Development of Permeable Reactive Barrier System Utilizing Locally Available Geo- and Bio-Waste

R. Saito[1], Udayagee Kumarasinghe[1], G. N. Paranavithana[2], T. Saito[1], and K. Kawamoto[1,3]
[1]Graduate School of Science and Engineering, Saitama University, Saitama, JAPAN
[2]Faculty of Engineering, South Eastern University of Sri Lanka, SRI LANKA
[3]International Institute for Resilient Society, Saitama University, Saitama, JAPAN
E-mail: s15me105@mail.saitama-u.ac.jp

Abstract: *Open dumping is the common method for final waste disposal used in many developing countries. Various kinds of heavy metals are often detected in landfill leachate and groundwater surrounded at open dumpsites in Sri Lanka. Thus leachate and groundwater treatment facilities are strongly recommended in order to prevent contamination of natural ecosystems. Permeable Reactive Barrier (PRB) systems might be an effective method to treat contaminated water at open dumpsites, which required low initial cost, maintenance cost and technical support.. Therefore, the objectives of this study were to characterize the heavy metal adsorption and permeability performances of low-cost filling materials (soil, char, brick, and their mixed samples) locally found in Sri Lanka. Adsorption isotherms studies were conducted for Pb and Cd and results showed that the maximum adsorption capacity and removal percentage of Pb were higher than those for Cd. Maximum adsorption capacity and removal percentage of brick were relatively low for both Pb and Cd, thus the mixed samples with brick also showed lesser adsorption capacities. However, the removal percentage reached 90 for all mixed samples especially for Pb,. The mixed material with brick showed the highest hydraulic conductivity and satisfied with the targeted value (10^{-3} cm/s) under approximately 75% degree of compaction. Therefore, the mixture of brick is highly important to maintain required permeability of PRB filling materials.*

Keywords: *Leachate, Heavy metals, Permeable Reactive Barrier (PRB), Adsorption, Hydraulic conductivity*

1. INTRODUCTION

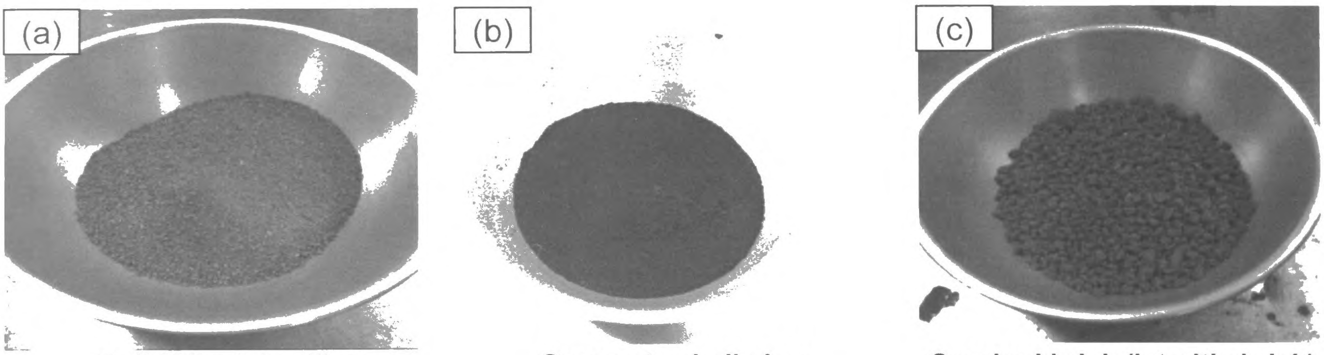
Open dumping is the common waste disposal method in most developing countries. Open dumpsites are absent of final covers, landfill liners, leachate collection and treatment systems. Landfill leachate, generated at the waste layers as a result of waste degradation rich with organic and inorganic compounds, major cations and anions, and heavy metals. High concentrations of heavy metals were often reported in leachate and groundwater samples obtained from open waste dumpsites in Sri Lanka (Sewwandi et al., 2013). The potential risk of groundwater and surface water contamination by heavy metals is high at open dumpsites, thus, waste water treatment facilities are essential to purify leachate and contaminated groundwater.

