*Journal of Environmental Science and Management 17(1): 50-59 (June 2014)*
*ISSN 0119-1144*

# Analysis of Heavy Metals in Cebu City Sanitary Landfill, Philippines

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**Research Notes**

**ABSTRACT**

*Selected heavy metals in leachate and groundwater in Cebu City Sanitary Landfill (CCSL), Philippines were studied. Levels of Pb, Cd, Cr, and Cu in total form were determined by Flame- AAS and Hg by cold vapor AAS. Study commenced on April, May, August, and October of 2010 covering wet and dry seasons. Studied leachate stations exceeded the standards for Pb (0.1968 mg $L^{-1}$) and Hg (0.14838 mg $L^{-1}$) with risk quotient (RQ) values >1. Groundwater stations exceeded the standard for Pb (0.0371 mg $L^{-1}$) and Cd (0.0042 mg $L^{-1}$) with RQ >1. It can be inferred that the groundwater adjacent to CCSL was slightly impacted by leachate metal constituents. Therefore, it is recommended that further monitoring would be carried out and the leachate would be contained to protect the groundwater prior to CCSL closure.*

**Key words**: *Heavy metals, leachate, Cebu City, landfills and groundwater*

## INTRODUCTION

The presence of a poorly managed waste disposal scheme is often manifested through the use of conventional landfills and dumpsites owing to their accessibility, inexpensiveness, and convenience of methane gas recovery (*Alloway and Ayres 1997*), although other options like composting and recycling are available. Standard recommendations for landfill design ideally involve appropriate control of leachate and landfill gas with the existence of lined pit (*Oyekuh and Eludoyin 2010*) with continuous maintenance and monitoring to ensure safe operation (*Uriarte 2006*). However, landfill utilization elsewhere showed incomplete information for leachate and gas handling (*Johannessen, and Boyer 1999*).

Locally, an example of this landfill scenario is the Cebu City Sanitary Landfill (CCSL). The Department of Environment and Natural Resources-Environmental Management Bureau Region 7 (DENR-EMB) cited CCSL to have operational deficiencies, no soil cover, absence of leachate treatment, and dumped medical wastes. The CCSL have total lot area of 15.41 ha and 11.73 ha allotted for dumping. Landfill operation began on September 11, 1998 with an estimated seven years of filling period. Daily average weight of garbage dumped is approximately 450 t (*WCS 2006*) without any leachate containment facility. This in return, suggests a need to examine levels of heavy metals in leachate and groundwater in CCSL to ensure environmental quality.

Ecological and health associated risks if landfills are poorly managed results to contaminating the groundwater resource with heavy metals and metalloids coming from dumped electronic wastes (*Jang and Townseed 2003*) among others. Heavy metals are generally known to act ascarcinogen giving toxic responses (*Alloway and Ayres 1997*) by bonding to protein sulfhydryl (-SH) groups and interferes the salt bridges between amino acid groups (*Denniston et al. 2007*), however, depending on specific pharmacokinetic pathways (*Williams et al. 2000*).

Common heavy metals in leachate with its corresponding mean values are copper (Cu) (5 ppm), zinc (Zn) (50 ppm), lead (Pb) (0.30 ppm), and mercury (Hg) (60 ppb) (Csuros, and Csuros, 2002). Other studies conducted in dormant landfill sites elsewhere (Mor et al. 2006; Oyoh and Evbuomwan, 2008; Yoshida et al. 2002; Jang and Townseed 2003) reported lesser concentrations of the mentioned metals including cadmium (Cd), and chromium (Cr). In the Philippines, only the study of *Sia Su* (*2008*) in Payatas dumpsite, Manila was carried to assess levels of metals and none was conducted in other metropolitans in the country, giving rise to the urgency of determining current landfill status specifically on metals speciation. Further, to date when the study was conducted there were limited published references in Southeast Asian countries about heavy metals in landfills and dumpsites thus further highlighting the need.

This study was conducted to characterize selected heavy metals (Pb, Cu, Cd, Cr, and Hg) in CCSL leachate and groundwater. The objectives were: to determine the concentrations of the studied heavy metals (Pb, Cu, Cd, Cr, and Hg); evaluate environmental risk brought by the studied metals; compare the concentrations of studied metals to available standards; and compare the concentrations of studied metals to other studies on dormant landfills and dumpsites elsewhere as reference to extrapolate the status of CCSL. In return this will provide baseline information on the environmental quality of CCSL.

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## MATERIALS AND METHOD

### Study site

In this study, four sampling stations for leachate were assessed through existing outflows at the downstream and three groundwater stations were selectively chosen within the 2 km mean radius to CCSL. Stations LI, L2, L3, and L4 were located at the CCSL downstream serving as reservoir for leachates (**Table 1** and **Figure 1**). These stations were exposed to landfill excavation brought about by continuous dumping of wastes. Stations G1 and G2 on the other hand were groundwater sites directly adjacent to CCSL used for domestic purposes among local settlers. On the other hand, station G3 was situated 30 m from CCSL. The three groundwater stations were all covered with cement linings but not monitored for suitability for consumption. Sampling of groundwater and leachate commenced on April, May, August, and October of 2010. These choosen to cover dry and wet seasons.

