JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
ISSN: 2339-076X, Volume 2, Number 3 (April 2015): 341-346
DOI:10.15243/jdmlm.2015.023.341

Research Article

Selection of mercury accumulator plants for gold mine tailing contaminated soils

N. Muddarisna [1*], B.D. Krisnayanti [2]

[1] Wisnuwardhana University, Jl. Danau Setani No 99, Malang 65139, Indonesia
[2] Faculty of Agriculture, University of Mataram, Jalan Pendidikan No 37 Mataram, Indonesia

* corresponding author: nurulmuddarisna@yahoo.co.id

Abstract: Phytoremediation, which is more efficient with less side effects than conventional physical and chemical methods, is increasing in popularity as a remediation system. This paper provides a brief overview of developments in research and application of phytoremediation of soil contaminated with gold mine tailings containing mercury. *Lindernia crustacea* L., *Digitaria radicosa* Presl. Miq., *Zingiber purpurium* L, *Paspalum conjugatum* Berg., *Cyperus kyllingia* Endl., and *Caladium bicolor* Vent., that were selected for this study were planted in the planting media consisting of soil (70%) and tailings (30%) for 9 weeks. The results showed that after 9 weeks of planting, *Paspalum conjugatum* had growth rate, biomass production, Hg accumulation, and ratio of shoot Hg : root Hg higher than those of other plant species tested, both in the media consisted of amalgamation and cyanidation tailings. It can thus be concluded that *Paspalum conjugatum* is potential plant species for remediating mercury-contaminated soil.

***Keywords**: amalgamation tailing, cyanidatio tailing, mercury, phytoremediation*

Introduction

Continuous efforts have been made to develop a technology that is easy to use, sustainable and economical, in order to maintain good quality of soil and water and keep them free of contamination (Nedelkoska and Doran, 2000; Lone et al., 2008). Physicochemical approach has been widely used to remediate contaminated soil and water on a small scale (Lone et al., 2008). Use of certain plant species to clean up contaminated soil and water that is known as phytoremediation has increasingly gained attention since the last decade as a new cheap technology.

Various plant species have been identified and tested for their ability in uptake and accumulation of a variety of different heavy metals (Lone et al., 2008). To date, more than 400 species have been identified as metal accumulator, representing less than 0.2% of all Angiospermae (Brooks et al., 1998; Baker et al., 2000; Lone et al., 2008), such as *Pteris vittata*that is able to accumulate 755 mg/g As (Ma et al., 2001), *Thlaspi caerulencens*that is able to accumulate more than 3% Zn, 0.5% Pb and 0.1% Cd (Brown et al., 1994; Pulford and Watson, 2003), can remove 60 kg Zn/ha and 8.4 kg Cd/ha in soil contaminated with metals (Robinson et al., 1998), and *Alyssum sp*. that accumulates more than 1% Ni (Brooks et al., 1979).

Activities of Artisanal and Small-Scale Gold Minings (ASGM)are expected to affect the quality of environment, including soil contaminated by mercury. The use of mercury in ASGM activities is an effective technology, easy, inexpensive and available in the market. Each gram of gold produced is estimated to discharge1-2 g of mercury into the environment. Based on this assumption, globally each year 1,000 t of mercury is discharged into the environment in which 300 t evaporates into the atmosphere and 700 t contaminates soil, rivers and lakes (Speigel and Veiga, 2010).Thus, mercury accumulator plants can offer alternative methods for removing heavy metals from the soil directly on ASGM locations such as in Sekotong District of West Lombok. Selection of plant species that are tolerant to metallic element is a key to a successful remediation of degraded mining lands (Mukhopadyay and Maiti, 2010). The use of some species, such as *Lindernia crustacea*, *Digitaria radicosa*, *Zingiber purpureum*, *Paspalum conjugatum*, *Cyperus kyllingia* and *Caladium bicolor* is expected to clean up mercury from soil. However, in order to assess the feasibility of mercury-contaminated soil phytoremediation, it needs to measure the relationship between environmental conditions including mercury levels in growing media, the rate of growth and metal uptake by plants. Therefore, the purpose of this study was to select plants with high levels of mercury uptake in conjunction with the ability to produce high biomass in soil contaminated with mercury.