Permeable Reactive Barrier (PRB) systems are one of the most effective methods which can be used to treat contaminated groundwater at open waste dumpsites. The systems can be implemented at the dumpsites as an *in-situ* method to filter the groundwater without interrupting the groundwater flow. (Natale et al., 2008; Nyarko et al., 2015). PRB material should be characterize with higher adsorption capacities for targeted contaminants and barrier should have higher permeability than the surrounding aquifer. Therefore, the objectives of this study were to characterize the heavy metal adsorption and permeability performances of low-cost filling materials (soil, char, brick, and their mixed samples) locally found in Sri Lanka.

2. MATERIALS AND METHODS

2.1. Tested Materials

Figure 1 shows locally available and low-cost materials obtained from Sri Lanka. Previous studies reported that soil (alluvial soil) from Bangadeniya in Sri Lanka has higher adsorption capacities for Cadmium (Cd) and Lead (Pb) (Paranavithana et al., 2013; 2014). In same study they used coconut shell char to remove heavy metals effectively.
The materials used in this study were Bangadeniya soil, coconut shell char, and crushed brick. The materials were collected, air dried, crushed and sieved into pre-desired particle sizes (Table 01). Basic physical and chemical properties of the tested materials are shown in Table 1.



Soil (Alluvial soil) (Bangadeniya, Sri Lanka) **Coconuts shell char** **Crushed brick (lateritic brick)**

Figure 1 Locally available and low-cost materials obtained from Sri Lanka, (a) Soil, (b) Coconut shell char, and (c) Crushed brick

Table 1 Basic physical and chemical properties of the tested materials

Materials	D (mm)*	pH	EC (μS/cm)	ρ_s (g/cm^3)**
Bangadeniya soil	< 2.00	4.7	59	2.66
Coconuts shell char	< 0.075	8.8	139	1.51
Crushed brick	2.00 < D < 4.75	5.4	47	2.77

*Diameter
**Particle density

2.2. Adsorption Test

Kinetic and isotherm experiments were performed to evaluate adsorption characteristics for heavy metals (Cd and Pb) on tested materials. Materials were mixed with 9 different proportions as shown in Table 02.

Table 2 Mixed proportions

Adsorbents	Soil (%)	Char (%)	Brick (%)
1	100		
2		100	
3			100
4	75	25	
5	50	50	
6	25	75	
7	37.5	37.5	25
8	25	25	50
9	12.5	12.5	75

Kinetic experiments were conducted to investigate equilibrium time of adsorption for Cd and Pb. Stock solutions were prepared with 300 and 350 ppm respectively for Cd and Pb. Materials and solutions were mixed with 1:10 ratio, 1 g of adsorbate was mixed with 10 mL of solution. Then, the tubes were shaken with 100 rpm at 25°C, taken out at different time intervals, centrifuged at 8000 rpm for 15 minutes and filtered by0.22 µm filter papers. Finally, the samples were analyzed with atomic absorption spectrometer (AA-6200, SHIMADZU CORPORATION, JAPAN).

Same experimental procedure was used to conduct isotherm experiments. Experimental solutions were prepared with100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1250, 1500, 1750, and 2000 ppm for Cd and Pb. Shaking time (24h) was desired based on the kinetic experiments. Obtained data were analyzed with Langmuir isotherm model and maximum adsorption capacities (Q_m) were estimated.

2.3. Water Permeability Test

Water permeability test was carried out for the tested materials with different degree of compaction prepared by standard proctor compaction (proctor A method, 1000 cm^3 volume core) or hand compaction (100 cm^3 volume core). The experimental apparatuses are shown in Figure 2.