### Metal Analyses

Leachate and groundwater samples were stored in a polyethylene bottles pre-washed with 10 % nitric acid ($NHO_3$) and the samples analyzed. All contained samples were submerged in an ice cooling tank to prevent chemical absorption and ion interference prior to heavy metal analyses. All samples were analyzed in the University of San Carlos Water Laboratory. Owing to limited samples on the onset of El Nino when the study was carried and the limited funding available selected metals were studied. Studied metals included Pb, Cu, Cr, and Cd in total form by Flame-Atomic Absorption Spectrophotometry (AAS) with pre-calibrated standards (*APHA 1998*) at wavelengths 283.3 nm, 324.8 nm, 357.9 nm, and 228.8 nm, respectively. The analysis of Hg was carried using cold vapor-AAS (*APHA 1998*) covering April-May, 2010.

### Data Analysis

All results were pre-treated with Q-test eliminating data outliers. Standard deviation and arithmetic mean of each of the studied metals Pb, Cd, Cr, Cu, and Hg were also obtained. T-test at α = 95 % was employed to evaluate the difference of the studied metals between leachate and groundwater in two seasons. Environmental risk analysis was expressed using risk quotient (RQ) calculated as the ratio between the determined concentration and the available

Table 1. Description of the sampling stations in CCSL.

| Sample | Station codes | Latitude | Longitude | Location | Description |
|---|---|---|---|---|---|
| Leachate | L1 | 10°16’9.01”N | 123°51’55.29”E | Landfill downstream | Uncovered and uncontained |
| Leachate | L2 | 10°16’4.51”N | 123°51’59.23”E | Landfill downstream | Uncovered and uncontained |
| Leachate | L3 | 10°16’1.93”N | 123°52’6.61”E | Landfill downstream | Uncovered and uncontained |
| Leachate | L4 | 10°15’59.06”N | 123°52’1.70”E | Landfill downstream | Uncovered and uncontained |
| Groundwater | G1 | 10°15’59.89”N | 123°51’57.93”E | 10 m from the landfill | Water pump deep well |
| Groundwater | G2 | 10°15’57.62”N | 123°51’55.48”E | 10 m from the landfill | Water pump deep well |
| Groundwater | G3 | 10°15’55.56”N | 123°51’33.36”E | 30 m from the landfill | Water pump deep well |


Figure 1. DOST-NOAH satellite map of CCSL with the sampling stations.

standard (*GEF/UNDP/IMO 2004*). The calculated RQ of >1 can gauge the metal to likely pose environmental risk. Three standards were used for estimating RQ in groundwater (**Table 2**). For estimating RQ in leachate the standards used were DENR DAO 1990 directive, which included Class AA, C, SA, SB, and SC. To draw more perspective standards for ANZECC (*PHILMINAQ 2006*; *ANZECC 1990*), ASEAN (*PHILMINAQ 2006*), and *US EPA* (*2012*) guidelines for freshwater and marine waters were also used. Both freshwater and marine water surrounds CCSL thus these interim guidelines were considered (**Table 3**).

## RESULTS AND DISCUSSIONS

### Heavy Metals in Leachate in Comparison to Standard

Of the studied metals, Pb (0.1968 mg $L^{-1}$), Cu (0.6132 mg $L^{-1}$), and Cr (0.0963 mg $L^{-1}$) were found to be dominant in all leachate stations compared to Cd (0.0068 mg $L^{-1}$) (**Table 4**) (**Figure 2**). Abundance of wastes scrap metals, paints, pigments, plastics, cleaners, and batteries (*Bagchi 2004*) were found in CCSL, which can be the potential sources of these metals.

Concentration of Pb in CCSL ranged 0.0926-0.2898 mg $L^{-1}$ exceeding national regulation (*DENR DAO 1990*). This is typical in landfill leachate usually containing 0.30 ppm of Pb (*Csuros and Csuros 2002*). Presence of Pb in leachate is a possible indicator that Pb based paints, pipes, batteries, and chemicals for photograph processing are dumped in the area (*Mor et al. 2005*). Locally, waste composition in CCSL were 16 % plastics, 0.25 % electronic, and 7 % scrap metals (*WCS 2006*) exhibiting possible source of Pb. Active landfills like CCSL were studied to likely pollute via Pb leaching (*Ogundiran and Afolabi 2008*).

Determined Cd levels in leachate stations passed the national standard-0.01 ppm (*DENR DAO 1990*). Like Pb, the presence of Cd is attributed to similar waste materials such as paints, pigments, plastics (*Bagchi 2004*), effluents of batteries (*Alloway and Ayres 1997*), scrap metal, old slum tenements, dirty scrap, and waste disposal yard (*Cumar and Nagaraja 2011*).

