd, Pb, Cu, and Zn were digested by a concentrated mixture of HNO_3-$HClO_4$ acids and measured using induction-coupled plasma-mass spectrometry (ICP-MS, Perkin Elmer, USA). The chemical properties of MSWA are presented in Table 1. Our previous study (Al–Oud and Ghoneim, 2018) demonstrated that, the the major elements present in MSWI were: 18.8, 27.3, 2.50, 3.50, 31.1, 4.20, 2.50, 1.50 and 1.40% of SiO_2, AL_2O_3, Fe_2O_3, MgO, CaO, K_2O, Na_2O, P_2O_5 and TiO_2, respectively.

***Soils sampling and analysis*:** The two representative soil samples were collected from the top soil (0-30 cm soil depth). Samples were collected from Dierab farm, 40 km south west of Riyadh city, KSA. The soil samples were air-dried, crushed with mortar and pestle and sieved through a 2-mm mesh. Soil texture, pH, EC, $CaCO_3$, CEC and organic matter (OM) were determined using standard methods. The related chemical characteristics of the soils are presented in Table 1.

Table 1. Selected properties of the soils and MSWA used.

Parameter	Soils		MSWA [a]
	Loamy Sand	Sandy Loam	
Sand (%)	85.5	73.5	
Silt (%)	8.00	19.0	
Clay (%)	6.48	7.48	
CEC (cmol/ kg)	4.85	6.46	8.10
$CaCO_3$ (g/kg)	232	343	119
O.M (g/kg)	104	107	200
pH	7.80	8.07	11.8
EC (dS/m)	1.00	1.60	5.60
Total heavy metals (μg/g)			
Zn			113.6
Cu			42.1
Pb			36.8
Cd			1.18
Cations and anions (meq/L)			
Ca^{2+}	4.31	8.51	
Mg^{2+}	3.42	4.10	
Na^+	1.13	2.05	
K^+	0.69	0.72	
HCO_3^-	4.25	7.56	
Cl^-	1.91	3.64	
SO_4^{2-}	3.82	4.50	

MSWA, municipal solid waste ash.

***Transport experiment*:** To quantify the extent of Pb transport in soils, columns experiment had been conducted under steady state flow conditions. Air-dried soils samples were mixed with MSWA at different rates of 0, 1, 2, 3 and 5% (w/w). Water was added to the soils samples until they were filled to capacity, and then they were air-dried, and passed through 2- mm sieves. The samples were uniformly packed into **s**oil columns (6x25 cm; inner diameter x length) at bulk densities of 1.40 and 1.60 g/cm. Lead transport was studied in soil columns by applying 150 mg/L of Pb solution at the rates of 0.09 cm min^{-1} for loamy sand soil and 0.035 cm/min for sandy loam soil, then applying water the same rates to reach the steady-state condition. The effluent solutions were collected at 30 min time intervals until the end of the experiment. The soils column was divided into five equal parts, 2.0 cm in length, and three equal sections 5.0 cm length. The retained and soluble Pb in each soil in various depths and effluent were determined using ICP-OES (Spectro CItros CCD, model CCD; Spectro Analytical Instruments, Kleve, Germany). The data were mathematically analyzed using the mathematical model, HYDRUS-2D, and the results were compared with experimental data.

Under steady state flow, the solute transport in homogeneous porous media could be described as shown in equation 1.

$$\frac{\partial C}{\partial T} = DL\frac{\partial^2 C}{\partial X^2} - Vx\frac{\partial C}{\partial X} - \frac{\rho}{\theta}\frac{\partial C^*}{\partial T} \pm \left[\frac{\partial C}{\partial T}\right]_{rxn} \quad (1)$$

Where, C is the solute concentration (mg/L), Vx is the velocity of fluid (cm/h), DL is the dispersion coefficient length (cm^2/h), ρ is the bulk density of soil (Mg/m^3), C* is the adsorption of solute per unit weight of the medium porous (mg/g), rxn is the subscript indicate to the chemical reaction of the solute.

