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Magnetic and Electrical Properties of Leachate

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Abstract. Heavy metals content as well as magnetic and electrical properties of leachate from Sarimukti, West Java were studied in an attempt to seek correlation between heavy metals content and magnetic/electrical properties. Such correlation is expected to open the way for the use of magnetic/electrical properties as proxy indicators for the concentration of heavy metals in the leachate. The number of leachate samples studied is 21; 15 were taken spatially at depth of 1 m while the remaining 6 samples were taken vertically at a particular point. Measurement results showed that the heavy metals content in the leachate has a smaller concentration, except for Fe. The correlation between magnetic susceptibility and heavy metals content was found to be not so significant. The best correlation coefficient between magnetic susceptibility with heavy metals in leachate was found in Zn. Correlation between electrical conductivity and heavy metal is also not so significant, except for Zn and Cd. The use of magnetic properties as proxy indicator for heavy metals content in leachate is plausible provided that the magnetic susceptibility exceeds certain threshold value. Correlation between magnetic susceptibility, electrical conductivity and heavy metal content would be good if each quantity has a large value.

Keywords: *electrical conductivity; heavy metals content; leachate; magnetic susceptibility; municipal solid waste.*

1 Introduction

One of the problems often faced by local government is waste management. In many cities in Indonesia the waste is discarded in the Municipal Solid Waste (MSW) disposal site. Solid waste are dumped and filled in a process known as sanitary land-filling [1]. This process, unfortunately, will produce leachate as by product. Leachate is a liquid produced by the entry of rain or groundwater into the piles solid waste [2]. Leachate is a potentially polluting liquid as it may cause harmful effects on the ground water and the surface water surrounding the MSW [3]. Composition and characteristic of leachate depends on the type of waste, climate, hydro-geological structure of MSW, humidity, and age of MSW [2,4]. If the landfill has no leachate collection system, the leachate can enter groundwater, and this can pose environmental or health problems as a result [5].

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Since leachate is hazardous to the environment, it needs to be monitored closely. The monitoring system is expected to be quantitative so that proper evaluation could be done.

Leachate has physical, chemical, and biological properties that can be measured quantitatively [6,7]. Physical properties of leachate can be measured, among others, by measuring magnetic parameters, including magnetic susceptibility and magnetic mineralogy [5] and by electrical conductivity [8]. Meanwhile, leachate might contain many other constituents, including heavy metals in considerable concentrations [9]. Heavy metals (such as Fe, As, Cd, Cr, Hg, Ni, Zn, Cu, Pb, and Co) are known to be found in leachate [5].

Earlier studies [1,5] have identified the presence of magnetic minerals and heavy metals content in leachate sludge from Sarimukti, an MSW near Bandung, Indonesia. The predominant magnetic mineral in the sludge was found to be magnetite, while the heavy metals content in the sludge was found to be much higher than the maximum allowable standard for liquid waste.

In this study, the suitability of magnetic and electrical properties as proxy indicators of heavy metals content in liquid leachate is tested. Magnetic and electrical properties are relatively easy to measure allowing the quality of leachate to be measured quantitatively. The measured magnetic property is magnetic susceptibility, while the measured electrical property is electrical conductivity. The results would be correlated with heavy metals content. Such correlations have been observed previously as significant correlation between magnetic susceptibility and heavy metals content in leachate sludge from Bandung, Indonesia and significant correlation between electrical conductivity and Cl content in leachate from Dal Skog and Esval landfill, Norway [5,10].

2 Methodology

2.1 Site Descriptions and Sampling Methods

The Sarimukti Municipal Solid Waste (MSW) is located around Bandung, the capital of West Java province. The site is about 25 km westward from downtown Bandung and it has been opened since 2006. The geographic coordinates of Sarimukti are S 6° 48 '19.7 "; E 107° 20' 55.9". The site is located on the ridge where the geological condition is dominated by andesitic rocks, basalt breccias, lava, tuff sandstone, and conglomerate [1]. The leachate pond in Sarimukti is about 1551 m^2 in area and is located 345 m above the sea level. The pond is well walled by concrete blocks. The depth of the pond during sampling was about 1.75 m.