Levels of Cu on the other hand ranged 0.1812-1.1048 mg $L^{-1}$, relatively below 5 mg $L^{-1}$ (*Csuros and Csuros,2002*) common to landfill leachate. Although for L1 and L3 (**Table**

Table 2. Description of the standards used for groundwater.

| Standard | Metal concentration (mg $L^{-1}$) | | | |
|---|---|---|---|---|
| | Cu | Cd | Cr | Pb |
| PNSDW 2007 | 1.3 | 0.005 | 0.1 | 0 |
| US EPA Maximum contaminant level goal (MCLG) | 1.3 | 0.005 | 0.1 | 0 |
| WHO 2005 | 2 | 0.003 | 0.05 | 0.01 |
| DENR DAO Class AA Standard 1990 | 1 | 0.01 | NA | 0.05 |

Table 3. Description of the standards used for leachate.

| Standard Description | |
|---|---|
| **DENR DAO 1990** | |
| Inlandwater/freshwater | |
| AA | Public Water Supply Class I. This class is intended primarily for waters having watersheds which are uninhabited and otherwise protected and which require only approved disinfection in order to meet the National Standards for Drinking Water (NSDW) of the Philippines. |
| C | Fishery Water for the propagation and growth of fish and other aquatic resources |
| Coastal and marine water | |
| SA | Waters suitable for the propagation, survival and harvesting of shellfish for commercial purposes |
| SB | Fishery Water Class I (Spawning areas for Chanos chanos or "Bangus" and similar species). |
| SC | Fishery Water Class II (Commercial and sustenance fishing |
| **ANZECC 1990** | water quality guideline for fresh and marine water quality 1990 |
| **ASEAN** | Marine water quality criteria |
| **US EPA 2012** | Marine chronic criteria and acute criteria |

Table 4. Selected Heavy Metals in CCSL Leachate Stations.

| Total heavy metal (mg $L^{-1}$) | Leachate stations | | | | Mean ± SD | CV |
|---|---|---|---|---|---|---|
| | L1 | L2 | L3 | L4 | | |
| Pb | 0.2898 | 0.1865 | 0.0926 | 0.2183 | 0.1968 ± 0.0818 | 0.4165 |
| Cd | 0.0145 | 0.0054 | 0.0029 | 0.0044 | 0.0068 ± 0.0052 | 0.7647 |
| Cu | 0.8612 | 0.3055 | 0.1812 | 1.1048 | 0.6132 ± 0.4414 | 0.7197 |
| Cr | 0.0562 | 0.0837 | 0.0702 | 0.1752 | 0.0963 ± 0.0537 | 0.5576 |