Compaction test was conducted with standard Proctor method to obtain compaction curve, giving maximum dry density according to JIS A 1210. For the permeability test, constant head method was used to the samples having hydraulic conductivity of 10^{-3} to 10^{-5} cm/s, while for the samples having hydraulic conductivity of 10^{-5} to 10^{-9} cm/s, falling head method was applied. In these experiments, 5 kinds of the mixed materials (soil 100%, soil 75% + char 25%, soil 50% + char 50%, soil 25% + char 25% + brick 50%, and brick 100%) were used.

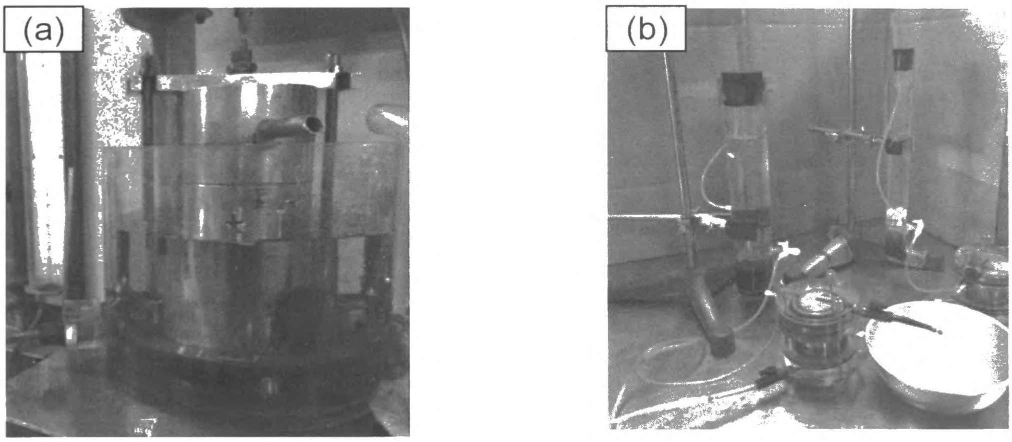


Figure 2 Water permeability test apparatuses
(a) Samples prepared by the standard proctor compaction and (b) Samples prepared by the hand compaction

3. RESULTS AND DISCUSSION

3.1. Adsorption Characteristics

Figure 3 shows results obtained from kinetic experiments for 3 kinds of tested materials. The amount of adsorption equilibrated within an hour for all tested materials other than Cd on char 100%. The equilibrium adsorption for Cd on char was reached at 6h. Therefore, in the isotherm experiment, shaking time was maintained as 24hto estimate maximum adsorption capacity.

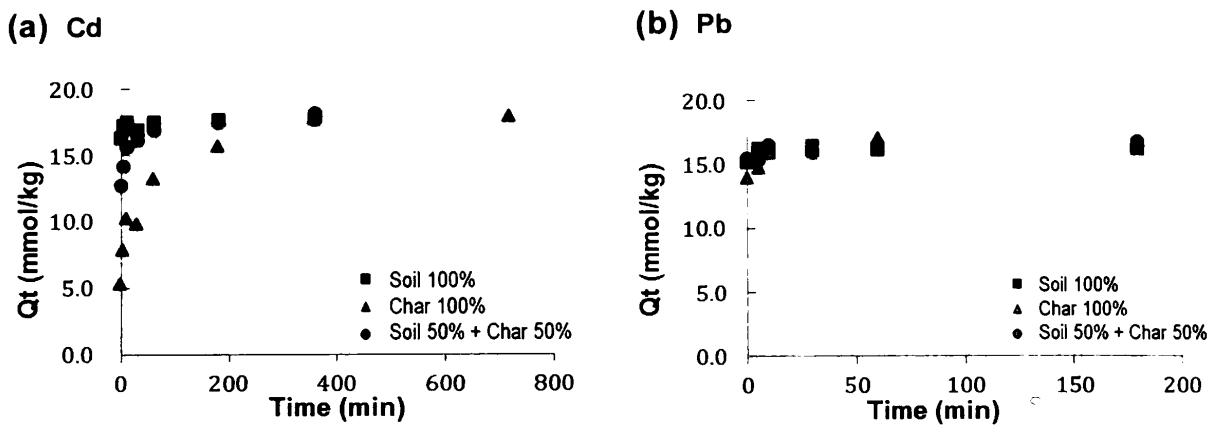


Figure 3 Temporal variation of adsorbed amount for (a) Cd (300 ppm) and (b) Pb (350 ppm)

