Heavy Metal Contamination in Soil and Phytoremediation Potential of Naturally Growing Plants in Bagong Silang Dumpsite, Talavera, Nueva Ecija, Philippines

Ann Jhudeil C. Santos[1*], Cynthia C. Divina[1] and Juvy J. Monserate[2]
[1]Department of Biological Sciences
[2]Nanotechnology R&D Facility
Central Luzon State University
Science City of Muñoz, Nueva Ecija 3120 Philippines
[*]*annjhudeilsantos@gmail.com*

Date received: June 14, 2020
Revision accepted: March 26, 2021

Abstract

This study determined the heavy metal concentration of soil of Bagong Silang dumpsite and screened the phytoremediation potential of naturally occurring plants in the area. The concentrations of the heavy metals on soil and plant samples were determined using inductively coupled plasma mass spectrometry. Soil analysis showed that lead (Pb) and chromium (Cr) exceeded the permissible level accepted by the United States Environmental Protection Agency (USEPA) regulatory standards for heavy metals in residential and industrial soil. Ipomoea aquatica, Chloris barbata and Cynodon dactylon were the most dominant plant species present in the dumpsite area. In terms of heavy metal uptake in shoots, C. dactylon was the most efficient in accumulating Pb and Cr, while C. barbata and I. aquatica for arsenic (As) and cadmium (Cd) accumulations, respectively. In terms of heavy metal uptake in roots, I. aquatica was the best in accumulating almost all the heavy metals tested except Pb. Meanwhile, I. aquatica has the capacity of As and Cd phytostabilization (BCF >1) and C. barbata of Cd phytostabilization. In this study, only I. aquatica showed an enrichment factor of greater than 1 (Cd = 1. 17). The findings of the present study showed that the Bagong Silang dumpsite is contaminated with Pb and Cr. The study also revealed that C. dactylon was an efficient translocator of heavy metals in the shoots, while I. aquatica and C. barbata were most efficient in stabilizing heavy metals in the roots. However, supplementary analysis must be done to substantiate the potential of I. aquatica, C. barbata and C. dactylon as phytoremediators of heavy metals.

Keywords*: heavy metals, phytostabilization, bioconcentration factor, translocation factor, enrichment factor*

1. Introduction

The rapidly increasing population coupled with fast industrialization growth causes serious environmental problems, such as accumulation and release of considerable quantities of toxic waste materials into the environment (Zhuang *et al*., 2007). Soil contamination by heavy metals as a result of anthropogenic activities is one of the major environmental concerns all over the world. Solid waste disposals such as dumpsites represent a significant source of heavy metals released into the environment (Kanmani and Gandhimathi, 2013). Dumpsite is an old traditional method of waste disposal similar to landfill method of waste management and is often established in disused quarries, mining, or excavated pits away from the residential areas (Abdus-Salam, 2009). Improper dumpsite management could lead to adverse environmental impacts such as leachate that possibly contains toxic heavy metals that pollute the underground soil bed (Shittu *et al*., 2015). According to Ali *et al*. (2014), open dumpsites are common in developing countries like the Philippines because of the low budget allotted for waste disposal management and the non-availability of trained manpower. The common heavy metals present in dumpsites are arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), iron (Fe), mercury (Hg), manganese (Mn), lead (Pb), nickel (Ni), and zinc (Zn) (Olayiwola *et al*., 2017). The presence of these heavy metals in the environment has a great ecological impact due to certain reasons including toxicity, translocation through food chains and non-biodegradability, which are responsible for their accumulation in the biosphere according to Aekola *et al*. (2008) as cited in Jyothi *et al*. (2017).