RESULTS AND DISCUSSION

***Transport of Pb in soils*:** Figures 1 and 2 show the concentrations of Pb in the collected effluent solutions, for both loamy sand and sandy loam soil columns at different time intervals. The sharp reduction of Pb concentrations in the effluent solutions resulting from the leaching solutions of the soil columns over time regardless of the MSWA application rates. These low concentrations were only recorded at 120 and 480 minutes in loamy sand and sandy loam soils, respectively. In addition, the concentration of Pb in the effluent solutions decreased with increasing application rates of MSWA. Such low Pb mobility may be due to higher $CaCO_3$ content in the studied soils (Table 1). Where, increasing pH and surface area of $CaCO_3$ have a positive affinity with Pb adsorption (Rouff *et al*., 2005). Thus, the decrease in Pb solubility in leachate solution is mainly due to adsorption reaction (Sekito *et al*., 2000).

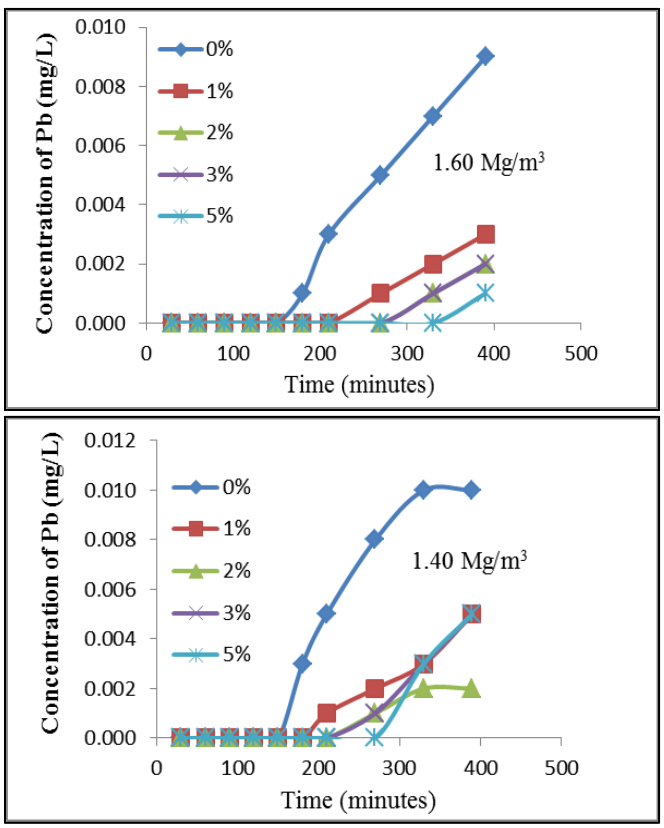

Figure 1. Effect of different rates of MSWA application on concentrations of Pb in effluent solution from loamy sand soil.