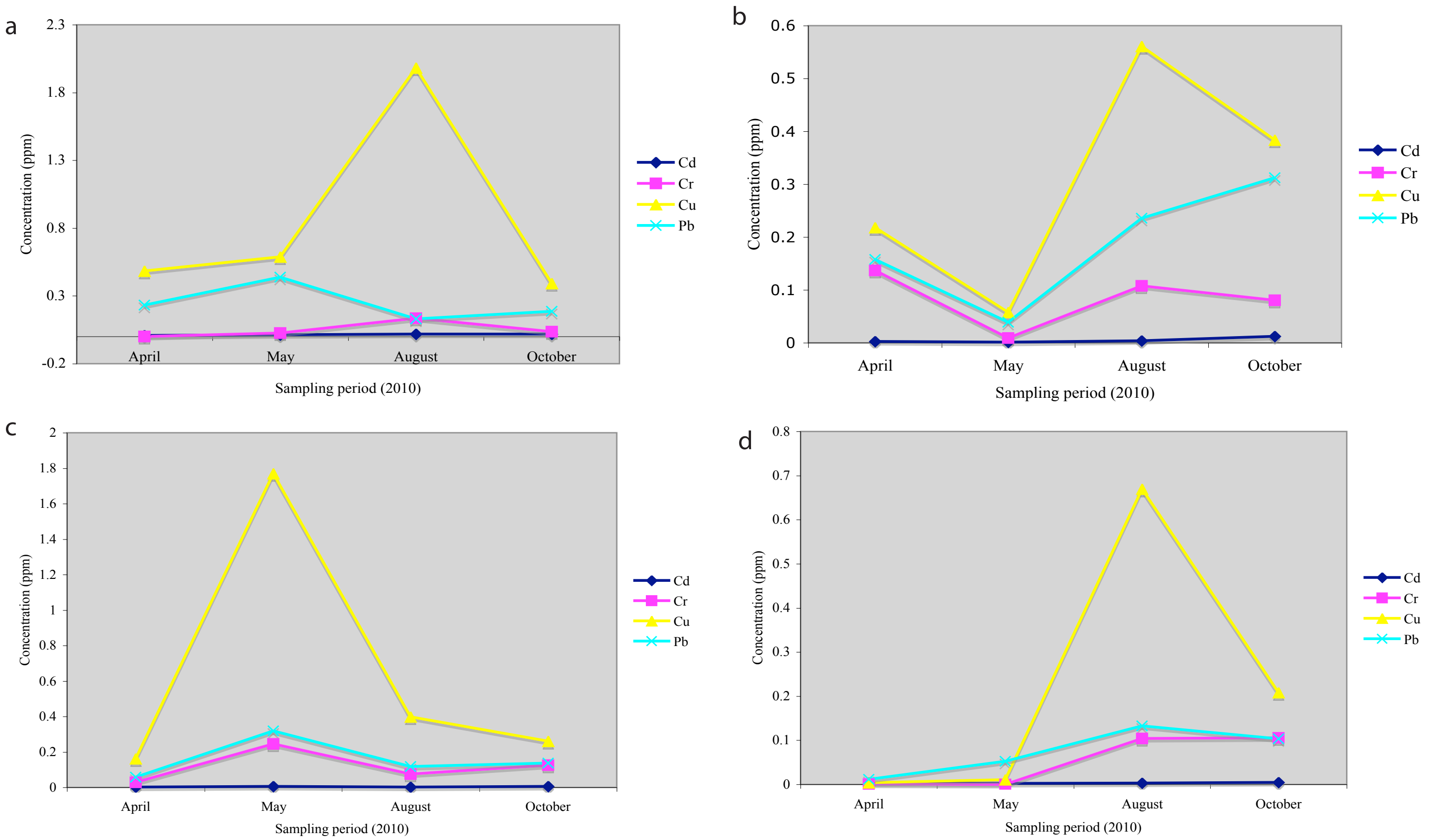


Figure 2. Heavy metal concentration in leachate stations a) L1, b) L2, c) L3, & d) L4.

4, **Figure 2a** and **c**) the Cu concentration were beyond the standard set in one of the sampling period. Overall, mean values for Cu during the duration of the study passednational regulation (1 mg $L^{-1}$). Typical concentrations of Cu in landfill leachate within 0.08- 0.30 mg $L^{-1}$ indicate a young landfill (*Alloway and Ayres 1997*). The CCSL had been operating for 12 years when this study was carried indicating landfill maturity. However, prolong and gradual disposal may exhibit properties of generating fresh leachate bearing chemical constituents of a young landfill. Age of the landfill therefore primarily governs leachate characteristics (*Kale et al. 2010*).

Total Cr in leachate was also characterized to be lower which were unlikely to exhibit toxicity. Trace concentration of Cr is associated with dumped materials containing Cr such as stainless steel, paint pigments, and wood preservatives (*Hughes 1996*) found to be present in CCSL.

Of the studied leachate sites, invariability of heavy metals were found indicating site-specific condition owing to waste loading and the constant landfilling operation. It is noticeable however that higher concentration of the studied metals was found in L1 (**Table 4** and **Figure 2a**). This site was found to have much leachate catchments compared to the other studied sites resulting to contaminant drainage. The general trend of the studied metals showed Cu>Pb>Cr>Cd which was in agreement with the study of *Singh et al.* (*2008*) and Cu>Pb>Cd of *Banar et al.* (*2006*). Generally, observed concentrations were still lower most likely attributed to pH near neutral values hindering metals solubility (*Banar et al. 2006*). The pH values of the studied leachate ranged 6.23-8.17.

Elevated concentration levels for the month of August followed by October were likely associated to higher precipation rate indicating the onset of wet season (**Figure 2**). Greater rainfall apparently yields diluted leachate that may percolate into the surface water and groundwater (*Esakku et al. 2007; Eusuf et al. 2007*). The months of August, 2010 had precipation of 203.4 mm and October 2010 of 289.2 mm. However, this was not the trend found in L3 indicating site specific reason. Station L3 was less likely to receive dumped waste found at the edge of CCSL (**Figure 1**). Despite increased precipation rate on August and October insufficient metals were leached due to absence of potential waste source. Generally, the quality and quantity of dumped waste in the station may determine the load of contaminants (*Bagchi, 2004; Mcbean et al. 1999; McDougall 2001*).

The levels of Hg were also evaluated in the studied leachate stations however covering the months of April and May, 2010 only owing to resource constraints.. Levels of Hg in leachate stations ranged 0.007 mg $L^{-1}$ -0.6456 mg $L^{-1}$ and can be ranked in the order L1>L2>L3>L4 (**Figure 3**). This was found in agreement with other studied metals with pronounced levels in station L1. This station tends to become

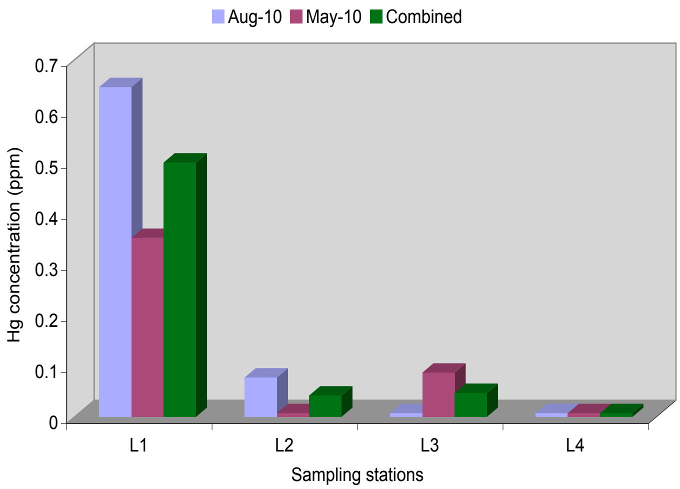


Figure 3. Hg concentration in leachate stations.

drainage of combined fresh and old leachate forming about 200 $m^2$ leachate pools. The gradual deposition in L1 probably caused for the increased concentration of metals. Overall all leachate stations exceeded the set standard for Hg, which is 0.002 mg $L^{-1}$.