To lessen the toxic effects of heavy metals, certain practices such as chemical and physical applications and agronomical crop management have been used with a bit of success. Similarly, exogenous application of osmolytes such as proline, glycine betaines and polyamines among others has also been used to induce the capability of plants to fight the detrimental effects of heavy metals toxicities (Singh *et al*., 2015). However, these methods have serious limitations, such as high cost, irreversible changes in soil properties, destruction of native soil microflora and creation of secondary pollution problems (Jutsz and Gnida, 2015). In contrast, an alternative method is phytoremediation. This method, which has gained greatest interest recently, relies on the use of plants and their associated rhizospheres to degrade, stabilize and/or remove soil contaminants (Pinto *et al*., 2014). As compared with other methods, phytoremediation is more environmentally friendly and at the same time a low-cost technology that can be used to decontaminate soils, water and sediments holding organic compounds and/or metals (Gerhardt *et al.*, 2009; Kramer, 2010). According to Jutsz and Gnida (2015), plants thriving under heavy metal contaminated soil like dumpsite soils have developed several adaptation strategies such as tolerance to high concentrations of toxic compounds; ability to assimilate and accumulate toxic substances in plant organelles; and conversion of toxic substances present in the environment into non-toxic compounds. These plants grown in land polluted areas can absorb heavy metals in the form of mobile ions present in the soil through their roots or foliar absorption. These absorbed metals accumulate in plant parts such as roots, stems, fruits, grains, and leaves (Fatoki, 2000).

At present, there are no available data about the status of Bagong Silang dumpsite in terms of heavy metal contamination in the soil. Moreover, there are no previously conducted studies on the phytoremediation potential of the naturally growing plants in the said area. Therefore, this study aimed to determine the concentration of Pb, As, Cr, Cd and Hg in the soil and evaluate the phytoremediation potential of the plants growing in Bagong Silang dumpsite in Talavera, Nueva Ecija, Philippines.

2. Methodology

2.1 Study Site Location and Description

The study site is located at Barangay Bagong Silang, Talavera, Nueva Ecija, Philippines (Figure 1). The study area is approximately 500 m^2 and is located at N 15° 38” 37.8” and E 120°54”11.0” with an elevation of 61 m above sea level (masl). The dumpsite was characterized and described based on the types of wastes present. The plants naturally occurring in the dumpsite area were observed and recorded. The coordinates and elevation of the study area were also determined using Garmin e-Trex geographical positioning system (GPS).

Currently, the Municipal Environment and Natural Resources Office (MENRO) of Talavera is mandated to expedite the establishment and completion of a sanitary landfill in compliance with the Republic Act No. 9003 or the Ecology Solid Waste Management Act of 2000 on the formulation and implementation of ecological solid waste management plans and programs to ensure the protection of the environment and general welfare of its constituents. Bagong Silang dumpsite hosts wastes from the barangays of Talavera, such as household, market, agricultural, and industrial wastes among others. The dumpsite area generally consists of wastes including scraps of paper, plastics, metals, used tires, textile products, styrofoams, tin cans and glass. (Figure 2).

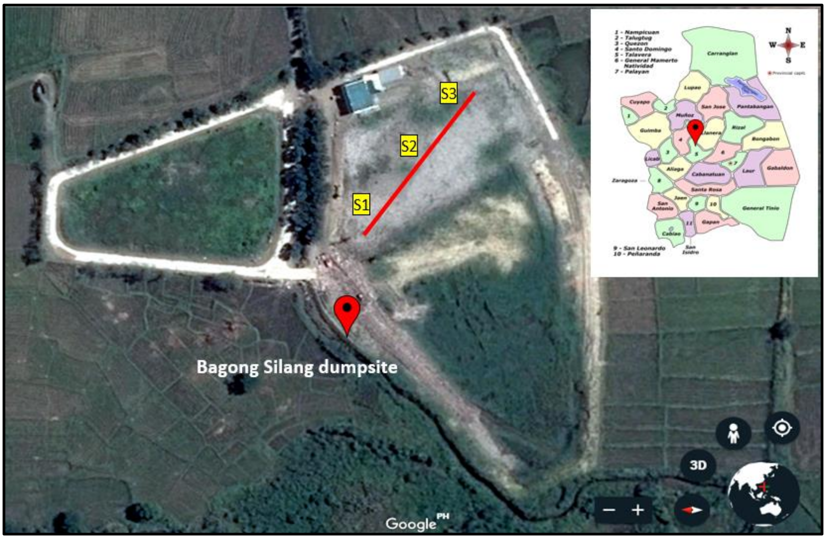


Figure 1. Satellite Map of Barangay Bagong Silang, Talavera, Nueva Ecija in indicating the location of the sampling stations (S1, S2 and S3).