Figure 4 illustrates Cd and Pb adsorption isotherm for materials mixed with 9 different proportions. Based on the results, maximum adsorption capacities and removal percentages were calculated. The calculated values are presented in Table 3. Maximum adsorption capacities and removal percentages of Pb were generally higher than that for Cd. Since the maximum adsorption capacity and removal percentage of brick were relatively low for both Pb and Cd, the values for the mixed materials including the brick were less. However, the removal percentage was reached 90 for brick mixed materials for Pb.

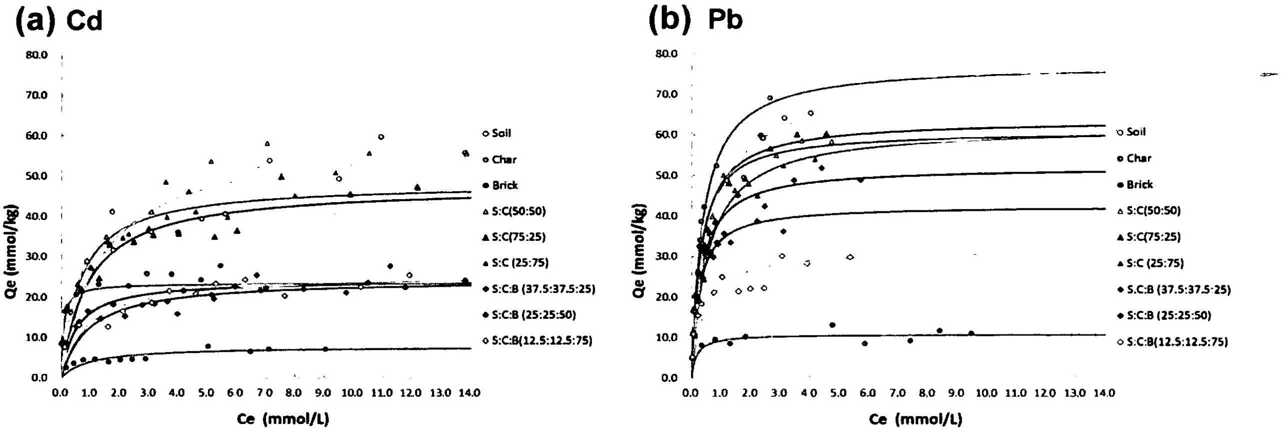


Figure 4 Adsorption isotherm fitted with Langmuir model for (a) Cd and (b) Pb. The x-axis and y-axis mean equilibrium concentration (C_e) and adsorbed amount at equilibrium (Q_e), respectively

Table 3 Maximum adsorption capacity and removal percent of Cd and Pb for all materials

Adsorbents	Cd		Pb	
	Q_m (mmol/kg)	Removal %	Q_m (mmol/kg)	Removal %
Soil 100%	40.2	77.2	48.3	92.9
Char 100%	25.2	80.0	88.5	94.9
Brick 100%	4.9	21.2	7.1	55.0
Soil 75%+Char 25%	40.2	76.0	44.1	96.6
Soil 50%+Char 50%	50.3	78.8	48.3	95.6
Soil 25%+Char 75%	41.7	80.8	79.4	89.7
Soil 37.5%+Char 37.5%+Brick 25%	21.7	64.4	38.6	94.7
Soil 25%+Char 25%+Brick 50%	19.3	52.7	36.5	94.4
Soil 12.5%+Char 12.5%+Brick 75%	25.1	44.3	22.9	87.7

3.2. Water Permeability Characteristics

Figure 5 depicts compaction curves with hydraulic conductivity for 5 different mixed materials. Compaction curve had clear peak for soil 100%, giving maximum dry density of 1.829 g/cm³. On the other hand, the dry density of brick 100% was almost constant and the maximum dry density was obtained by averaging these data. Results obtained for maximum dry densities and optimum water content are illustrated in Table 4.