## Comparison of Heavy Metals in Leachate to Other Landfills and dumpsites

Extrapolating from this Pb concentration in CCSL was still lower compared to other characterization studies of dormant landfills in Nigeria: 1.5400 mg $L^{-1}$ (*Oyoh and Evbuomwan 2008*), Yemen: 2.600-2.850 mg $L^{-1}$ (*Sabahi et al. 2009*), Tanzania: 0.94±0.78 mg $L^{-1}$ (just below the dump) (*Shemdoe 2010*), Algeria: 3.49 mg $L^{-1}$ (*Salem et al. 2008*), and India: 1.4900 mg $L^{-1}$ (*Mor et al. 2006*). However, the determined Pb values were higher than studies in dormant landfills in Tunisia: 0.01-0.18 mg $L^{-1}$ (*Yoshida et al. 2002*), Pallestine: 0.112 mg $L^{-1}$ (*El-Sayrafi et al. 2011*), and Florida: <0.04-0.07 mg $L^{-1}$ (*Jang and Townseed 2003*) (**Table 5**).

The Cd levels in CCSL leachate was lower compared to other dormant landfill studies with concentrations in Nigeria: 0.3300 mg $L^{-1}$ (*Oyoh and Evbuomwan 2008*), Yemen: 0.250-0.300 mg $L^{-1}$ (*Sabahi et al. 2009*), Tanzania: 0.04±0.01 mg $L^{-1}$ (just below the dump) (*Shemdoe 2010*), India: 0.0600 mg $L^{-1}$ (*Mor et al. 2006*), and Tunisia: 0.01-0.03 mg $L^{-1}$ (*Yoshida et al. 2002*) (**Table 5**).

The Cu levels in CCSL leachate was considerably lower compared to dormant landfill studies in India: 0.9300 mg $L^{-1}$ (*Mor et al. 2006*) and Yemen: 21.500 mg $L^{-1}$ (*Sabahi et al. 2009*), However, higher than the study in Tunisia: 0.04-0.09 mg $L^{-1}$ (*Yoshida et al. 2002*), Pallestine: 0.180 mg $L^{-1}$ (*El-Sayrafi et al. 2011*), and Algeria: 0.39 mg $L^{-1}$(*Salem et al. 2008*) (**Table 5**).

Although the levels of Cr in CCSL was higher than the study in Pallestine: 0.027 mg $L^{-1}$(*El-Sayrafi et al. 2011*) it was still generally lower compared to other characterization studies of dormant landfills in Yemen: 0.145-0.155 mg $L^{-1}$ (*Sabahi et al. 2009*), Tanzania: 4.15±3.51 mg $L^{-1}$ (just below the dump) (*Shemdoe 2010*), India: 0.2900 mg $L^{-1}$ (*Mor et al. 2006*), and Tunisia: 0.14-1.80 mg $L^{-1}$ (*Yoshida et al. 2002*) (**Table 5**).

While waste composition was a factor to affect metal concentration, variability of studied sites were also determined by other mobility and sorption factors like pH (*Banar et al. 2006*), reduction-oxidation potential (Eh), functional groups on humic matter, and the sorptive capacity of the refuse mass (*Kjeldsen et al. 2002*) in leachates.

## Environmental Risk Analysis of Heavy Metals in Leachate

For risk analysis both inland and coastal water effluent standards were used under DENR DAO 1990 since these water bodies surround CCSL. RQ values of studied metals can be ranked Cu>Hg>Pb, indicating environmental risk brought by these metals (**Table 5**). Distinctively RQ values for Hg and Pb (**Table 6**) were in agreement (**Table 4**) and (**Figure 3**) both exceeding the standards. Generally, the same condition applies using other standards (ANZECC, ASEAN marine water quality, and US EPA marine criteria). The RQ for total Cr was not determined since there were no standards available.