Figure 2. Solid wastes present in Bagong Silang dumpsite

2.2 Soil Sample Collection and Preparation

The collection of samples was done in March 2019 following the process of Lorestani *et al*. (2012) with minor modifications. Using a transect, three stations (S1, S2 and S3) were established diagonally along the dumpsite area:

two from the opposite sides and one from the center (Figure 1). From each station, three samples were randomly collected at a depth of 0-20 cm from the soil surface. All samples from the three stations were bulked together to form composite samples. Soil samples were air-dried for seven days and were homogenized by sieving them through a 0.5 mm mesh-sized stainless steel sieve. Composite samples were weighed to the amount required for heavy metal analysis.

2.3 Plant Sample Collection and Preparation

The vegetation in the area comprises primarily of weeds, herbaceous trailing vines and few bushes. The adjacent areas around the dumpsite (approximately 15-20 meters away from the dumpsite) are planted with rice. The three most dominant and evenly distributed plant species observed in the dumpsite were selected for the collection. The collection was done at the established three stations. Three replicate samples were purposively collected from each location within the area of 4.0 m^2. Samples were chosen based on the availability at each point of collection and uniformity of their growth. The whole plant parts were uprooted and transported in a properly labeled plastic bag. Collected plants were washed with running tap water three times to remove soils adhering to the roots and shoots and were air-dried for seven days. Air-dried plant samples were divided into two parts: the root system and shoot system. The plant parts were mixed to form a composite sample and were ground using a blender.

2.4 Soil and Plant Sample Analysis

Dried and homogenized soil and plant samples were sent to Intertek Testing Services Philippines, Inc. in Muntinlupa City, Philippines for the analysis of heavy metal concentration. Studied heavy metals in the dumpsite soil included Pb, As, Cd, Cr, and Hg. The same list of heavy metals were determined in the roots and shoots of the plant samples except for Hg. Total heavy metal contents were extracted using aqua regia digestion and were measured using inductively coupled plasma mass spectrophotometry (ICP-MS) (Agilent 7700, United States).

Moreover, the collected plants were identified by a weed expert at the Crop Protection Division of the Philippine Rice Research Institute – Central Experimental Station (PhilRice – CES). The plants were identified as the following: *Ipomoea aquatica* (common name: Kangkong), *Chloris barbata* (common name: Swollen finger grass), and *Cynodon dactylon* (common name: Bermuda grass).

2.5 Data Analysis

The bioconcentration factor (BCF) (Equation 1) – the ratio of metal concentration in the roots to the soil – was computed to evaluate the mobility of the heavy metals from the contaminated soils into the roots of the plants (Yoon *et al.*, 2006). The translocation factor (TF) (Equation 2) – the ratio of metal concentration in the shoots to the roots – was used to determine the ability of plants to translocate the metals from the roots to the aerial part/shoot system (Yoon *et al*., 2006). The enrichment factor (EF_{plant}) (Equation 3) – the ratio of plant shoot concentration to soil concentration – is the mobility of the heavy metals from the contaminated soil into the shoot of the plant (Ghosh and Singh, 2005).

$$BCF = \frac{Metal\ concentration\ in\ roots\ (ppm)}{Metal\ concentration\ in\ soil\ (ppm)} \qquad (1)$$

$$TF = \frac{Metal\ concentration\ in\ shoots\ (ppm)}{Metal\ concentration\ in\ roots\ (ppm)} \qquad (2)$$

$$EF_{plant} = \frac{Metal\ concentration\ in\ shoots\ (ppm)}{Metal\ concentration\ in\ soil\ (ppm)} \qquad (3)$$

According to Yoon *et al.* (2006), the plant's ability to tolerate and accumulate heavy metals is beneficial for phytoextraction and phytostabilization purposes. If the plant has both bioconcentration and translocation factors greater than one (BCF and TF > 1), it has the potential to be used in phytoextraction. Also, plants with a bioconcentration factor greater than one and translocation factor less than one (BCF > 1 and TF < 1) have the potential to stabilize heavy metals (Yoon *et al.*, 2006). In hyperaccumulation, the metal concentration in the above-ground biomass and the soil are both taken into consideration, which means that enrichment factor (EF), as well as translocation factor (TF), have to be considered while evaluating whether a certain plant is a metal hyperaccumulator (Ma *et al.*, 2001). A hyperaccumulator plant should have an EF or TF greater than one as well as total accumulation of greater than 1000 mg kg^{-1} of Cu, Co, Cr, Ni, or Pb, or greater than 10000 mg kg^{-1} of Fe, Mn or Zn.