Materials and Methods

The study was conducted at the experimental farm of the Faculty of Agriculture, University of Mataram, Lombok, West Nusa Tenggara using pots to determine the potential of some plant species to accumulate mercury from soils contaminated with gold mine tailings containing mercury. The tailings were obtained from gold ore processing units using the methods of amalgamation and cyanidation in the Sekotong District of West Lombok. Characteristics of the two types of tailings are presented in Table 1.

Table 1. Chemical characteristics of small-scalegold mine tailings at Sekotong District of West Lombok.

Analysis	A-tailings *)	C- tailings **)
pH H_2O	7.3	9.1
Organic C (%)	1.19	1.18
Total N (%)	0.001	0.006
C/N	568	2062
P-Olsen (mg/kg)	2.89	22.16
Exch K (cmol/kg)	0.001	0.058
Exch Na (cmol/kg)	0.64	1.34
Exch Ca(cmol/kg)	1.99	5.85
Exch Mg(cmol/kg)	0.84	0.39
CEC (cmol/kg)	11.57	13.34
Base Saturation (%)	31	58
Hg (mg/kg)	1090	1312
Au (mg/kg)	11.68	1.72

*) amalgamation tailings, **) cyanidation tailings

This study used a randomized block design consisting of plant species (T), tailings (L), and N fertilizer (N) factors. Tailing factor consisted of amalgamation tailings (L1) and cyanidation tailings (L2). Fertilizer factor consisted of two levels i.e. without N fertilizer (N1) and N fertilizer rate of 100 kg N/ha (N2). Six plant species used in this study were *Lindernia crustacea* L. (T1), *Digitaria radicosa* Presl. Miq. (T2), *Zingiber purpureum* (T3), *Paspalum conjugatum* Berg. (T4), *Cyperus kyllingia* Endl. (T5) and *Caladium bicolor* Vent. (T6).

Air-dried top soils that were not contaminated by the gold mine tailings were sieved to pass through a2 mm sieve and then mixed with either air-dried amalgamation tailings or cyanidation tailings with the proportion of 70% (soil) and 30% (tailings). Fifteen kilograms of each soil-tailing mixture was used as a planting medium for each plant species tested. Before planting, the compost with a rate equivalent to 100 kg N/ha was added to each planting medium. All pots were incubated for ± 1 week to keep the water content at field capacity. Basal fertilizers of 50 kg P/ ha (as SP36), and 50 kg K /ha (as KCl)were applied to each pot at the time of planting. N fertilizer (as Urea) was applied at the appropriate dose of treatment, i.e. without N fertilizer (N1) and with N fertilizer of 100 kg N/ ha (N2). Seeds of six plant species were grown in the growing media for 9 weeks. Shoot and root dry weights of each plant species were observed at the age of 3, 6 and 9 weeks after planting. Observations of mercury accumulation in plant tissues (shoot and root) were made at the time of harvest (9 weeks after planting). Mercury concentration in plant tissues was observed by using F732-S Cold Vapor Atomic Absorption Mercury Analyzer (Shanghai Huaguang Instrument Company).

Results and Discussion

Plant dry weight

Among other plant growths reflected by the increase of biomass dry weight of plants were shoots and roots. The existence of non-essential elements of heavy metals including mercury in the soil in high concentrations exceeding the threshold generally inhibits plant growth, except for plants that genetically have the ability to tolerate and adapt to stress metal elements in the soil. Certain plants develop effective mechanisms to tolerate high levels of metals in the soil. Results of tolerability test of the studied six plant species showed that all tested plant species had a high tolerance to soils contaminated with gold mine tailings containing mercury. This was demonstrated by no inhibition of plant growth and no visible signs of physical damage showing symptoms of toxicity on all tested plant species. Results of a study previously conducted by Hidayati et al. (2009) on the soil and the area around the river contaminated by gold mining tailings containing 7.73 - 22.68 mg/kg of mercury in Pongkor and Kurai of West Java, indicated that there are some plants showing a high tolerance and potentially accumulating mercury in shoots and roots to more than 20 mg/kg (exceeding the threshold of mercury concentration in plant shoots of 0.001% of total dry weight). This indicates that the tested six plant species are potential for phytoremediation of mercury-contaminated soils. The observations of shoot and root dry weight of the tested six plant species at 3,6 and 9 weeks after planting are presented in Figures 1and 2.