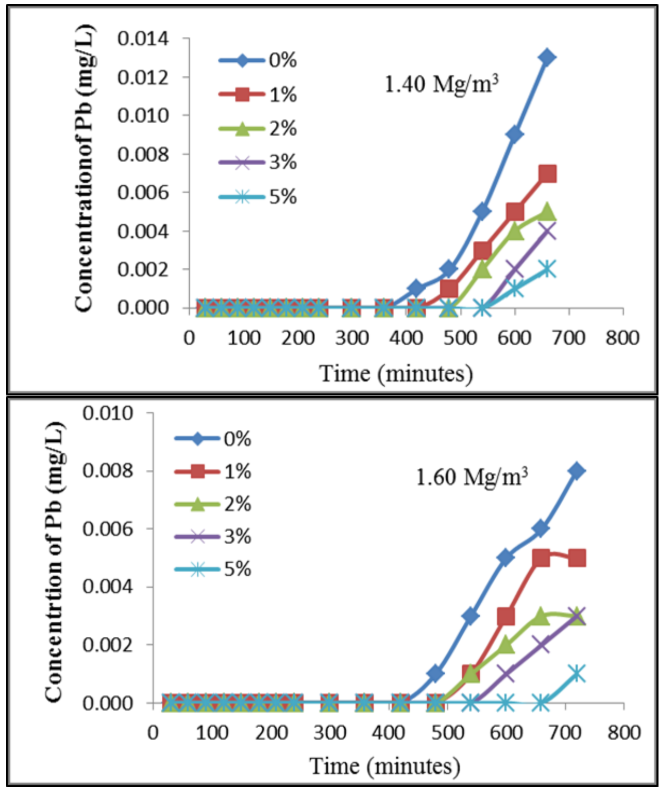

Figure 2. Effect of different rates of MSWA applications on concentrations of Pb in effluent solution from sandy loamy soil with time.

***Distribution of Pb in soils versus depths*:** The adsorbed part of Pb on the soils samples at different soil is very important for supporting further information about element mobility into soil profiles and groundwater as well. The distribution of Pb in soils amended with different rates of MSWA in soil columns are presented in Tables 2-5. In general, Pb was primarily found in the top 5 cm soil surface, and had low mobility. Maximum Pb concentrations were observed in the top 1 cm of the soils surfaces while there was a sharp decrease in Pb concentrations at different soil depths. Such strong Pb adsorption was noticed according the concentration in effluent solution. Thus, the application of MSWA led to a significant increase in Pb concentrations in the top soils. Al–Oud and Ghoneim, (2018) reported that sandy loam soil was more likely to adsorb Pb than the loamy sand soil. In addition, the application of 5% MSWA to loamy sand and sandy loam soils resulted in distribution coefficient (K_d) values that were greater than the control (0%) by 36.6% and 29.0%, respectively. The addition of organic matter (OM) due to MSWA applications (Table 2) may affect Pb mobility by increasing dissolved organic matter (DOM), especially in soils with higher pH (Rashad *et al*., 2010). The soils samples in our study had relatively high pH levels and $CaCO_3$ (Table 1).

Table 2. Distribution of Pb in loamy sand soil at a bulk density of 1.40 Mg/m^3 (Experimental data).

Soil depth (cm)	Application rates of MSWA									
	0%		1%		2%		3%		5%	
	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1}	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})
1	8.20	0.269	8.40	0.293	8.50	0.313	8.70	0.337	8.90	0.363
3	2.20	0.072	2.40	0.084	2.50	0.092	2.50	0.097	2.60	0.106
5	0.80	0.026	0.60	0.021	0.50	0.018	0.30	0.012	0.20	0.008
7	0.30	0.010	0.20	0.007	0.10	0.004	0.00	0.000	0.00	0.000
9	0.10	0.003	0.05	0.002	0.00	0.000	0.00	0.000	0.00	0.000
12.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
17.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
22.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000

Table 3. Distribution of Pb in loamy sand soil at a bulk density of 1.60 Mg/m^3 (Experimental data).

Soil depth (cm)	Application rates of MSWA									
	0%		1%		2%		3%		5%	
	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})
1	8.10	0.253	8.30	0.277	8.50	0.298	8.60	0.318	8.80	0.334
3	2.20	0.069	2.40	0.080	2.50	0.088	2.70	0.100	2.80	0.106
5	0.70	0.022	0.60	0.020	0.60	0.021	0.30	0.011	0.10	0.004
7	0.40	0.012	0.30	0.010	0.10	0.004	0.00	0.000	0.00	0.000
9	0.15	0.005	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
12.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
17.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
22.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000

Table 4. Distribution of Pb in sandy loam soil at a bulk density of 1.40 Mg/m^3 (Experimental data).

Soil depth (cm)	Application rates of MSWA									
	0%		1%		2%		3%		5%	
	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})
1	2.50	0.102	2.50	0.107	2.70	0.119	2.90	0.133	3.10	0.148
3	0.90	0.037	1.00	0.043	1.20	0.053	1.40	0.064	1.70	0.081
5	0.50	0.020	0.50	0.021	0.60	0.026	0.40	0.018	0.20	0.010
7	0.10	0.004	0.20	0.009	0.00	0.000	0.00	0.000	0.00	0.000
9	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
12.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
17.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
22.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000

Table 5. Distribution of Pb in sandy loam soil at a bulk density of 1.60 Mg/m^3 (Experimental data).