3. Results and Discussion

The concentrations of heavy metals present in the dumpsite soil are presented in Table 1. The results of soil analysis showed that among the 5 tested heavy metals, Cr had the highest concentration in soil (69.6386 ppm), followed by Pb (13.8699 ppm), As (2.6309 ppm) and Cd (0.2576 ppm). On the other hand, Hg had the lowest concentration in soil (0.0343 ppm). A comparison of the obtained data from the available standard from the United States Environmental Protection Agency (USEPA) showed that Pb and Cr exceeded the permissible level for both residential and industrial soil. Pb concentration in the dumpsite soil was 42.32-71.16% higher than the allowable concentration. Moreover, Cr concentration in Bagong Silang dumpsite highly exceeded the maximum permissible concentration (USEPA). Other heavy metals including As, Cd, and Hg were within the acceptable range. Thus, they do not pose a serious threat to the environment. The concentrations of metals in the soils collected from the dumpsite can be ordered as Cr > Pb > As > Cd > Hg.

Table 1. Comparison of Bagong Silang Dumpsite soil heavy metal concentrations to the USEPA regulatory standards for heavy metals in residential soil and industrial soil

Heavy metal	Concentration (ppm)		
	Permissible level for residential soil	Permissible level for industrial soil	Bagong Silang dumpsite soil
Lead (Pb)	4.0	8.0	13.8699*
Arsenic (As)	6.8	3.0	2.6309
Cadmium (Cd)	7.1	9.8	0.2576
Chromium (Cr)	3.0	6.3	69.6386*
Mercury (Hg)	1.1	4.6	0.0343

*exceeding the permissible level

The study of Cortez and Ching (2014) in a closed dumpsite in Tondo, Manila obtained almost the same Pb (15.465 ppm) and Cd (0.167 ppm) concentrations. According to Xintaras (1992), the main sources of Pb poisoning in our environment include lead paint and old gasoline spills resulting in dust and soil contamination of food and water, which can cause severe health effects at relatively low levels of exposure. Sources of Cr, on the other hand, include cement dust, asbestos lining erosion and contaminated landfill and dumpsites.

The heavy metal concentrations in plants varied with plant species. Results of heavy metal analysis in the shoot system of the collected plants showed that *I. aquatica* accumulates Cr in the highest amount (1.6017 ppm) (Table 2). The total Pb, As, and Cd concentrations in *I. aquatica* shoots were 0.7834, 0.6671, and 0.3022 ppm, respectively. In *C. barbata*, Cr had also the highest concentration among the four tested heavy metals with a concentration value of 1.8270 ppm. It was followed by As (0.8534 ppm) and Pb (0.6252 ppm). The least accumulated heavy metal in *C. barbata* shoots was Cd (0.1524 ppm).

Table 2. Heavy metal concentration in the shoots of naturally growing plants in Bagong Silang dumpsite

Scientific name	Heavy metal concentration (ppm)			
	Pb	As	Cd	Cr
Ipomoea aquatic	0.7834	0.6671	0.3022	1.6017
Chloris barbata	0.6252	0.8534	0.1524	1.8270
Cynodon dactylon	5.3155	0.6932	0.0920	2.7404

For heavy metal concentration in the shoots of *C. dactylon*, Pb was accumulated in the highest amount (5.3155 ppm) followed by Cr (2.7404 ppm). The concentrations of As and Cd on *C. dactylon* shoots were 0.6932 and 0.0920 ppm, respectively. In terms of heavy metal uptake efficacy, among the three plants, *C. dactylon* was observed to be the most efficient in accumulating Pb and Cr. On the other hand, *C. barbata* showed the best performance in terms of As accumulation, while *I. aquatica* was best in Cd accumulation. These results suggest that the accumulation efficacy of each plant was only specific to a certain heavy metal.