Sampling is conducted on October 10, 2009 at a depth of 1 meter in 15 different lateral positions and 6 vertical positions (see Figure 1 for sampling positions). The liquid leachate sample was taken using a modified water pump on board of a rubber boat. The pump is made of acrylic pipe with external diameter of 16 mm that is connected to a water pump. The liquid sample should be obtained right from the location of the pipe. This method ensures that each sample would have roughly the same amount of particles and colloids [9].

The total number of samples taken from Sarimukti is 21, consisting of 15 samples taken laterally at a depth of 1 meter (SP1 to SP 15 in Figure 1) and 6 samples taken vertically (SV1 to SV6) from the center of the pond. Each sample consists of 5 liters liquid for magnetic susceptibility and electrical conductivity measurement plus a 100 ml sample for chemical analyses. The 100 ml samples were mixed with nitric acid (HNO_3) solution to prevent any chemical changes [11-12].

2.2 Leachate Measurements

All 21 samples were chemically analyzed for heavy metals content using an AAS (Atomic Absorption Spectrometer). The measured heavy metals are Cr, Hg, Zn, Cu, Pb, Cd, and Fe. This chemical analysis was carried out at the Center for Geological Survey in Bandung.

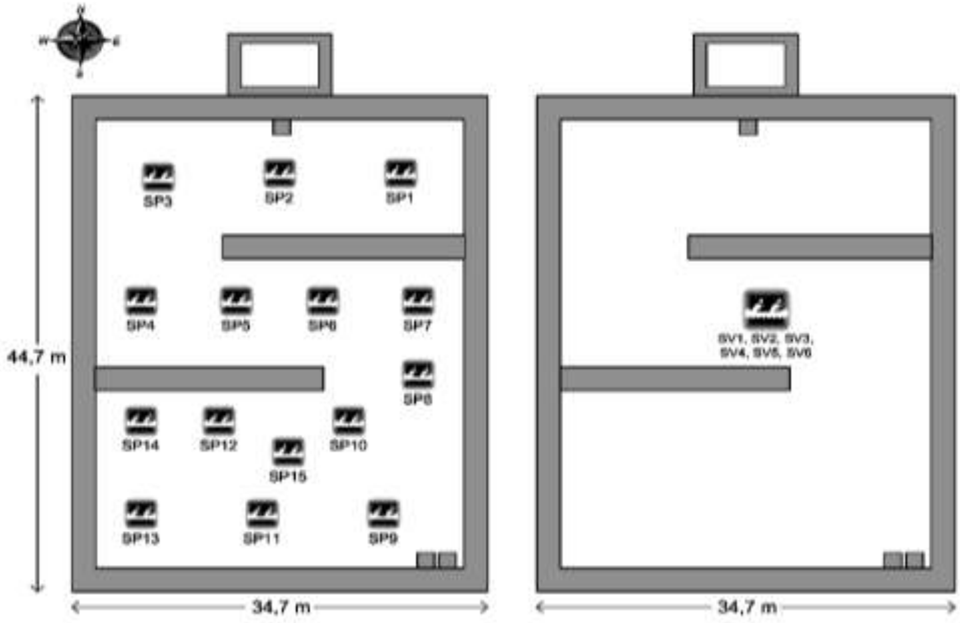
The measurement of magnetic susceptibility, in the form of volume-based magnetic susceptibility, was conducted on the liquid leachate placed in a standard plastic holder that is 10 ml in volume. The sample was also measured for its mass using an Ohaus analytical balance. The mass-based magnetic susceptibility (χLF) was measured using a Bartington MS2 Susceptibility Meter (Bartington Instruments Ltd., Oxford, United Kingdom) set at the frequency of 470 Hz. Magnetic susceptibility was also measured for solid samples that we obtained by centrifuging the liquid samples for 1.5 hour at the speed of about 3600 rpm.