Soil depth (cm)	Application rates of MSWA									
	0%		1%		2%		3%		5%	
	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})	Solution mg L^{-1})	Sorbed (mg g^{-1})	Solution (mg L^{-1})	Sorbed (mg g^{-1})
1	2.50	0.102	2.60	0.107	2.70	0.119	2.80	0.128	3.00	0.143
3	0.90	0.037	1.00	0.043	1.10	0.048	1.40	0.064	1.60	0.076
5	0.40	0.016	0.50	0.021	0.40	0.018	0.30	0.014	0.20	0.010
7	0.10	0.004	0.20	0.009	0.00	0.000	0.00	0.000	0.00	0.000
9	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
12.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
17.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
22.5	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000

Thus, complete recovery of Pb in the soil amended with MSWA, as the strong relationship between metal and soil was not clear. Lead sorption in soils is mainly affected by soil pH, CEC, clay content, $CaCO_3$ and OM content (Steinnes, 2013). In addition, the maximum capacity of metal sorption in a single system is generally higher than that in either multielement or a binary system particularly in columns study (Chotpantarat *et al.*, 2012), as well as in loamy sand soils (Fonseca *et al*., 2011). In most cases, Pb is found immobile in soils due to its further bound with organic fraction and iron oxides, but in case of higher concentrations a big portion converts to mobile fraction (Steinnes, 2013; Ghoneim *et al*., 2014; Al-Oud *et a*l., 2015). The difference in Pb distribution between these two types of soil may be attributed to their initial analysis such as clay content and CEC, which responsible for metal mobility. Similar study of Pb transport in columns experiment showed a higher retention of Pb in soils due to increasing the tortuosity of beds, bed height, and soil-water surface contact (Barkouch *et al*., 2007). In contrast, Pb retention decreased with increasing flow rates and pulse volumes. The lead mobility in the acidic soils is affected by adding various organic and chemical amendments such as phosphor-gypsum, rock phosphate and sugar foam (Garrido *et al*., 2006). Furthermore, the derived colloids from biosolid wastes encourage Pb movement in subsurface soil environments (Karathanasis *et al*., 2005). Where, Pb mobility was enhanced by decreasing colloid size, soil pH and increasing OM content. This resulted in a higher elution of adsorbed and effluent solution loads through the formation of a Pb–organic complex. Transport and distribution of Pb in soil columns was associated with the ability of Pb to adsorb on the soil surface as expressed by the distribution coefficient (Al–Oud and Ghoneim, 2018). Lead was distributed in soils column between the soil solution and adsorbed phase, of which the great portion in the adsorbed phase. Kabata-Pendias and Pandias (2001) found that Pb is adsorbed with SO_4^-, $H_2PO_4^-$, OM and clay minerals. Rouff *et al*. (2002) found that Pb would be adsorbed to the surface very quickly after which its sorption follows and slow continuous over time.

***Effect of MSWA application on Pb mobility in soil columns*:** With increasing application rates of MSWA, Pb concentrations in leaching solutions from soil columns and the adsorbed phase increased (Tables 2-5). In the effluent solutions of soil samples treated with MSWA, Pb concentrations were higher than in untreated soil (0%). These results indicated that, the presence of MSWA enhanced Pb mobility in soils. Moreover, the concentrations of Pb in effluent solution were higher than in adsorbed phases. In addition, loamy sandy soil retained more Pb amounts than sandy loam soil (Al–Oud and Ghoneim, 2018). Dissolved organic matter (DOM) derived from MSWA is considering as one of the important factors affecting the mobility of pollutants in soils (Rashad *et al*., 2013). When DOM is adsorbed on the soils surfaces, it occupies the adsorption sites and competes with both free and associated Pb for space and consequently lower amounts of Pb are adsorbed and the remaining Pb is leached out of the soil columns. In addition, the pH of the studied soils was alkaline (ranged from 7.80 to 8.07), which probably promoted the dissociation and deprotonation of DOM. Thus, humic substances in DOM becomes negatively charged organic anions, leading to their substantial competition with Pb ions for adsorption sites on soil surface (Voegelin *et al*., 2003; Lin *et al*., 2008; Rashad *et al*., 2013). Previous research has shown that soil OM and pH are the main factors contributing to the retention of Pb in soils (Ashworth and Alloway, 2008).