Table 3 shows the heavy metal concentration in the roots of *I. aquatica*, *C. barbata* and *C. dactylon*. In *I. aquatica*, results showed that Cr was accumulated in the highest amount (8.3265 ppm) followed by As (4.5825 ppm) and Pb (4.4897 ppm). Cd concentration was the lowest at 0.3660 ppm. In *C. barbata*, Cr was also accumulated in the highest concentration (5.5507 ppm). The concentrations of Pb, As and Cd in the roots of *C. barbata* were observed to be 4.5680, 2.2725, and 0.3325 ppm, respectively. Similarly, *C. dactylon* had a total Cr concentration of 3.9242 ppm, which was the highest among the tested heavy metals. Other metals such as Pb, As, and Cd had concentrations of 1.0027 ppm, 0.8681 ppm, and 0.0720 ppm, respectively. Higher uptake of heavy metals in the roots as compared to the shoots was generally observed in *I. aquatica* and *C. barbata* which indicates possible phytostabilization potential. However, *C. dactylon* exhibited higher uptake of metals in shoots than in roots which indicates that *C. dactylon* is more efficient in translocating heavy metals rather than stabilizing them in its root system.

Table 3. Heavy metal concentration in the roots of naturally growing plants in Bagong Silang dumpsite

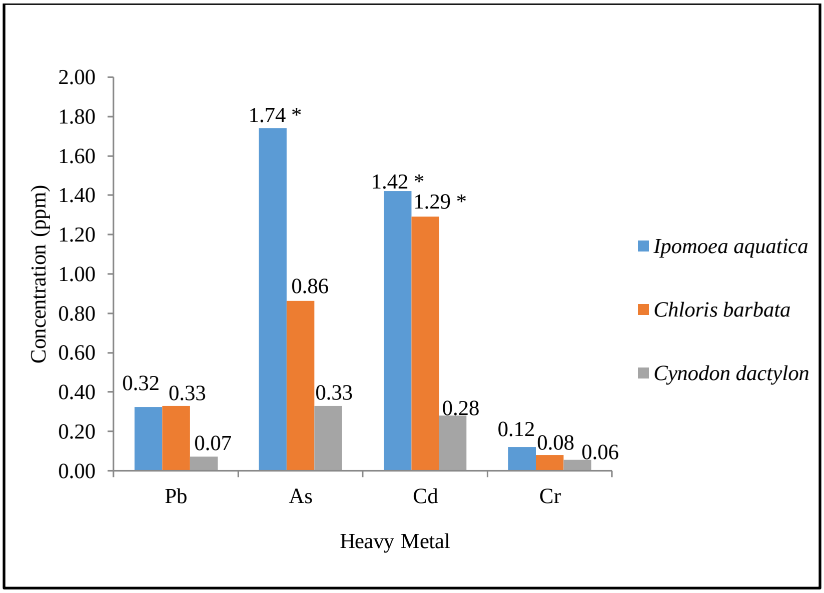
Scientific name	Heavy metal concentration (ppm)			
	Pb	As	Cd	Cr
Ipomoea aquatica	4.4897	4.5825	0.3660	8.3265
Chloris barbata	4.5680	2.2725	0.3325	5.5507
Cynodon dactylon	1.0027	0.8681	0.0720	3.9242

A comparison among plants showed that *I. aquatica* was the most efficient in accumulating heavy metals. The highest concentration was recorded in *I. aquatica* in almost all heavy metals tested except for Pb. *C. barbata* exhibited the highest uptake of Pb with a concentration value of 4.5680 ppm.

The ability of a plant to accumulate heavy metals from the soil can be assessed using the bioconcentration factor (BCF). The phytoextraction process involves the translocation of heavy metals to the parts of the plant that can be easily harvested (i.e., shoots) (Yoon *et al*., 2006), while the phytostabilization process entails the strong ability of the plant to reduce metal translocation from roots to shoots (Deng *et al*., 2004). Yoon *et al*. (2006) reported that by evaluating the BCF and TF, the ability of various plants to take up metals from the soil and translocate them to the shoots can be compared. Plants with both bioconcentration factor and translocation factor of greater than one have the potential to be used in phytoextraction. Moreover, the plant has the potential for phytostabilization if its bioconcentration factor is greater than one and its translocation factor is less than one (Yoon *et al*., 2006).