Electrical conductivity was measured using the Oyster pH/Conductivity + TDS meters. The electrical conductivity was measured by dipping the probe into the liquid leachate. The results will be displayed directly in the instruments.

3 Results and Discussion

3.1 Heavy Metals Content in Leachate

Heavy metals content identified in leachate should reflect the degree of pollution. Based on AAS analysis, the Fe content was generally higher compared to that of other metals. For instance, the average value of Fe is 14.09 mg/L, whereas the average value of the other metals such as Cu is only 0.053 mg/L. Compared to the value of Fe from Dal Skog landfilling site in Norway with Fe concentration between 138 to 154 mg/L [10], the Fe content in this study is very small.



(a) (b)

Figure 1 The position of sample taking laterally (a); the position of sample taking vertically (b).

On the 15 lateral samples, there is a great variation of heavy metals content, notably for Fe and Zn in Table 1. The greatest values of Cu, Zn, and Fe were found in SP2 sample, whereas the greatest values of Pb and Cr were found in SP3 and SP5 samples. The concentration of the remaining two metals, Cd and Hg, was found to greatest in SP1 and SP12 samples. There is also a significant variation of heavy metal contents in the vertical samples Table 1. Highest concentration of Cu, Fe, and Cr was found in SV5 sample (taken at the depth of 20 cm), while highest concentration of Pb and Zn was found in SV6 sample that is taken at the surface of the pond. The highest concentration of Cd, meanwhile, was found in sample SV2 taken at the depth of 80 cm.

Table 1 Heavy metals content of leachate for lateral and vertical samples.

No	Samples Code	Parameter						
		Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Cd (ppm)	Cr (ppm)	Hg (ppb)
Lateral Samples								
1	SP1	0.050	0.093	0.759	11.50	0.0022	0.076	0.18
2	SP2	0.070	0.110	0.920	29.71	0.0017	0.094	<0.09
3	SP3	0.055	0.188	0.620	14.36	0.0008	0.096	<0.09
4	SP4	0.056	0.058	0.622	15.38	0.0007	0.088	0.09
5	SP5	0.060	0.098	0.450	16.83	0.0005	0.102	0.09
6	SP6	0.057	0.058	0.375	15.45	<0.0002	0.085	<0.09
7	SP7	0.052	0.081	0.364	11.27	0.0009	0.075	<0.09
8	SP8	0.042	0.052	0.337	10.24	0.0002	0.073	0.18
9	SP9	0.052	0.052	0.337	13.82	0.0013	0.068	<0.09
10	SP10	0.044	0.023	0.261	11.52	0.0002	0.063	0.27
11	SP11	0.041	0.051	0.238	11.26	0.0006	0.055	<0.09
12	SP12	0.049	0.121	0.265	13.38	0.0007	0.064	0.27
13	SP13	0.062	0.055	0.298	12.27	<0.0002	0.076	0.09
14	SP14	0.056	0.054	0.257	13.23	<0.0002	0.066	0.09
15	SP15	0.046	0.033	0.228	11.13	0.0012	0.067	<0.09
Vertical samples								
16	SV1	0.057	0.070	0.277	14.380	<0.0002	0.079	<0.09
17	SV2	0.051	0.078	0.239	11.960	0.002	0.068	0.090
18	SV3	0.049	0.050	0.215	13.590	0.001	0.075	<0.09
19	SV4	0.058	0.073	0.268	15.12	0.0012	0.068	0.18
20	SV5	0.061	0.083	0.287	17.04	0.0006	0.080	0.18
21	SV6	0.057	0.096	0.304	13.92	0.0007	0.077	<0.09