***Mass balance calculation*:** Tables 6 and 7 presented the mass balance calculations of Pb in the soil columns affected by different MSWA application rates. The results indicated that the recovery of applied Pb ranged from 88.3 to 110% and 95.3 to 113% in the sandy loam soil at bulk densities of 1.40 and 1.60 Mg/m^3, respectively. The recovery in the loamy sand soils ranged from 97.0 to 134% and 101 to 145% at bulk densities of 1.40 and 1.60 Mg/m^3, respectively (Tables 8 and 9). Mass balance calculations of Pb according the HYDRUS-2D mathematical model were similar to that of the

Table 6. Mass balance calculations of Pb (mg) in sandy loam soil amended with different rates of MSWA at a bulk density of 1.40 Mg/m^3 (Experimental data).

Soil depth (cm)	Application rates of MSWA														
	0 %			1 %			2 %			3 %			5 %		
	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total
1	0.167	21.3	21.5	0.171	23.2	23.4	0.183	24.8	25.0	0.188	26.7	26.9	0.198	28.8	29.0
3	0.044	5.7	5.8	0.045	6.6	6.7	0.050	7.3	7.3	0.052	7.7	7.7	0.054	8.4	8.5
5	0.016	2.1	2.1	0.011	1.7	1.7	0.010	1.5	1.5	0.006	0.9	0.9	0.004	0.6	0.7
7	0.006	0.8	0.8	0.004	0.6	0.6	0.002	0.3	0.3	0.000	0.0	0.0	0.000	0.0	0.0
9	0.002	0.3	0.3	0.001	0.1	0.1	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
12.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
17.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
22.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
soil	0.234	30.1	30.4	0.232	32.2	32.4	0.245	33.8	34.1	0.245	35.3	35.5	0.256	37.8	38.1
Out flowing			0.0			0.0			0.0			0.0			0.0
Total			30.4			32.4			34.1			35.5			38.1
Recovery (%)			88.4			94.2			99.1			103			110

Table 7. Mass balance calculations of Pb (mg) in sandy loam soil amended with different rates of MSWA at a bulk density of 1.60 Mg/m^3 (Experimental data).

Soil depth (cm)	Application rates of MSWA														
	0 %			1 %			2 %			3 %			5 %		
	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total
1	0.143	22.9	23.0	0.153	25.1	25.3	0.161	27.0	27.2	0.163	28.8	29.0	0.169	30.3	30.5
3	0.038	6.2	6.3	0.043	6.4	6.4	0.046	7.0	7.0	0.051	7.9	8.0	0.048	8.4	8.5
5	0.012	2.0	2.0	0.010	1.6	1.6	0.011	1.7	1.7	0.005	0.9	0.9	0.002	0.3	0.3
7	0.007	1.1	1.1	0.005	0.8	0.8	0.002	0.3	0.3	0.000	0.0	0.0	0.000	0.0	0.0
9	0.003	0.4	0.4	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
12.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
17.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
22.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
soil	0.203	32.6	32.8	0.211	33.8	34.0	0.220	35.9	36.1	0.219	37.6	37.8	0.219	39.0	39.2
Out flowing			0.0			0.0			0.0			0.0			0.0
Total			32.8			34.0			36.1			37.8			39.2
Recovery (%)			95.3			98.8			104			109			113

Table 8. Mass balance calculations of Pb (mg) in loamy sand soil amended with different rates of MSWA at a bulk density of 1.40 Mg/m^3 (Experimental data).