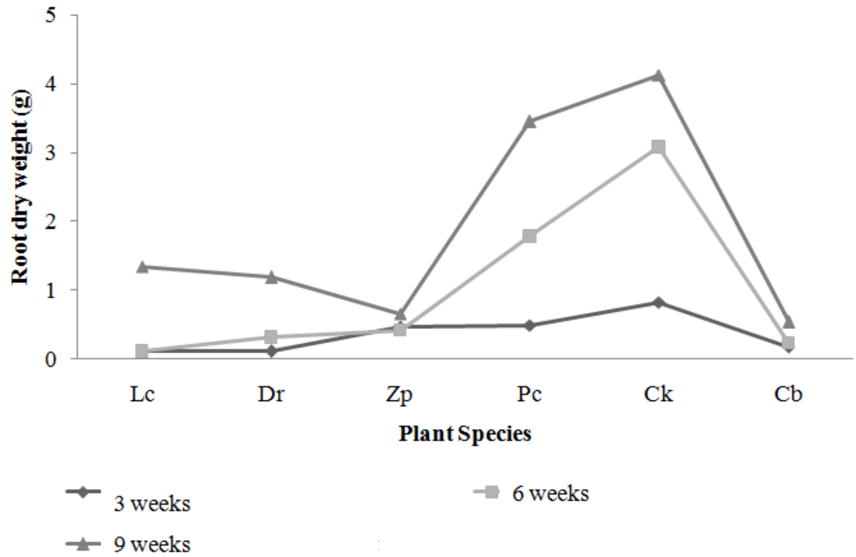

Figure1. The root dry weight of tested plant species at 3, 6 and 9 weeks. *Lc = Lindernia crustacea, Dr = Digitaria radicosa, Zp = Zingiber purpureum,Pc = Paspalum conjugatum, Ck = Cyperus kyllingia, and Cb= Caladium bicolor.*

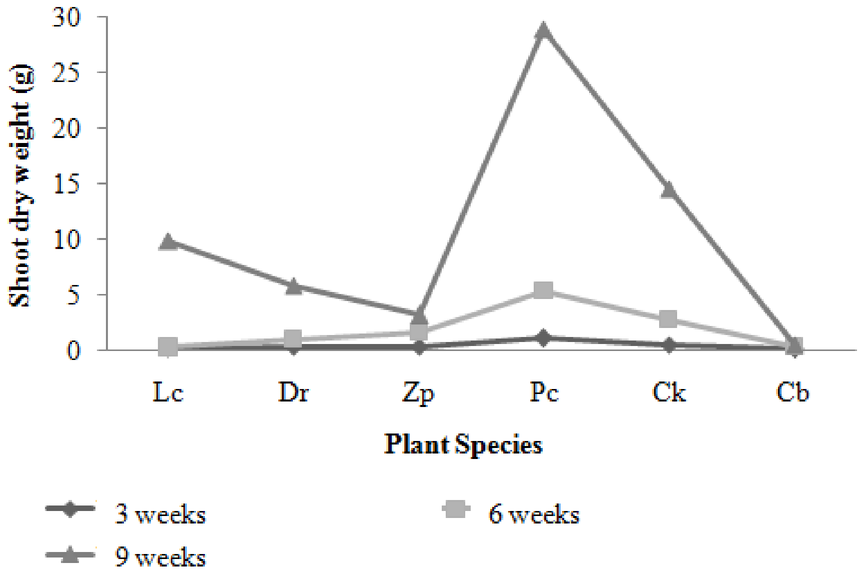

Figure 2. The shoot dry weight of tested plant speciesat 3, 6and9 weeks. *Lc = Lindernia crustacea, Dr = Digitaria radicosa, Zp = Zingiber purpureum, Pc = Paspalum conjugatum, Ck = Cyperus kyllingia,* and *Cb= Caladium bicolor.*

Based on Figure 1, the highest root dry weight generated by *Cyperus kyllingia* was not significantly different with *Paspalum conjugatum*, followed by *Digitaria radicosa*, *Lindernia* *crustacea, Zingiber purpureum*, and *Caladium bicolor*. The highests hoot dry weight generated by *Paspalum conjugatum* was not significantly different with *Cyperus kyllingia*, followed by *Digitaria radicosa, Lindernia crustacea, Zingiber purpureum* and *Caladium bicolor* (Figure 2). A plant species that can be classified as a heavy metal accumulator group must meet the criteria in order to have the ability to withstand at high concentrations of metals in the soil. The level of absorption and translocation of metals in tissues with a high rate also should ideally have a high potential for biomass production.