Compared to the heavy metals content in leachate sludge, the heavy metals content in liquid leachate is about two orders of magnitude weaker [5]. Factors that might affect the heavy metals content in leachate include the quantity of heavy metals leached from the solid waste as well as the heavy metals originated from the soils. The small heavy metals content in leachate could arise from the fact that the heavy metals input to leachate pond are insignificant. In contrast, the high heavy metal contents observed in the leachate sludge is likely due to accumulation over period of time. Thus the level of heavy metals content in leachate is affected by the accumulation time. For instance, if the leachate pond is stagnant, it is likely that the leachate would have higher heavy metal content compared to the leachate in running pond. Also, leachate from older pond might have higher heavy metals content compared to that from the younger pond [1].

During the time of sampling, the leachate pond in Sarimukti was running quite fast. This also supports our observation that there is variation of heavy metals content in both spatial and vertical distribution. Therefore, distribution of heavy metals content in leachate, to some extent, reflects the mobility of leachate in the pond.

Leachate contains dissolved and colloidal fractions that would affect the mobility of heavy metals within the leachate pond. The flow of leachate within the pond is not always laminar. Thus, turbulence in leachate flows for example during rain seasons could also affect the distribution pattern of heavy metals in leachate.

3.2 Magnetic Properties of Leachate

Mass susceptibility measurements of leachate show that the greatest value of magnetic susceptibility was found for SP2 sample (78.85×10^{-8} m^3/kg), whereas the values for the other 14 samples are close to zero (Table 2). Mass susceptibility measurement of leachate samples taken vertically shows that the magnetic susceptibility of all samples are less than zero (Table 2). Therefore, the variation of mass susceptibility values both in lateral and vertical samples are small. The measurement for solid leachate samples shows that the mass susceptibility for most samples is around 2.5×10^{-8} m^3/kg, except for SP2 that is 107.3×10^{-8} m^3/kg (Table 2). This low value of magnetic susceptibility infers that the liquid leachate has a very small magnetic content. SP2 sample is peculiar compared to other samples as it has reasonably high magnetic susceptibility indicating higher concentration of magnetic minerals. SP2 is located right at the inflow channel to leachate pond, where sediments and solid particulates accumulate creating small dirt island. Thus, compared to other samples, SP2 is thicker and contains more solid particulates.

As expected, the mass magnetic susceptibility of liquid leachate would be much smaller than that of leachate sludge [1]. In leachate sludge, magnetic minerals accumulate over period of time causing higher magnetic susceptibility. Magnetic minerals content in leachate could also be affected by magnetic minerals content in both waste and soils. It could also be influenced by the time of accumulation so that leachate from older sites should generally be more magnetic than that from younger sites.

The abundance of magnetic minerals in leachate might also affected by the seasons. Leachate could dissolve surrounding rocks, metals, and other inorganic wastes producing even more magnetic minerals [13]. Thus, the abundance of magnetic minerals in leachate is expected to be higher during rain seasons when leachate is more abundance and more mobile compared to that during dry seasons. In the literature, other factors have also been suggested to play an important part in magnetic minerals accumulation in leachate. Those factors include humidity, water infiltration and hydrological condition. Solid waste decomposes faster in humid condition while water infiltration and suitable hydrological condition could speed up leachate production.

Table 2 Magnetic susceptibility and EC of lateral and vertical liquid leachate samples.

No	Samples Code	Liquid χ_{LF} ($\times 10^{-8}$ m^3/kg)	Solid χ_{LF} ($\times 10^{-8}$ m^3/kg)	EC (× 10 µS/cm)
Lateral Samples				
1	SP1	-0.524		1269
2	SP2	78.854	107.3	1263
3	SP3	-0.206		1294
4	SP4	-0.627		1311
5	SP5	-0.856	2.7	1301
6	SP6	-0.737		1302
7	SP7	-0.634		1316
8	SP8	-1.040		1314
9	SP9	-1.142	2.4	1300
10	SP10	-0.945		1319
11	SP11	-1.047		1324
12	SP12	-1.050		1328
13	SP13	-1.154		1326
14	SP14	-1.474	2.4	1305
15	SP15	-0.953		1313
Vertical Samples				
16	SV1	-1.156		1283
17	SV2	-1.033		1323
18	SV3	-1.051		1309
19	SV4	-0.601		1314
20	SV5	-0.943		1309
21	SV6	-1.171		1308