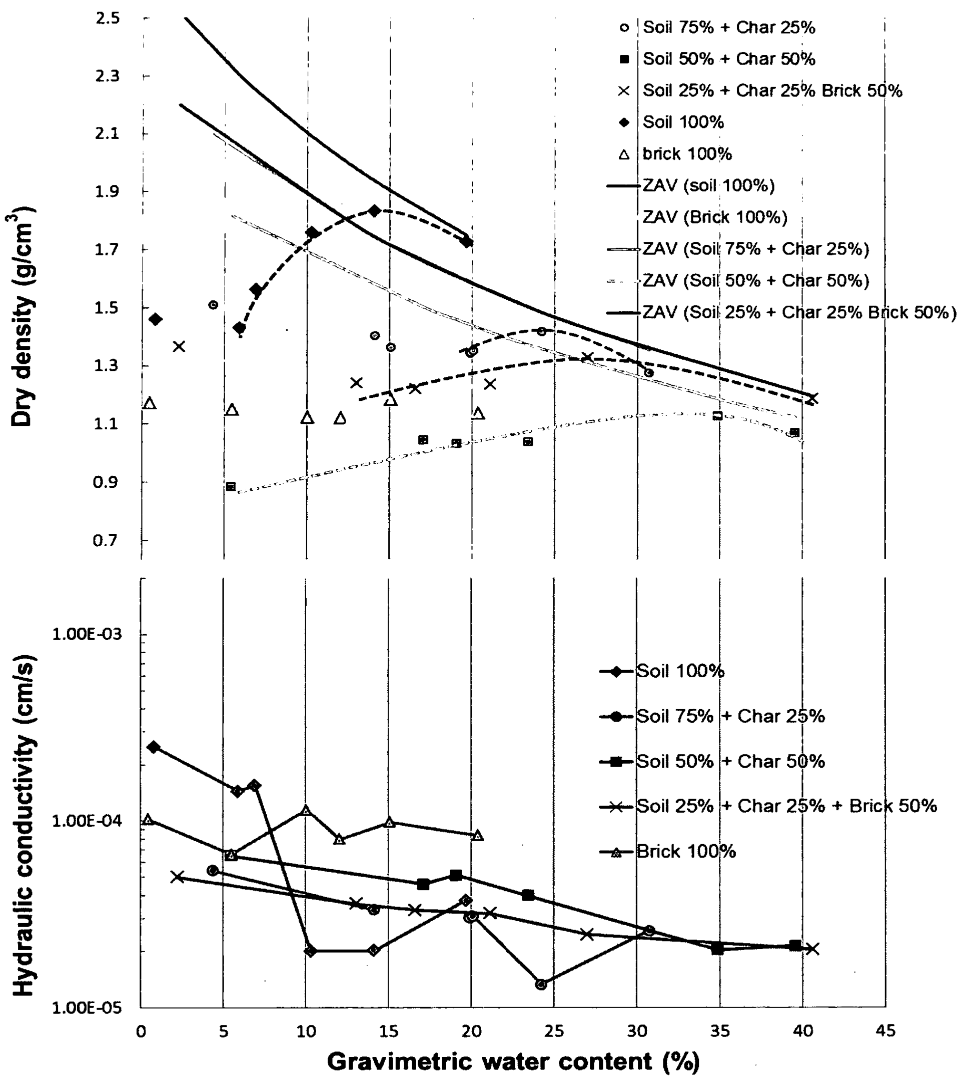


Figure 5 Compaction curves with hydraulic conductivity for five kinds of the tested materials