Mercury accumulation in shoots and roots

Mercury phytoextraction and accumulation potential of the tested six plant species at 9 weeks after planting presented in Figure 3 showed that the levels of Hg in the plant shoots ranged from 80-275 mg/kg. This exceeded the threshold value 0.001% of mercury in plant shoots. Metal accumulator plants can naturally accumulate metals exceeding the threshold value of 1% Zn and Mn, 0.1% Ni, Co, Cr, Pb and Al, 0.01% Cd and Se, 0.001% Hg or 0.0001% Au from the biomass dry weight,and tolerate higher metal concentrations in the shoots than that which is normally found in the non-accumulator plants without showing symptoms of toxicities (Brown etal., 1995; Baker and Brooks, 1989; Brooks et al., 1998; Hidayati, 2005).

Plants develop effective mechanisms to tolerate high levels of metals in the soil. Accumulator plants do not prevent the metal into the roots but to develop specific mechanisms to detoxify heavy metals in soil with high level of accumulation in the cell. This mechanism allows the bioaccumulation of metals in high concentrations. High accumulation in plant species reflects the high metal concentrations in the rhizosphere. According to Patra and Sarma (2000), there is a link between the level of heavy metal pollution in soil with absorption by plants. Elevated levels of mercury in the soil will give effect to the increase in mercury uptake by plants that will be accumulated in roots or shoots. Accumulation occurs because there is a tendency of heavy metals to form complex compounds with inorganic substances contained in the body of organisms.

The highest level of mercury was observed in the shoot of *Lindernia crustacea* followed by*Digitaria radicosa, Cyperus kyllingia, Paspalum conjugatum, Zingiber purpureum* and Caladium *bicolor* (Figure 3). This is consistent with the results reported by Hidayati et al. (2009). *Cyperus kyllingia* showed high tolerance and potentially effective mercury accumulation in roots and shoots. The mercury accumulations in the tested plant species were 89.13, 50.93, 49.33, 9.12, 1.78 and 0.77 mg/kg for *Paspalum conjugatum, Cyperus kyllingia, and Lindernia crustacea*. *Digitaria radicosa, Zingiber purpureum* and *Caladium bicolor*, respectively (Figure 4).

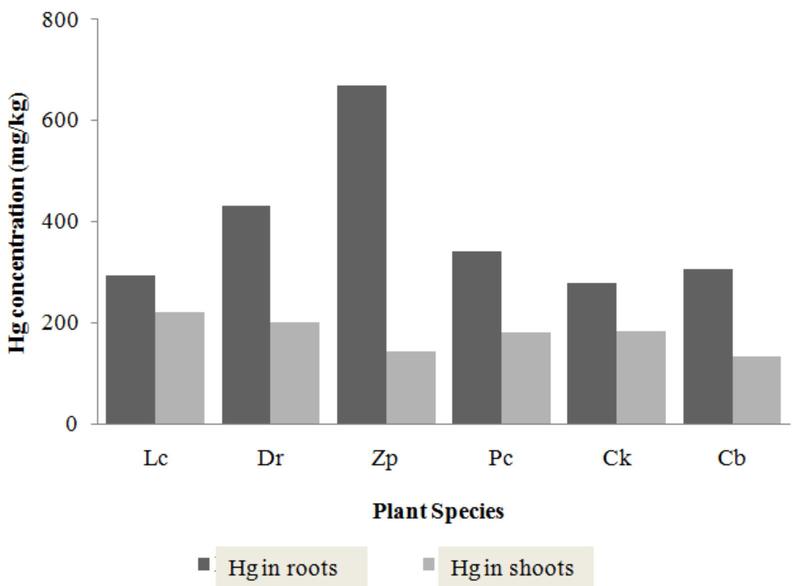

Figure 3. Concentrations of Hg in shoots and roots of the tested plant species at 9 weeks after planting. *Lc = Lindernia crustacea, Dr = Digitaria radicosa, Zp = Zingiber purpureum, Pc = Paspalum conjugatum, Ck = Cyperus kyllingia,* and *Cb= Caladium bicolor.*