3.3 Electrical Conductivity of Leachate

The results of electrical conductivity measurements show that sample SP12 has the greatest value of electrical conductivity relative to the other lateral samples (Table 2). Meanwhile, sample SP2 has the smallest electrical conductivity. Electrical conductivity values for samples SP12 and SP2 are respectively 1328 (× 10 µS/cm) and 1263 (× 10 µS/cm). The electrical conductivity measurements for vertical samples show that SV1 and SV2 have respectively the smallest (1283 × 10 µS/cm) and the largest (1323 × 10 µS/cm) values of electrical conductivity. Comparing the electrical conductivity data for Sarimukti with the electrical conductivity for sites in another country, it is clear that they are of comparable values [9].

Although SP2 has the highest value of magnetic susceptibility among the 15 lateral samples, it has the lowest electrical conductivity. This implies that SP2 has lower concentration of conducting ions. No specific relationship between magnetic susceptibility and electrical conductivity was found for other samples. Therefore, the low electrical conductivity in SP2 could only be explained by the physical nature of SP2. Compared to the other samples, SP2 is more viscous. Viscous liquid leachate contains less liquid per volume than the less viscous ones. As conductivity is carried by the liquid part instead of by the solid part, less viscous liquid leachate would have higher electrical conductivity than that of more viscous one. It is likely that the ions mobility in this sample is somehow smaller than that of the other samples giving low value of electrical conductivity. The electrical conductivity is a valuable indicator of the amount of dissolved materials in water [13]. The value of electrical conductivity depends on the quantity of dissolved particles as some of these particles could be conducting ions [12].

3.4 Relationship between Heavy Metals Content, Magnetic Susceptibility, and Electrical Conductivity

To test the feasibility of using magnetic susceptibility and electrical conductivity as proxy indicators for heavy metals content in leachate, it is natural to seek the correlations between these two parameters and heavy metals content. In the result of the measurement, Hg did not correlate well with other metals as well as with the susceptibility and electrical conductivity because it has very little value beyond the range of the measuring instrument. As shown in Table 3, the correlations between magnetic susceptibility and heavy metals content, in general, are poor or insignificant. The correlation is considered significant if it meets the 95% level of confidence ($p = 0.05$). Compared with other metals, Zn and Pb are better correlated in the lateral samples. Figure 2 shows the correlations between magnetic susceptibility versus Zn and Pb for the lateral samples. In the vertical samples, Cr and Fe are examples of heavy metals content correlated with magnetic susceptibility as shown in Figure 3. The differences of correlation coefficient of Zn for lateral and vertical samples are due to the fact that the flow of liquid leachate in the leachate pond is quite fast producing great variation of Zn content in lateral samples. The existence of walls within the pond also alters the flow significantly. The flow of leachate within the pond is not always laminar. Thus, turbulence in leachate flows affects the distribution pattern of heavy metals in leachate.

Table 3 Matrices showing correlation coefficients (*r*'s values) between heavy metals contents and physical parameters (magnetic susceptibility and electrical conductivity) for lateral and vertical liquid leachate samples. The 95% level of confidence (p = 0.05) requires that $r > 0.514$ (for n = 15) and $r > 0.811$ (for n = 6). Coefficients that satisfy such requirement are written in bold characters.