Table 4 Maximum dry density and optimum water content from compaction curves

Materials	Maximum ρ_d (g/cm³)	Optimum water content W_{opt} (%)
Soil 100%	1.83	14.1
Soil 75% + Char 25%	1.41	24.2
Soil 50% + Char 50%	1.12	34.9
Soil 25% + Char 25% + Brick 50%	1.32	27.0
Brick 100%	1.15*	-

*Averaged ρ_d values

Figure 6 shows relationship between hydraulic conductivity and degree of compaction for 3 different mixed materials (soil, soil 50% + biochar 50%, and soil 25% + biochar 25% + brick 50%). As previous studies reported, the hydraulic conductivity at open dumpsites in Sri Lanka is approximately 10^{-4} cm/s (reference). Therefore, the targeted hydraulic conductivity value in this study was 10 times higher than that(10^{-3} cm/s). For the mixed sample of soil 50% and char 50%, obtained hydraulic conductivities were less than 10^{-3} cm/s, while for soil 100% and soil 25% + char 25% + Brick 50%,more than 10^{-3} cm/s under relatively low degree of compaction. The tested material of soil 25% + char 25% + brick 50% showed the highest hydraulic conductivity approximately at a degree of compaction of 75%. The hydraulic conductivity value was 5 times greater than soil 100% under the same degree of compaction. Mixing of brick is highly important to achieve the targeted hydraulic conductivity.