As shown in Figures 3 and 4, none among the sampled plants was suitable for phytoextraction since all of them did not reach both BCF and TF values that are greater than one. However, *I. aquatica* was found to have the capability of As and Cd phytostabilization with BCF of 1.7418 for As and 1.4208 for Cd. On the other hand, BCF of Pb and Cr was less than one. Therefore, *I. aquatica* cannot stabilize these heavy metals. Similarly, *C. barbata* had also the capability to stabilize Cd with BCF of 1.2908. On the other hand, results showed that *C. dactylon* did not stabilize any of the 4 studied heavy metals.

The highest BCF exhibited by *C. dactylon* was in As (0.3300), which is still far from the acceptable value to be considered as a phytostabilizer.

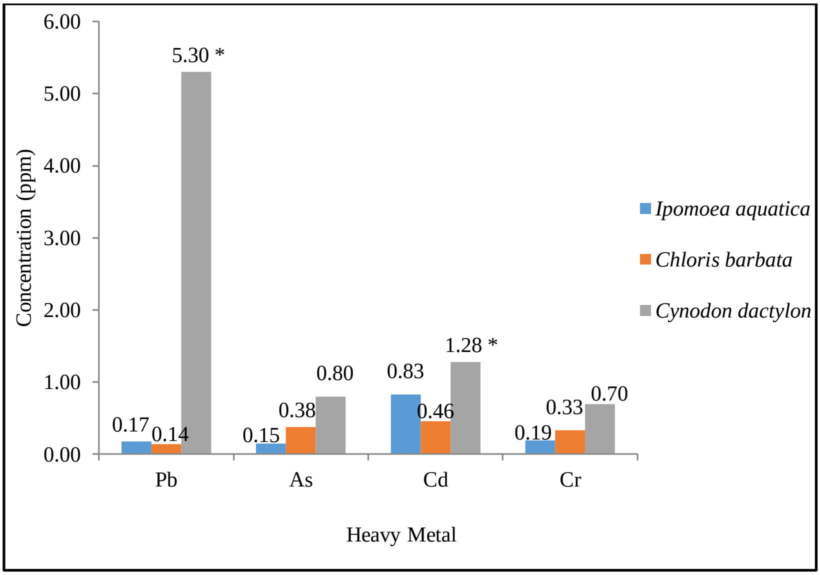


*Values > 1

Figure 3. BCF of Pb, As, Cd, and Cr in naturally growing plants in Bagong Silang dumpsite

A plant's ability to translocate metals from the roots to the shoots was measured using the TF. Results showed that both *I. aquatica* and *C. barbata* exhibited low translocation property since the translocation factor of all heavy metals studied was less than one. *C. dactylon*, on the other hand, had a Pb translocation factor of 5.3012 and a Cd translocation factor of 1.2778. Based on these results, it could be inferred that *I. aquatica* and *C. barbata* were best suited for phytostabilization, while *C. dactylon* was more efficient in translocating heavy metals to its above-ground parts.

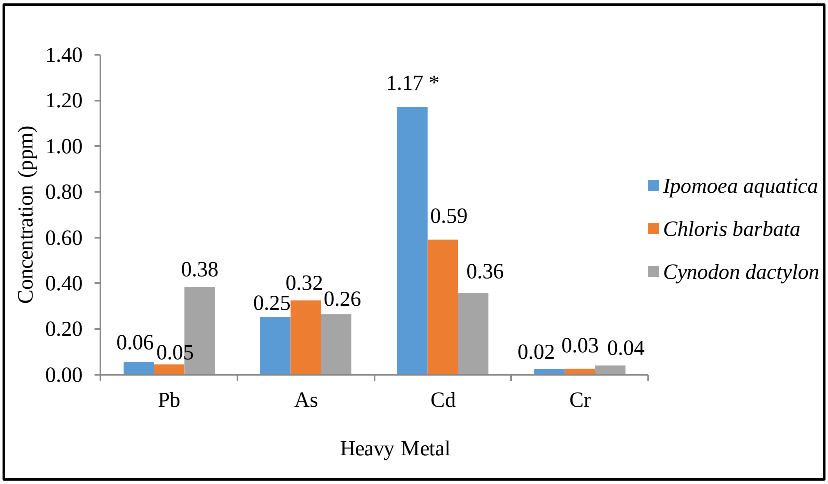
Translocation factor greater than one implies high mobility of heavy metals from the source to the receiving level. This indicates the strong ability of the plant to transport metals from roots to shoots and, most possibly, the presence of tolerance mechanisms to survive high concentrations of metals. A similar study of Shittu *et al.* (2015) about heavy metals uptake by plant around Nigeria showed that Pb, Zn and Mn exhibited high mobility or translocation potentials in all the sampled plants' parts. Shittu *et al*. (2015) reported that the results they gathered is an indication that the plants' roots can solubilize and take up heavy metals from very low levels in the soil, even from nearly insoluble precipitates. Hence, they concluded that the sampled plants were suitable as phytostabilizers.