Heavy Metals	**Cu**	**Pb**	**Zn**	**Fe**	**Cd**	**Cr**
Lateral Samples (*n* = 15)						
Cu	1.000					
Pb	0.367	1.000				
Zn	**0.579**	**0.542**	1.000			
Fe	**0.781**	0.352	**0.696**	1.000		
Cd	0.098	**0.539**	**0.878**	0.480	1.000	
Cr	**0.720**	**0.572**	**0.687**	**0.594**	0.127	1.000
χ_{LF}	0.110	**0.618**	**0.772**	0.214	0.428	**0.614**
EC	0.506	0.396	**0.862**	**0.641**	**0.691**	**0.540**
Vertical Samples (*n* = 6)						
Cu	1.000					
Pb	0.610	1.000				
Zn	**0.871**	**0.842**	1.000			
Fe	**0.827**	0.175	0.526	1.000		
Cd	0.458	0.588	0.543	0.457	1.000	
Cr	0.417	0.135	0.457	0.534	**0.872**	1.000
χ_{LF}	0.274	0.122	0.077	0.366	0.402	0.578
EC	0.300	0.139	0.322	0.267	**0.924**	0.686

The poor correlations between magnetic susceptibility and heavy metals content are likely due to the fact that the leachate in this study is poorly magnetic and it has small heavy metals content. This implies that in this particular case (Sarimukti), the magnetic susceptibility could not be used as proper proxy indicator for heavy metal contents. Thus, the positive correlation between these two parameters could not be found. This does not necessarily means that the leachate could not be used as proxy indicator for heavy metals content. Further studies with at different season or at different site should be conducted to test this prospect. Earlier study shows that the correlations between magnetic susceptibility and heavy metals content in leachate sludge are better in older site compared with younger one [1]. That study also supports earlier suggestion that correlation between Fe and magnetic susceptibility is shown only in samples whose magnetic susceptibility exceeds 176 × 10^{-8} m^3/kg [14].

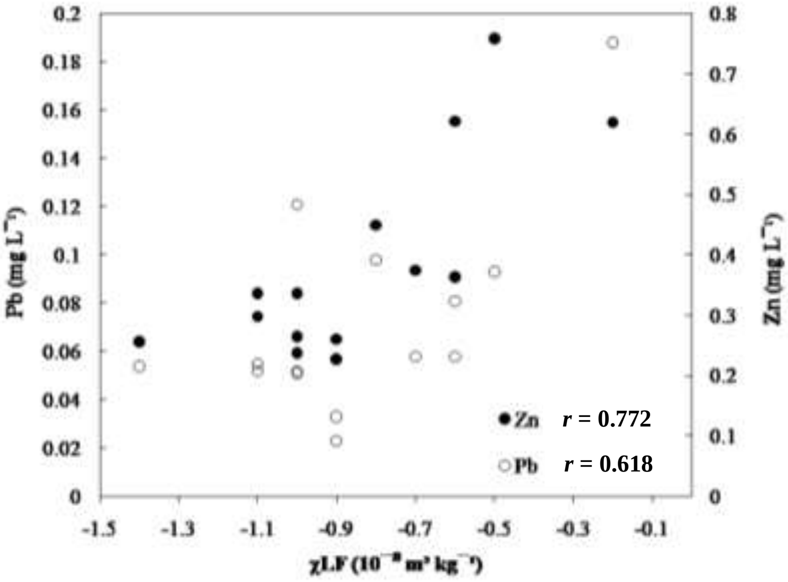


Figure 2 Plots of magnetic susceptibility (χLF) versus Zn and versus Pb for the 15 lateral samples, except for SP2.