Soil depth (cm)	Application rates of MSWA														
	0 %			1 %			2 %			3 %			5 %		
	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total
1	0.045	8.1	8.1	0.047	8.4	8.5	0.049	9.1	9.1	0.054	10.1	10.2	0.059	11.2	11.3
3	0.016	2.9	2.9	0.017	3.4	3.4	0.020	4.2	4.2	0.024	5.1	5.1	0.030	6.4	6.4
5	0.008	1.6	1.6	0.009	1.7	1.7	0.010	2.1	2.1	0.005	1.1	1.1	0.002	0.4	0.4
7	0.002	0.3	0.3	0.003	0.7	0.7	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
9	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
12.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
17.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
22.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
soil	0.071	12.9	13.0	0.076	14.1	14.4	0.080	15.3	15.4	0.083	16.3	16.4	0.090	18.0	18.0
Out flowing			0.0			0.0			0.0			0.0			0.0
Total			13.0			14.4			15.4			16.4			18.0
Recovery (%)			97.0			107.5			114.9			122.4			134.3

Table 9. Mass balance calculations of Pb (mg) in loamy sand amended with different rates of MSWA at a bulk density of 1.60 Mg/m^3 (Experimental data).

Soil depth (cm)	Application rates of MSWA														
	0 %			1 %			2 %			3 %			5 %		
	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total	Solution	Sorbed	Total
1	0.051	8.7	8.7	0.053	9.1	9.2	0.059	10.1	10.1	0.062	10.9	10.9	0.070	12.1	12.2
3	0.018	3.1	3.1	0.021	3.6	3.7	0.023	4.1	4.1	0.029	5.4	5.5	0.035	6.5	6.5
5	0.007	1.4	1.4	0.010	1.8	1.8	0.008	1.5	1.5	0.006	1.2	1.2	0.004	0.8	0.8
7	0.002	0.3	0.3	0.004	0.7	0.7	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
9	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
12.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
17.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
22.5	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0
soil	0.078	13.5	13.6	0.088	15.3	15.4	0.090	15.7	15.8	0.097	17.5	17.6	0.110	19.4	19.5
Out flowing			0.0			0.0			0.0			0.0			0.0
Total			13.6			15.4			15.8			17.6			19.5
Recovery (%)			101.4			114.9			117.9			131.3			145.5

experimental data with an experimental error no greater than 5%. These differences often occur in laboratory studies and are due to the presence of heterogeneity in the soil when filling in the columns. The results showed the high efficiency of the HYDRUS-2D mathematical model and its potential for predicting Pb distribution in soil samples under the experimental conditions of this study.

Conclusion**:** Disposal or leachate resulted from municipal solid waste ash dumpsites affects the distribution, mobilization and mobility of potential toxic Pb metal in soil. Lead transport and distribution in the soils is of great importance because of the both surface and ground water contamination. The stabilization of Pb-contaminated soils using immobilizing amendments such as municipal solid waste ash (MWSA) is the kind of remediation procedure practical for reducing Pb mobility in such soils. A soil quality indicator is considered as a key element of sustainable agriculture and hence soil quality plays an important role in deciding the municipal solid waste disposal methods. Therefore, proper municipal solid waste ash management practice should be implemented to minimize the adverse impact on the soil. Further bioaccumulation studies can also be conducted to avoid soil and irrigation contamination due to open dumping of municipal solid waste ash.

Acknowledgements**:** The authors appreciate and thank the College of Food and Agricultural Sciences, Agricultural Research Center and Deanship of Scientific Research, King Saud University, Saudi Arabia, for financial support for this research study.

REFERENCES

Al–Oud, S. and A. Ghoneim. 2018. Lead transport in soils amended with municipal solid waste ash. Pol. J. Environ. Stud. 27:2437-2442.

Al–Oud, S.S., A.M. Ghoneim, M.A. Nadeem and S. Al-Harbi. 2015. Application efficiency of Clinoptilolite natural zeolite for Pb^{2+} and Cu^{2+} removal from wastewater. Wulf. J. 22:317-332.