Table 5. Total heavy metal in CCSL leachate compared to dormant landfills.

| **Area** | **Heavy metals (mg $L^{-1}$)** | | | | |
|---|---|---|---|---|---|
| | Pb | Cd | Cu | Cr | Reference |
| CCSL | 0.1968 | 0.0068 | 0.6132 | 0.0963 | This study |
| India | 1.5400 | 0.0600 | 0.9300 | 0.2900 | *Mor et al.* (*2006*) |
| Nigeria | 1.4900 | 0.3300 | - | - | *Oyoh and Evbuomwan* (*2008*) |
| Tunisia | 0.01-0.18 | 0.01-0.03 | 0.04-0.09 | 0.14-1.80 | *Yoshida et al.* (*2002*) |
| Florida, USA | <0.04-0.07 | - | - | - | *Jang and Townseed* (*2003*) |
| Yemen | 2.600-2.850 | 0.250-0.300 | 21.500 | 0.145-0.155 | *Sabahi et al.* (*2009*) |
| Tanzania | 0.94 | 0.04 | - | 4.15 | *Shemdoe* (*2010*) |
| Pallestine | 0.112 | - | 0.180 | 0.027 | *El-Sayrafi et al.* (*2011*) |
| Algeria | 03.49 | <0.03 | 0.39 | - | *Salem et al.* (*2008*) |

Table 6. Risk quotients of studied metals in CCSL leachate stations.

| Standard | RQ of heavy metals | | | |
|---|---|---|---|---|
| | Pb | Cu | Cd | Hg |
| DENR DAO 1990 Inlandwater/Freshwater | | | | |
| AA | 3.94 | 0.61 | 0.68 | 74.19 |
| C | 3.94 | 12.26 | 0.68 | 74.19 |
| DENR DAO 1990 Coastal and marine water | | | | |
| SA | 3.94 | No standard | 0.68 | 74.19 |
| SB | 3.94 | 30.66 | 0.68 | 74.19 |
| SC | 3.94 | 12.26 | 0.68 | 74.19 |
| ANZECC standard 1990 | 196.80 | 306.60 | 34.00 | 741.90 |
| ASEAN marine water quality criteria | 23.15 | No standard | 0.68 | 927.38 |
| US EPA marine chronic criteria | 24.30 | 211.45 | 0.77 | 7419 |
| US EPA marine acute criteria | 1.41 | 211.45 | 0.17 | 70.66 |

## Heavy Metals in Groundwater in Comparison to Standards

Metals in groundwater were found to be lower compared to leachate (G<L) with higher concentrations for total Cu and Pb. The noticeable levels of these metals can be accounted from the groundwater movements. Study conducted in Malaysia reported detectable Cd and Pb levels in selected groundwater sites even at depths 21-25 m below ground surface (*Samuding et al. 2009*).

Levels of Pb in groundwater failed to meet national (PNSDW) and WHO regulations. Obtained result indicates potential percolation of leachate Pb constituent to studied groundwater stations. Alarmingly, Pb may bring effects to neurological, reproductive, and hematopoietic ill effects upon entering in the metabolic pathways (*Williams et al. 2000*).

On the other hand, Cd levels in groundwater sites failed to meet the national (*PNSDW 2007*) and *WHO* (*2008*) standards. Levels of Cd in groundwater are of concern since it may bring toxic response if it enters the body. This metal alters the stereostructure of the enzyme, impairing catalytic activity, affecting the blood pressure, testicular tissue, and red blood cells (*Manahan 2001*). Particularly with an estimated biological half-life of 10-30 years, it tends to burden the kidneys (*Williams et al. 2000*).

The levels of Cu in all sites passed national standard (PNSDW). Common industrial uses of Cu include the manufacturing of electrical wires, water pipes, sheet metals, and alloys (*Williams et al. 2000*), which could be potential sources of Cu in leachate and in adjacent groundwater when these materials are dumped in landfills. Environmental exposure of Cu is relatively nontoxic, however, oral intake of <15 mg $kg^{-1}$ results to stomach upset and vomiting. Symptoms may include tremors, labored respiration and hemolysis, all signs of -SH binding (*Crosby 1998*).

Similarly, total Cr (0.0700 mg $L^{-1}$) failed to meet MCL (maximum concentration level) for WHO drinking water quality standard. Cr is a naturally occurring element in trivalent ($Cr^{3+}$) and hexavalent ($Cr^{+6}$) forms. Unlike $Cr^{+6}$, $Cr^{+3}$ do not bring serious damage to body tissue, since it is a requisite for animal diet and its deficiency is detrimental to the glucose and lipid metabolism in mammals. However, at higher concentration especially $Cr^{6+}$ in a water body, it may bring ill effects, considered as contact allergen and is toxic (*Hughes 1996; Manahan 2001; and Williams et al. 2000*). Distinctively once it enters the body, $Cr^{6+}$ is converted into $Cr^{3+}$ in cells and forms tightly bound adducts with DNA and proteins (*Williams et al. 2000*).

Overall, stations G1 and G2 have higher total metal concentrations located at 10 m from the CCSL compared to G3 located at approximately 30 m mean distance (**Figure 1**) from CCSL. Groundwater sites adjacent to landfills and dumpsites with close proximity are inevitably contaminated with heavy metals (*Oyeku and Eludoyin 2010*) upon percolation. Although leachate metal constituents probably migrated to the groundwater, anthropogenic sources like improper septic discharges among adjacent communities (*Longe and Balogun 2010*) must also be accounted. The groundwater sites were surrounded by settlements..