Figures 4 and 5 show examples of correlation between Zn and Fe content with electrical conductivity for the lateral and vertical samples measured by The Oyster pH/Conductivity + TDS meters. In general, the correlations between electrical conductivity and heavy metals content are poor or insignificant (Table 3). Compared with other metals, Zn is better correlated in the lateral samples with correlation coefficient of 0.862 (Figure 4), but the correlation coefficient in the vertical sample is only 0.322 (Figure 4). Meanwhile Fe is the most abundance heavy metal in leachate. The correlation between electrical conductivity and Fe, however, is rather poor for with correlation coefficient of 0.641 for lateral samples (Figure 5) and of 0.267 for vertical samples (Figure 5). Although the Fe content in the liquid leachate samples is higher than that of Zn content, the Fe content is still insignificant. For instance the Fe content in leachate sludge vary from 195.40 to 5418.80 ppm, while that of Zn vary only from 0.48 to 3.21 ppm [1]. Thus, relatively speaking, the Zn content in liquid leachate of 0.215 to 0.920 ppm is more important than that of Fe that vary only from 10.24 to 29.71 ppm.

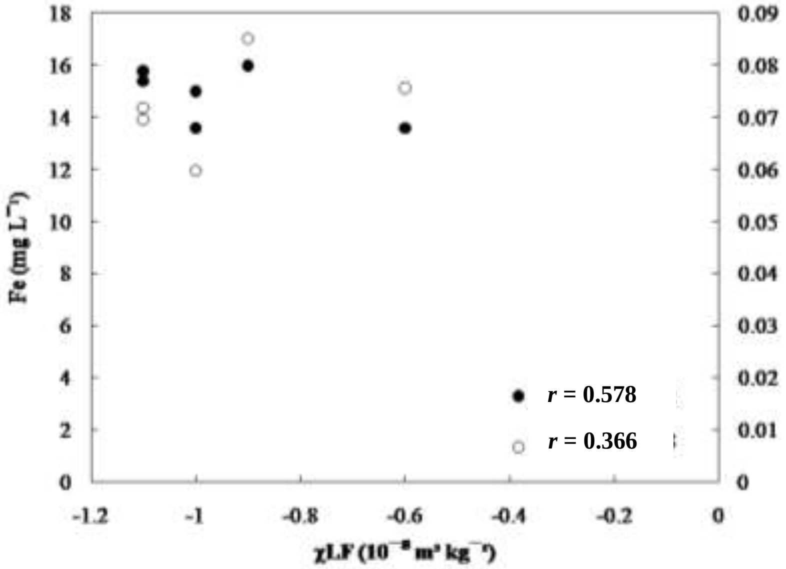


Figure 3 Plots of magnetic susceptibility (χLF) versus Cr and versus Fe for the 6 vertical samples.

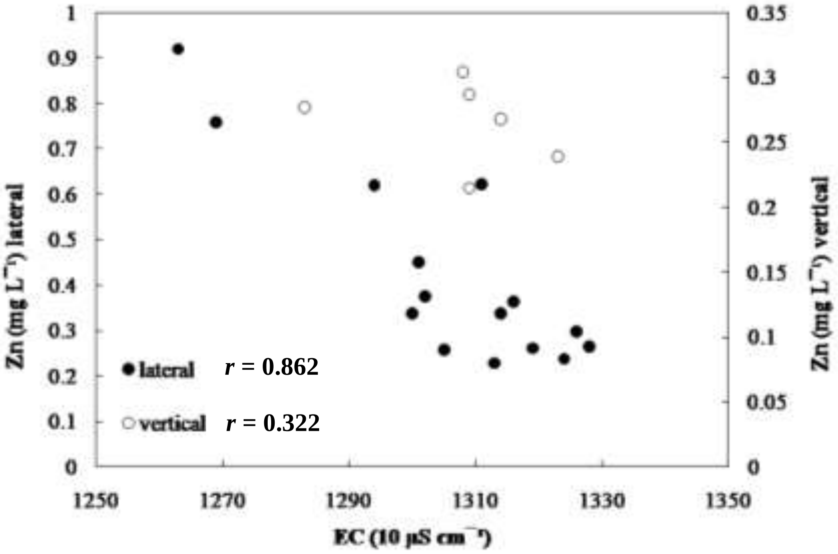


Figure 4 Plots of electrical conductivity (EC) versus Zn for the 14 lateral samples and the 6 vertical samples.