Ashworth, B. and J. Alloway. 2008. Influence of dissolved organic matter on the solubility of heavy metals in sewage-sludge-amended soils. Comm. Soil Sci. Plant Anal. 39:538-550.

Chaudhari, S. and V. Tare. 2008. Removal and recovery of heavy metals from simulated wastewater using insoluble starch xanthate process, practice periodical of hazardous, toxic, and radioactive waste management, © ASCE, pp.170-180.

Chotpantarat, S., S.K. Ong, S. Sutthirat and K. Osathaphan. 2012. Competitive modeling of sorption and transport of Pb^{2+}, Ni^{2+}, Mn^{2+} and Zn^{2+} under binary and multi-metal systems in lateritic soil columns. Geoderma 189-190: 278-287.

Dela Cruz, N.E., C.P. Aganon, M.G. Patricio, E.S. Romero, S.A. Lindain and J.L. Galindez. 2010. Production of organic fertilizer from waste, and its utilization in intensive organic–based vegetable production, and for sustaining soil health and productivity. Ramon Magsaysay Centre for Agricultural Resources and Environment Studies (RM –CARES), Central Luzon state Univ., Science City of Munoz, Nueva Ecija, 3120, Philippines. pp.1-12.

Elbana, T.A. 2013. Transport and adsorption-desorption of heavy metals in different soils. Ph.D. diss., Louisiana State Univ., Baton Rouge.

Elbana, T.A., D.L., Sparks and H.M. Selim. 2014. Transport of tin and lead in soils: Miscible displacement experiments and second-order modeling. Soil Sci. Soc. Am. J. 78:701-712.

Filgueiras, A.V., I. Lavilla and C. Bendicho. 2002. Chemical sequential extraction for metal portioning in environmental solid samples. J. Environ. Monito. 4:823-857.

Fonseca, B., H. Figueiredo, J. Rodrigues, A. Queiroz and T. Tavares. 2011. Mobility of Cr, Pb, Cd, Cu and Zn in a loamy soil: a comparative study. Geoderma 164:232-237.

Garrido, F.V., C.G., Illera, M.T. Campbell and T. Carcía-González. 2006. Regulating the mobility of Cd, Cu and Pb in an acid soil with amendments of phosphogypsum, sugar foam, and phosphoric rock. Euro. J. Soil Sci. 57:95-105.

Gee, G.W. and J.W. Bauder. 1986. Particle size analysis. In: Klute (eds.), Methods of Soil Analysis: Physical and mineralogy methods, Part 1. ASA and SSSA, Madison. pp.383-412.

Ghoneim, A.M. 2002. Reaction of nano-ball allophone with zinc and copper and its mechanism by molecular orbital method. Ph.D diss., United Graduate School of Agric. Sci. Ehime Univ. Matsuyama, Japan.

Ghoneim, A.M., O.I. Elbassir, A.S. Modahish and M.O. Mahjoub. 2017. Compost production from olive tree pruning wastes enriched with phosphate rock. Compost Sci. Utiliz. 25:13-21.

Ghoneim, A.M., S.S. Al-Zahrani, S. El-Maghraby and A.S. Al-Farraj. 2014. Heavy metal distribution in *Fagonia indica* and *Cenchrus ciliaris* native vegetation plant species. J. Food Agric. Environ. 12: 320-324.

Kabata-Pendias, A. and H. Pendias. 2001. Trace Elements in Soils and Plants, 3rd Ed., CRC Press, Boca Raton, FL.

Karathanasis, A.D., D.M. Johnson and C.J. Matocha. 2005. Biosolid colloid mediated transport of copper, zinc and lead in waste-amended soils. J. Environ. Qual. 34: 1153-1164.

Kaschl, A., V. Römheld and Y. Chen. 2002. Binding of cadmium, copper and zinc to humic substances originating from municipal solid waste compost. Israel J. Chem. 42: 89-98.