## Heavy Metals in Groundwater in Comparison to Other Landfills and Dumpsites

Relatively, Pb in CCSL was higher than the study conducted in Payatas Dumpsite, Philippines with concentration <0.015 mg $L^{-1}$ (*Su 2008*), Yemen: 0.142-0.283 mg $L^{-1}$ (*Sabahi et al. 2009*), Lagos, Nigeria: 0.05 mg $L^{-1}$(*Akoteyon et al. 2011*), and Turkey: 0.02 mg $L^{-1}$ (*Bakis and Tuncan, 2011*). However, lower compared to study of groundwater in dormant landfill in Nigeria: 3.2 ± 4.0 mg $L^{-1}$ (dry season); 1.5 ± 2.2 mg $L^{-1}$ (wet season) (*Oyeku and Eludoyin 2010*) (**Table 8**).

Table 7. Selected Heavy Metals in CCSL Groundwater Stations.

| Total heavy metal (mg $L^{-1}$) | PNSDW Standard | Groundwater stations | | | Mean ± SD | CV |
|---|---|---|---|---|---|---|
| | | G1 | G2 | G3 | | |
| Pb | 0.01 | 0.0320 | 0.0495 | 0.0299 | 0.0371 ± 0.0108 | 0.5200 |
| Cd | 0.003 | 0.0036 | 0.0033 | 0.0058 | 0.0042 ± 0.0014 | 0.8026 |
| Cu | 0.5 | 0.0124 | 0.0336 | 0.1432 | 0.0631 ± 0.0702 | 0.8059 |
| Cr | 0.1 | 0.0131 | 0.0052 | 0.0189 | 0.0124 ± 0.0069 | 0.1971 |

Table 8. Total heavy metal in CCSL groundwater compared to dormant landfills.

| Area | Heavy metals (mg $L^{-1}$) | | | | |
|---|---|---|---|---|---|
| | Pb | Cd | Cu | Cr | Reference |
| CCSL | 0.0371 | 0.0042 | 0.0631 | 0.0124 | This study |
| Payatas dumpsite, | <0.015 | <0.007 | - | <0.0199 | *Sia Su* (*2008*) |
| Philippines | - | | 0.221 | | |
| India | dry season: 3.2 | 0.010 | dry season: 1.05 | - | *Raman and Narayanan* (*2008*) |
| Nigeria | wet season: 1.5 | - | wet season: 1.01 | - | *Oyeku and Eludoyin* (*2010*) |
| Lagos, Nigeria | 0.05 | 0.04 | 3.19 | 0.01 | *Akoteyon et al.* (*2011*) |
| Yemen | 0.142-0.283 | 0.0095-0.1890 | 0.107-9.611 | 0.001-0.012 | *Sabahi et al.* (*2009*) |
| Algeria | 0.02 | - | 0.03 | - | *Bakis and Tuncan* (*2011*) |

The Cd (0.0076 ± 0.0061 mg $L^{-1}$) in CCSL was lower compared to a dormant sites in India: 0.010 mg $L^{-1}$ (*Raman and Narayanan 2008*), Lagos, Nigeria: 0.04 mg $L^{-1}$ (*Akoteyon et al. 2011*), and Yemen: 0.0095-0.1890 mg $L^{-1}$ (*Sabahi et al. 2009*) (**Table 8**).

Further, the Cu levels in groundwater sites in CCSL were still lower compared to dormant landfill studies conducted in Nigeria: 1.05 ± 0.99 mg $L^{-1}$ (dry season); 1.01 ± 1.3 mg $L^{-1}$ (wet season) (*Oyeku and Eludoyin 2010*), Lagos, Nigeria: 3.19 mg $L^{-1}$ (*Akoteyon et al. 2011*), in India: 0.521 mg $L^{-1}$ (*Raman and Narayanan 2008*) (**Table 8**).

The Cr levels in CCSL groundwater sites are found to be in conformance with studies in Lagos, Nigeria: 0.01 mg $L^{-1}$ (*Akoteyon et al. 2011*), Yemen: 0.001-0.012 mg $L^{-1}$ (*Sabahi et al. 2009*), and Payatas Dumpsite, Philippines: <0.019 mg $L^{-1}$ (Su, 2008) (**Table 8**).

## Environmental Risk Analysis of Heavy Metals Groundwater

RQ values for Cu and Cr were <1 indicating no environmental risk. However, Cd and Pb had RQ values of 1.400 and 3.71 for WHO guidelines respectively (**Table 9**). This indicated the potential risk posed by these metals in the landfill. The determined values were in agreement with the mean data (**Table 7**) in which both Cd and Pb exceeded the threshold value for drinking water guideline (*PNSDW 2007 and WHO 2005*).

## Overall Comparison of Heavy Metals in Leachate and Groundwater

Overall, the metals in leachate were significantly higher compared to groundwater (T-test p value <0.05). Leachate is a crude extract produced directly from waste degradation and precipitation dilution, thereby containing inorganic pollutants like metals. To date the studied landfill is 12 years operating when sampling was carried supposedly this age of the landfill is associated to lower leachate contaminants as a consequence of biological activity (*Faeiza et al. 2004*). However, prolong usage of the landfill hinders leachate detoxification, resulting to higher levels of metals.