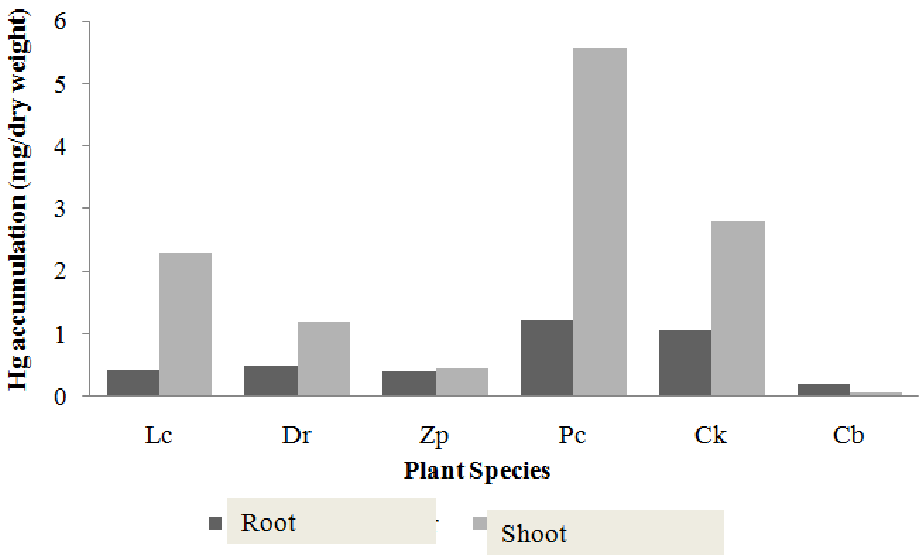

Figure 4. Accumulation of Hg in shoots and roots of the tested plant species at 9 weeks after planting. *Lc = Lindernia crustacea, Dr = Digitaria radicosa, Zp = Zingiber purpureum, Pc = Paspalum conjugatum, Ck = Cyperus kyllingia,* and *Cb= Caladium bicolor.*

High biomass production significantly affected the accumulation of Hg as presented in Figures1and 2. *Paspalum conjugatum* at 9 weeks produced higher biomass than other plant species tested.

Based on the ability to accumulate heavy metals, a plant species can be categorized as a potential phytoremediator when the ratio of accumulation of Hg in the shoot and in the root is more than one. Translocation system of elements from roots to shoots of metal accumulator plants is more efficient than normal plants. This is indicated by the ratio of metal concentration in shoot: metal concentration in root that is more than one (Gabbrielli et al., 1991). Data presented in Figure 5 showed that all tested plant species had shoot Hg: root Hg ratios of more than one except for *Caladium bicolor*. The shoot Hg: root Hg ratios of the six tested plant species were in the order of *Paspalum conjugatum* > *Lindernia crustacea* > *Cyperus kyllingia* > *Digitaria radicosa* > *Zingiber purpureum* > *Caladium bicolor.*

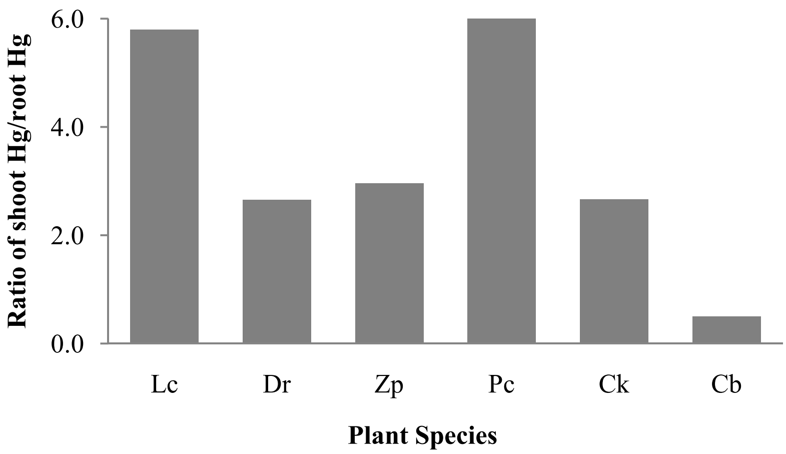

Figure 5. Ratio of shoot Hg : root Hg of the tested plant species at 9 weeks after planting. *Lc = Lindernia crustacea, Dr = Digitaria radicosa, Zp = Zingiber purpureum, Pc = Paspalum conjugatum, Ck = Cyperus kyllingia,* and *Cb= Caladium bicolor.*

The difference in the ratio of shoot Hg : root Hg on all tested plant species showed that the effectiveness of the mechanisms developed differences of each plant species in translocating mercury from the root to the shoot.