*Values > 1

Figure 4. TF of Pb, As, Cd and Cr in naturally growing plants in Bagong Silang dumpsite

The enrichment factor was calculated as the ratio of plant shoot concentration to soil concentration. In this study, only *I. aquatica* showed an enrichment factor of greater than 1 (Cd = 1. 17) (Figure 5). This means that there is a higher Cd concentration in *I. aquatica* than in the soil, which emphasizes its efficacy of metal uptake. A similar study by Lorestani *et al*. (2012) tested the phytoremediation potential of naturally occurring plants in heavy metal contaminated soil, wherein the results showed that none of the collected plant species were suitable for phytoextraction of Cu, Zn, Fe and Mn. However, among the plants, *Euphorbia macroclada* was the most efficient in phytostabilization of Cu and Fe, while, *Ziziphora clinopodioides*, *Cousinia* sp. and *Chenopodium botrys* were the most suitable for phytostabilization of Zn and *Chondrila juncea*. *Stipa barbata* had the potential for phytostabilization of Mn.



*Values > 1

Figure 5. EF_{plant} of Pb, As, Cd, and Cr in naturally growing plants in Bagong Silang dumpsite

4. Conclusion and Recommendation

The present study reported that the Bagong Silang dumpsite is contaminated with Pb and Cr as it exceeded the permissible level accepted by the USEPA. *I. aquatica* and *C. barbata* exhibited higher concentration uptake of heavy metals in the roots than in the shoots. However, *C. dactylon* exhibited higher uptake of metals in shoots than in roots which indicates that it is more efficient in translocating heavy metals rather than stabilizing them in its root system. Also, *I. aquatica* can phyto-stabilize As and Cd. *C. barbata* also exhibited Cd phytostabilization. Moreover, *C. dactylon* was highly efficient in accumulating Pb and Cd from the soil and translocating them to its above-ground parts. Therefore, harvesting them is one possible mode of heavy metal removal in the dumpsite. In the case of *I. aquatica* and *C. barbata*, heavy metals were stabilized in the roots, and their accumulation in the shoots was very low. This will help reduce the spread of heavy metals through herbivores.

Since this study was able to test only certain heavy metals, determination of other heavy metal concentrations such as Zn, Mn and Co among others both in the soil and in naturally occurring plants in the dumpsite is recommended. Future studies could also look into the physiological mechanisms of the plants thriving in the contaminated dumpsite to provide better evidence of phytoremediation potential. Lastly, analysis of heavy metal concentration in the rice paddies adjacent to the dumpsite area is also recommended.

5. Acknowledgement

The authors would like to acknowledge the Department of Science and Technology – Accelerated Science and Technology Human Resource Development Program (DOST – ASTHRDP) for the financial support.

6. References

Abdus-Salam, N. (2009). Assessment of heavy metals pollution in dumpsites in Ilorin Metropolis. Ethiopia Journal of Environmental Studies and Management, 2(2), 92-99. https://doi.org/10.4314/ejesm.v2i2.45926

Ali, S.M., Pervaiz, A., Afzal, B., Hamid, N., & Yasmin, A. (2014). Open dumping of municipal solid waste and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad city. Journal of King Saud University – Science, 26(1), 59- 65. https://doi.org/10.1016/j.jksus.2013.08.003