Table 9. Risk quotients of studied metals in CCSL groundwater stations.

| Standard | RQ | | | |
|---|---|---|---|---|
| | Cu | Cd | Cr | Pb |
| PNSDW 2007 | 0.0485 | 0.840 | 0.124 | - |
| US EPA MCLG | 0.0485 | 0.840 | 0.124 | - |
| WHO 2005 | 0.0315 | 1.400 | 0.248 | 3.71 |

## CONCLUSION

Among the studied heavy metals Pb (0.1968 mg $L^{-1}$) and Hg (0.14838 mg $L^{-1}$) in CCSL leachate were found to exceed national standards in total form. This was also evidenced by computed RQ values of Pb and Hg >1. Similarly, groundwater adjacent to CCSL was slightly impacted with Pb (0.0371 mg $L^{-1}$) and Cd (0.0042 mg $L^{-1}$) exceeding water quality standards. These findings also coincide with calculated RQ values of Pb (3.71) and Cd (1.40) in the groundwater. Leachate from landfills brings contaminations especially to groundwater resources, which are dangerous to the health and to the entire ecological communities. It has further aggravated when the constructions of landfills are poorly managed. On the basis of the gathered data, it is recommended to contain CCSL leachate and be

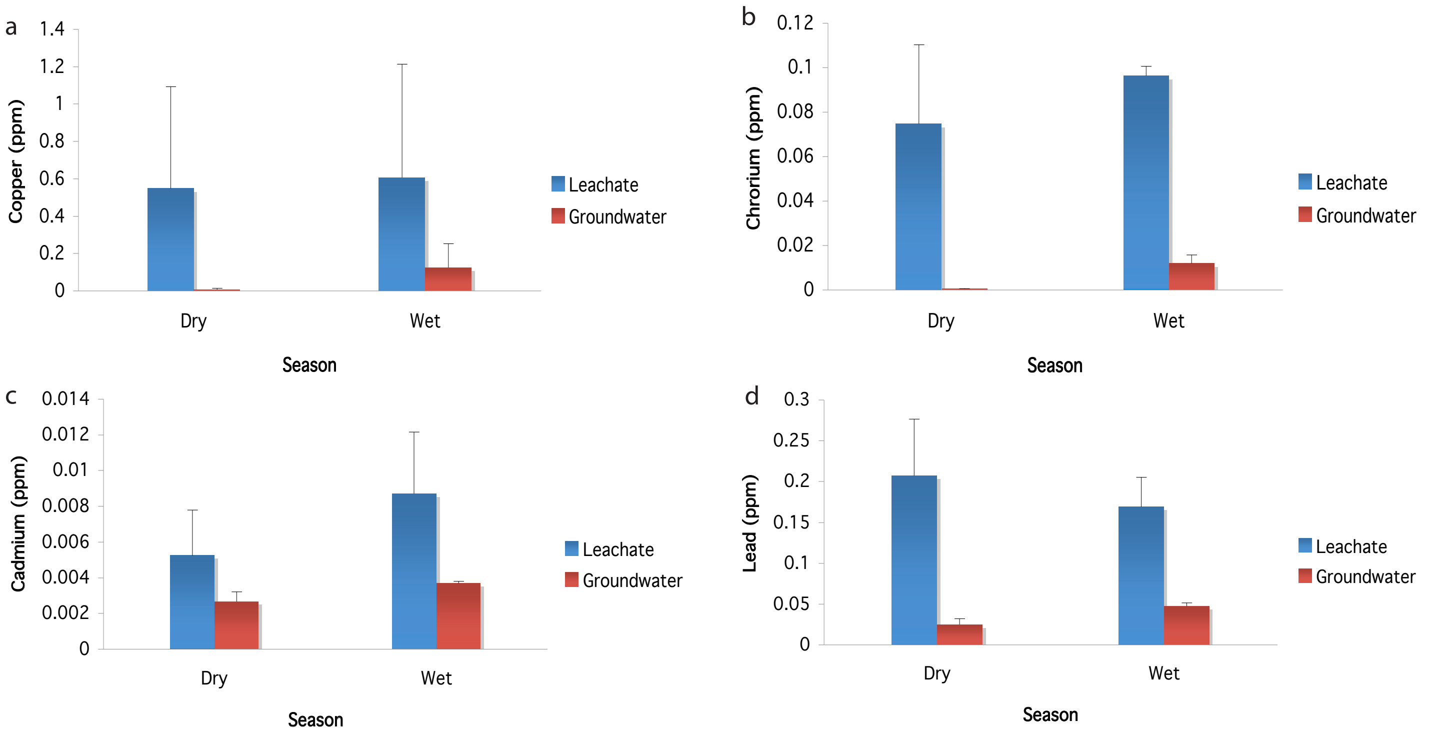


Figure 4. Overall comparison of heavy metals in leachate and groundwater a) Cu, b) Cr, c) Cd and d) Pb.

monitored prior and post closure. The groundwater must also be monitored to quantify extent of contamination by CCSL leachate.

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## ACKNOWLEDGEMENT

The researchers would like to acknowledge the Department of Science and Technology- Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD) for funding the study.