Conclusion

Paspalum conjugatum show the faster growth rate and the higher biomass as well as accumulation than *Cyperus kyllingia, Lindernia crustacea, Digitaria radicosa, Zingiber purpureum,* and *Caladium bicolor,* either on the growing media containing amalgamation tailings or cyanidation tailings. Therefore, it can be concluded that *Paspalum conjugatum* is a potential plant species for phytoremediation of mercury-contaminated soil.

Acknowledgements

The authors thank the UB and UNRAM laboratory analyses, and PT. Indofood Sukses Makmur Tbk for financial support through Indofood Riset Nugraha 2012.

References

Baker, A. J. M., McGrath, S.P., Reeves, R.D. and Smith, J.A.C. 2000. Metal hyperaccumulator plants: A review of the ecology and physiology of a biological resource for phytoremediation of metal-polluted soils. In: Terry, N. and Banuelos, G. (eds), *Phytoremediation of Contaminated Soil and Water.* Lewis Publishers, Boca Raton, FL., pp 85–107.

Baker, A.J.M. and Brooks, R.R. 1989. Terrestrial higher plants which hyperaccumulate metal elements- A Review of Their Distribution. Ecology and Development. England.

Brooks, R.R., Chambers, M.F.and Nicks, L.J.1998. Phytomining. *Trends in Plant Science* 3: 359-362.

Brooks, R.R., Morrison, R.D., Reeves, R.D., Dudley, T.R. and Akman, Y. 1979. Hyperaccumulation of nickel by *Alyssum Linnaeus* (*Cruciferae*). *Proceeding of Royal Society of London B* 203:387-403.

Brown, S.L., Chaney, R.L., Angle, J.S. and Baker, A.J.M. 1994. Phytoremediation potential of *Thlaspi caerulescens* and bladder campiom for Zinc- and cadmium contaminated soil. *Journal of Environmental Quality* 23(6): 1151-1157.

Brown, S.L.,Chaney, R.L., Angle, J.S. and Baker, A.J.M. 1995. Zinc and cadmium uptake by hyperacumulator *Thlaspi caerulescens* grown in nutrient solution. *Soil Science Society of America Journal* 59:125 – 133.

Gabbrielli, R., Mattioni, C. and Vergnano, O. 1991. Accumulation mechanism and heavy metal tolerance of a nickel hyperaccumulator. *Journal of Plant Nutrition* 14: 1067-1080.

Hidayati, N. 2005. Phytoremediation and the potential of hyperaccumulator plants. *Jurnal Hayati* 12(1): 35 – 40. (*in Indonesian*)

Hidayati, N., Juhaeti, T. and Syarif, F. 2009. Mercury and cyanide contaminations in gold mine environment and possible solution of cleaning up by using phytoextraction. *Hayati-Journal of Bioscience* 16(3): 88-94.

Lone, M.I., He, Z., Stoffella, P.J. and Yang, X. 2008. Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives. *Journal of Zhejiang University Science* 9 (3): 210-220.

Ma, L.Q., Komar, K.M., Tu, C., Zhan, W., Cai, Y.and Kenneley, E.D. 2001. A fern that hyperaccumulates arsenic. *Nature* 409: 579-584.

Mukhopadhyay, S. and Maiti, S.K. 2010. Phytoremediation of metal mine waste. *Applied Ecology and Environmental Research* 8(3): 207 – 222.

Nedelkoska, T.V. and Doran, P.M. 2000. Characteristics of heavy metal uptake by plant species with potential for phytoremediation and phytomining. *Minerals Engineering* 13 (5): 549-561.

Patra, M. and Sharma, A. 2000. Mercury toxicity in plants. *Botanical Review* 66: 379-422.

Pulford, I.D. and Watson, C. 2003. Phytoremediation of heavy metal land by trees-review. *Environment International* 29 (4): 529 – 540.

Robinson, B.H., Leblane, M., Petit, D., Brooks, R.R., Kirkman, J.H. and Greggi, P.E.H. 1998. The potential of *Thlaspi caerulescens* for phytoremediation of contaminated soil. *Plant and Soil* 203:47-56.

Speigel, S.J. and Veiga, M.M. 2010. International guidelines on mercury management in small-scale gold mining. *Journal of Cleaner Production* 18: 375-389.