Cortez, L.A.S., & Ching, J.A. (2014). Heavy metal concentration of dumpsite soil and accumulation in *Zea mays* (corn) growing in a closed dumpsite in Manila, Philippines. International Journal of Environmental Science and Development, 5(1), 77-80. https://doi.org/10.7763/IJESD.2014.V5.454

Deng, H., Ye, Z.H., & Wong, M.H. (2004). Accumulation of lead, zinc, copper, and cadmium by 12 wetland plant species thriving in metal-contaminated sites in China. Environmental Pollution Journal, 132(1), 29-40. https://doi.org/10.1016/j.envpol.2004.03.030

Fatoki, O.S. (2000). Trace zinc and copper concentrations in roadside vegetation and surface soils: A measurement of local atmospheric pollution in Alice, South Africa. International Journal of Environmental Studies, 57, 501-513. https://doi.org/10.1080/00207230008711293

Gerhardt, K.E., Huang, X.-D., Glick, B.R., & Greenberg, B.M. (2009). Phytoremediation and rhizoremediation of organic soil contaminants: Potential and challenges. Plant Science, 176, 20-30. https://doi.org/10.1016/j.plantsci.2008.09.014

Ghosh, M., & Singh, S.P. (2005). A comparative study of cadmium phytoextraction by accumulator and weed species. Environmental Pollution 133, 365-371. https://doi.org/10.1016/j.envpol.2004.05.015

Jyothi, M, Srinivasarao D., Swarnalatha G., & Sudhakar G. (2017). Assessment of heavy metals content in surface and sub-surface soil samples in waste dumpsites of

Guntur, Andhra Pradesh. International Research Journal of Engineering and Technology (IRJET), 4(3), 2420-2424.

Kanmani, S., & Gandhimathi, R. (2013). Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. Applied Water Science, 3, 193-205. https://doi.org/10.1007/s13201-012-0072-z

Kramer, U. (2010). Metal hyperaccumulation in plants. Annual Review of Plant Biology, 61, 517-534. https://doi.org/10.1146/annurev-arplant-042809-112156

Lorestani, B., Cheraghi, M., & Yousef, N. (2012). The potential of phytoremediation using hyperaccumulator plants: A case study at a lead-zinc mine site. International Journal of Phytoremediation, 14(8), 786-795. https://doi.org/10.1080/15226514.2011 .619594

Ma, L.Q., Komar, K.M., Tu, C., Zhang, W., Cai, Y., & Kennelley, E.D. (2001). A fern that hyper accumulates arsenic. Nature, 409, 579. https://doi.org/10.1038/35078151

Olayiwola, H.A., Abudulawal, L., Adewuyi, G.K., Azeez, M.O., & Eludoyin, O. (2010). Heavy metal contents in soil and plants at dumpsites: A case study of Awotan and Ajakanga dumpsite Ibadan, Oyo State, Nigeria. Journal of Environment and Earth Science, 7(4).

Pinto, E., Ana, A.R., Aguiar, M., Isabel, M.P.L., & Ferreira, V.O. (2014). Influence of soil chemistry and plant physiology in the phytoremediation of Cu, Mn, and Zn. Critical Reviews in Plant Sciences, 33(5), 351-373. https://doi.org/10.1080/07352 689.2014.885729

Shittu, O.S., Ayodele, O.J., Ilori, A.O., & Obe, B.V. (2015). Monitoring of selected heavy metals uptake by plant around Fagbohun dumpsite, Ikere-Ekiti, Ekiti State, Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), 9(11), 85-91.

Singh, M., Kumar, J., Singh, S., Singh, V.P., & Prasad, S.M. (2015). Adaptation strategies of plants against heavy metal toxicity: A short review. Biochemistry & Pharmacology, 4(2).

Xintaras, C. (1992). Analysis paper: Impact of lead-contaminated soil on public health. Retrieved from http://www.atsdr.cdc.gov/cxlead.html.

Yoon, J., Cao, X., Zhou, Q., & Ma, L. Q. (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Science of the Total Environment, 368(2-3), 456-464. https://doi.org/10.1016/j.scitotenv.2006.01.016

Zhuang, X., Chen, J., Shim, H., & Bai, Z. (2007). New advances in plant growth-promoting Rhizobacteria for bioremediation. Environment International, 33, 406-413. https://doi.org/10.1016/j.envint.2006.12.005