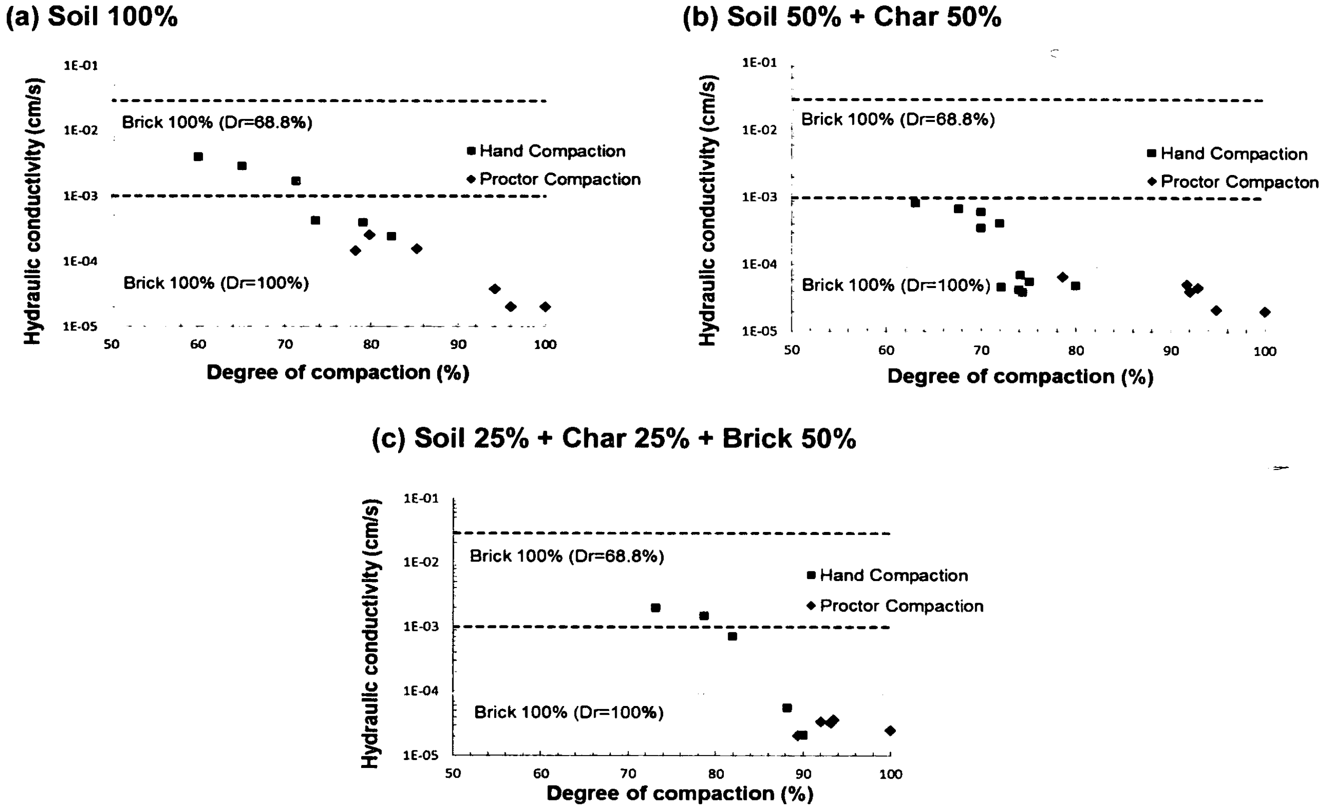


Figure 6 Relationship between hydraulic conductivity and degree of compaction for (a) Soil 100%, (b) Soil 50% + Char 50%, and (c) Soil 25% + Char 25% + Brick 50%

4. CONCLUSIONS

The results of this study indicate that tested materials have higher adsorption capacities and removal percentages for both Pb and Cd. However the materials performed better to Pb than Cd. Brick and brick mixed materials showed relatively less adsorption. However, the removal percentage was reached 90 for Pb. The mixed material containing the brick showed the highest values of hydraulic conductivity and satisfied the targeted value (10^{-3} cm/s) under approximately 75% degree of compaction. Therefore, the mixture of brick is highly important to maintain permeability of PRB filling materials.

5. ACKNOELEDGMENTS

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6. REFERENCES

Natalea, F.D., Nataleb, M.D., Grecob, R., Lanciaa, A., Laudanteb, C..and Musmarrab, D. (2008). Groundwater protection from cadmium contamination by permeable reactive barriers. Journal of Hazardous Materials, Volume 160, Issues 2–3, 30 December 2008, Pages 428–434.

Franklin Obiri-Nyarkoa, Jolanta Kwiatkowska-Malinab, Grzegorz Malinac, Tomasz Kaselaa (2015). Geochemical modelling for predicting the long-term performance of zeolite-PRB to treat lead contaminated groundwater. Journal of Contaminant Hydrology. Volumes 177–178, June–July 2015, Pages 76–84.

JIS A 1210 (2009). Test Method for Soil Compaction Using a Rammer, Japanese Industrial Standards Committee.

Paranavithana, G.N., B.G.N. Sewwandi, and K. Kawamoto (2013). Soil characterization for the development of site-specific permeable reactive barrier in Sri Lanka: Mineralogical and surface charge properties for selected surface geologic media. International Conference on Structural Engineering & Construction Management (ICSECM 2013), SECM/13/120.

Paranavithana, G.N., B.G.N. Sewwandi, T. Saito, and K. Kawamoto (2014). Adsorption characteristics of Cd(II) and Pb (II) onto coconut shell biochar and coconut shell activated carbon as media for permeable reactive barriers in Sri Lanka. Proceedings of 5th International Symposium on Energy from Biomass and Waste, 303.

Paranavithana, G.N., K. Kawamoto, Y. Inoue, T. Saito, M.Vithanage, C.S. Kalpage, and G. B. B. Herath (2016). Adsorption of Cd^{2+} and Pb^{2+} onto coconut shell biochar and biochar-mixed soil. Environ. Earth Sci. 75:484. DOI 10.1007/s12665-015-5167-z.

Sewwandi, B.G.N., T. Koide, K. Kawamoto, S. Hamamoto, S. Asamoto, and H. Sato (2013). Evaluation of leachate contamination potential of municipal solid waste dumpsites in Sri Lanka using leachate pollution index. Proceedings of Fourteenth International Waste Management and Landfill Symposium (Sardinia 2013), 233.