Based on the correlation between Zn and Fe with electrical conductivity, it is still plausible to use electrical conductivity as proxy indicator for certain heavy metals content. The sensitivity of electrical conductivity as proxy indicator for heavy metals content would depend on the types of metals. Metals that are higher in concentration or associated with conductivity, such as Zn could likely be inferred from electrical conductivity. Other metals, that are not associated with electrical conductivity or very small in quantity, such as Cd could not be estimated from electrical conductivity.

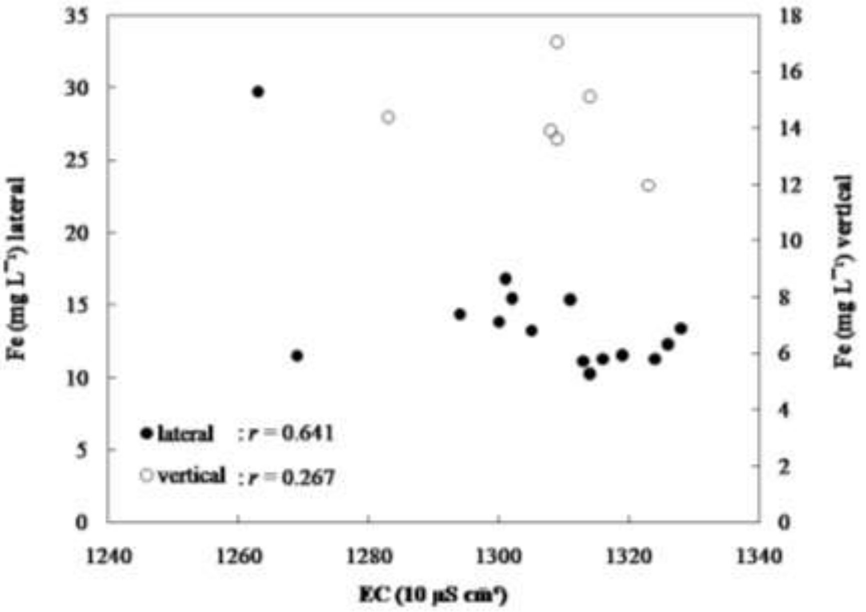


Figure 5 Plots of electrical conductivity (EC) versus Fe for the 14 lateral samples and the 6 vertical samples.

4 Conclusions

Based on the results and discussion the following conclusions are drawn:

1. Heavy metals content from samples taken at the Sarimukti MSW, both laterally and vertically have a lower value than minimum allowable standard for liquid waste, except for Fe metal. The small heavy metals content in leachate could arise from the fact that the heavy metals input to leachate pond are insignificant. Great variations in heavy metals content between both lateral and vertical samples reflect the mobility of leachate in the pond and the age of landfill site.
2. The variations of mass susceptibility both in lateral and vertical samples are small. This low value of magnetic susceptibility infers that the liquid

leachate has a very small magnetic content. Since magnetic content is likely to be seasonal, further studies at different season would be invaluable.

3. The results of electrical conductivity measurements showed that the leachate is conductive. The conductivity depends on ions mobility in the sample. Electrical conductivity of leachate in Sarimukti is in comparable values with another country.
4. Measurement of heavy metal contents is a standard analysis to evaluate a pollution level. However, as far as the authors are concerned, this study is a first ever attempt to correlate heavy metal contents and electrical conductivity. The correlation between magnetic susceptibility and heavy metals content was poor. These are likely due to the fact that the leachate in this study is poorly magnetic and it has small heavy metals content. The correlation could be more significant in other sites. In general, the correlations between electrical conductivity and heavy metals content are poor or insignificant. It is still plausible to use electrical conductivity as proxy indicator for certain heavy metals content. Metals that are higher in concentration or associated with conductivity, such as Zn could likely be inferred from electrical conductivity.

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