Klein, R., T. Baumann and E. Kahapka. 2001. Temperature development in a modern municipal solid waste incineration (MSWI) bottom ash landfill with regard to sustainable waste management. J. Hazar. Matt. 83: 265-280.

Lin, H.T., M.C. Wang and K. Seshaiah. 2008. Mobility of adsorbed arsenic in two calcareous soils as influenced by water extract of compost. Chemosphere 71:742-749.

Lu, S.G. and Q.F. Xu. 2009. Competitive adsorption of Cd, Cu, Pb and Zn by different soils of Eastern China. Environ. Geo. 57:685-693.

Mahmoud, E.K. and A.M. Ghoneim. 2016. Effect of polluted water on soil and plant contamination by heavy metals in El-Mahla El-Kobra, Egypt. Solid Earth 7:703-711.

Mohapatra, P.K. 2006. Biotechnology for solid waste management. Text of Environmental Biotechnology. I.K. International Publishing House Pvt. Ltd., New Delhi, India. pp.265-294.

Rashad, M., S. Dultz and G. Guggenberger. 2010. Dissolved organic matter release and retention in an alkaline soil of the Nile River Delta in relation to surface charge and electrolyte type. Geoderma 185:385-391.

Rhoades, J.D. 1996. Salinity: Electrical conductivity and total dissolved solids. Methods of Soil Analysis, Part III, Chemical M.thods, 2nd Ed., Agronomy, No. 5 Madison Wisconsin, USA, pp. 417-436.

Rouff, A.A., E.J. Elzinga, R.J. Reeder and N.S. Fisher. 2005. The influence of pH on the kinetics, reversibility and mechanisms of Pb (II) sorption at the calcite-water interface. Geochimica et Cosmochimica Acta 69:5173-5186.

Rouff, A.A. and R.J. Reeder. 2002. Pb (II) sorption with calcite: a radiotracer study. Aquatic Geochem. 8:203-228.

Sekito, T., N. Tanaka and T. Matsuto. 2000. Leachability and content of heavy metals in incombustible residues from resource recovery facilities. Waste Mana. Res. 18: 151-159.

Shekdar, A. 2009. Sustainable solid waste management: An integrated approach for Asian countries. Waste Manage. 29:1438-1448.

Simunek, J., M. Sejna, H. Saito, M. Sakai and M.T. Van Genuchten. 2009. The hydrus-1d software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media. 4.08 Ed.

Steinnes, E., 2013. Lead. In Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Their Bioavailability. B. Alloway (ed). 3rd. Springer, Dordecht, Netherlands, pp. 395-409.

Sumner, M.E. and W.P. Mille. 1996. Cation exchange capacity and exchange coefficient. In: D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loppert, P. Soltanpour, N.M. Tabatabai, C.T. Johnston and M.E. Sumner (eds.), Methods of Soil Analysis: Chemical methods, Part 3. ASA and SSSA, Madison. pp.1201-1230.

Thomas, G.W. 1996. Soil pH and soil acidity. In: D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston and M.E. Sumner (eds.), Methods of Soil Analysis: Chemical methods, Part 3. ASA and SSSA, Madison. pp.475-490.

United States Environmental Protection Agency. 1995. Test Methods for Evaluating Solid Wastes. USEPA SW 846. U.S. Gov. Print. Office, Washington, DC.

Voeglin, A., K. Barmetller and R. Kretzschmar. 2003. Heavy metal release from contaminated soils: comparison of column leaching and batch extraction results. J. Environ. Qual. 32:865-875.

Walkley, A. 1947. A critical examination of a rapid method for determining soil organic matter. Soil Sci. 63:654-661.

Wright, C.H. 1959. Soil Analysis. Thomas Murby and Co., London, UK.

Zhang, H., Y.H. Lin, Z. Zhang, X. Zhang, S.L. Shaw, E.M. Knipping, R.J. Weber, A. Gold, R.M. Kamens and J.S. Surratt. 2012. Secondary organic aerosol formation from methacrolein photooxidation: Roles of NOx level, relative humidity, and aerosol acidity. Environ. Chem. 9:247-262.