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Mercury and Cyanide Contaminations in Gold Mine Environment and Possible Solution of Cleaning Up by Using Phytoextraction

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Water contamination with heavy metals, mainly mercury and cyanide (CN) due to small scale of public mines and large scale of industrial mines have been in concern to residents around the area. Surveys of heavy metal contamination in aquatic environments, such as rivers and paddy fields over two gold mine areas in West Jawa were conducted and possible solution of using indigenous plants for phytoremediation was studied. The results showed that most of the rivers and other aquatic environments were affected by gold mine activities. Rivers, ponds, and paddy fields around illegal public mines were mostly contaminated by mercury in considerably high levels, such as paddy fields in two locations (Nunggul and Leuwijamang, Pongkor) were contaminated up to 22.68 and 7.73 ppm of Hg, respectively. Whereas rivers located around large scale industrial mines were contaminated by CN. Possible solution of cleaning up by using green technology of phytoremediation was examined. Some plant species grew in the contaminated sites showed high tolerance and potentially effective in accumulating cyanide or mercury in their roots and above ground portions. *Lindernia crustacea* (L.) F.M., *Digitaria radicosa* (Presl) Miq, *Paspalum conjugatum*, *Cyperus kyllingia* accumulated 89.13, 50.93, 1.78, and 0.77 ppm of Hg, respectively. Whereas, *Paspalum conjugatum*, *Cyperus kyllingia* accumulated 16.52 and 33. 16 ppm of CN respectively.

Key words: phytoextraction, contaminants, cyanide, mercury

INTRODUCTION

Heavy metal contamination in soils and waters is a common problem encountered at many hazardous waste sites. Once released into the soil matrix and waters, most heavy metals are strongly retained and their adverse effects can last for a long time. Metal contaminants such as lead cadmium, copper, zinc, mercury, and also cyanide are among the most frequently observed. They are present at elevated concentration at many National Priority List sites. Heavy metals are toxic to people and pose a great risk for safe ground water supply.

Area around gold mine is one of the most frequently found as a critical environment subjected to heavy metal and cyanide contaminations. Degraded environment due to gold mine activities have recently increased excessively. Contaminated soil and water with mercury and cyanide due to both small-scale public mine and large-scale industrial mines, therefore have been in resident concern around the area.

There are two types of gold mines in the study area i.e. large-scale industrial mine belongng to the government (PT. Aneka Tambang, Antam) and small-scale public mine which is considered illegal mines (called PETI). The large-scale gold mines applied a large amount of Cyanide (CN) for the extraction of gold from soil containing gold ore. Cyanide is released to environment through a waste reservoir or tailing dam. Unlike the large scale gold mine, small scale illegal mine or PETI applied a large amount of mercury (Hg) for extracting gold from soil containing gold ore. Mercury is released to environment from several processes of gold mining activities. Thus, cyanide and mercury contaminations in sorounded areas through the rivers and ground water flow can not be avoided.

In river water mercury was mostly associated with suspended particles. The contamination level of mercury in Cikaniki and Cidikit (West Java) rivers were higher than the maximum tolerable concentration (0.002 ppm), based on Indonesian Government Regulation for river water. In the Cikaniki river, the concentration of Hg reached 5.45-21.65 ppm in its water and in the sediments was up to 70 ppm (Yustiwati *et al*. 2003).

Cyanide is a ubiquitous compound that appears in industrial waste. Not surprisingly, cyanide has been the top 10% of contaminants on the priority list of hazardous contaminants since 1995. Cyanide in the environment can exist as free cyanide but typically reacts to form metal cyanide complexes. Iron cyanide complexes are highly stable in the subsurface or in the absence of light, but can undergo rapid photolysis in surface waters to release free cyanide (Yu *et al*. 2005).

Some cases show that it is highly possible to use plants for remediation of mercury and cyanide in aquatic environments and screen appropriate plant species adapted to local conditions (Prasat & Frietas 2003; Larsen 2004; Larsen *et al*. 2005; Hidayati 2005; Moreno *et al*. 2005b; Juhaeti *et al*. 2006; Rodriguez *et al*. 2007). Phytoremediation of cyanide contamination was studied by using cyanogenic plants that synthesize cyanogenic glucosides, compounds that readily decompose to cyanide when the plant tissue is injured. Since

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*Corresponding author. Phone: +62-21-8765066, Fax: +62-21-8765069, E-mail: criancht@yahoo.co.id cyanide is a natural component of these plants, they have enhance capacities for degrading cyanide. Phytoremediation using *Urtica dioica* and *Sinapis arvensis* in a contaminated basin by harvesting the upper parts after two vegetative periods removed the contaminants (Gerth 2000). Phytoextraction of mercury by using *Brassica juncea* in a field plots of Tui mine site yielded a maximum value of 25 g Hg/ha (Moreno *et al*. 2004; Moreno *et al*. 2005; 2005a).

Study on heavy metal contamination in Indonesian aquatic environments is urgently needed in order to understand the problems and to find suitable technology for the solution. This research aims to examine cyanide and mercury contamination, which is considered a crucial problem in gold mine areas, and to find a possible solution of cleaning up by using green technology of phytoremediation.

Phytoremediation is defined as cleaning up pollutants primarily mediated by photosynthetic plants. It is an emerging technology for environmental remediation that offers a low-cost technique suitable for different types of contaminants in a variety of media. Phytoremediation is potentially applicable to a diverse substances (Chaney *et al*. 1995; Chaney *et al*. 1997).

Almost all higher plants can absorb heavy metals. Some plants are capable of absorbing large quantities of metals. It has been reported that at least there are some taxa of plant as hyperaccumulator for Cd, 28 taxa for Co, 37 taxa for Cu, 9 taxa for Mg, 317 taxa for Ni, and 11 taxa for Zn. Extensive progress has been made in characterizing physiology of plants which hyperaccumulate metals (Baker & Brook 1989).

The plant types that are of particular interest for use as remediation are those that absorb, store and under certain circumstances, detoxify contaminants. Hyperaccumulators are plant species, typically endemic to metalliferous soils, that can both accumulate and tolerate shoot concentrations of heavy metals to level 100 times greater than those normally observed (Ebbs 2006).

Since plants vary in their ability to accumulate specific contaminants, it is necessary to identify candidate plant species that can both accumulate and tolerate the contaminants of concern at a given site. Therefore this study aims to characterize plants that grow under extreme contaminated media at gold mined sites and to analyse their potency as hyperaccumulator.

The examination was carried out to select the suitable plants with the best capabilities in absorbing mercury and cyanide and producing high biomass. In addition, possible limiting factors for absorption were determined, and corresponding tolerance limits for negative growth influences were ascertained by series of experiments.

MATERIALS AND METHODS

This study was carried out at both abandoned and active gold mines in Pongkor, Bogor and Cikotok, Banten. This study was concentrated on aquatic environments over small-scale illegal public mines (PETI) and industrial gold mines belong to PT. Aneka Tambang (Antam) in Pongkor and Cikotok. Contaminations of mercury and cyanide in aquatic environments i.e. tailing dams, rivers, ponds, paddy fields and ground water were examined. Possible use of vegetation for cleaning up contaminants was also studied by examined physiological characters of plants i.e their growth, their tolerance to heavy metals and their ability in accumulating the metals in their roots and above ground portions as an indicator of hyperaccumulator plants.

Sample sites in Pongkor consist of 6 rivers, 2 tailing dams, 2 paddy fields and 11 PETI ponds. Sample sites in Cikotok covering 4 rivers, 3 abandoned tailing dams and 2 PETI ponds. From each sampled sites (rivers, tailing dams, PETI ponds and paddy fields), water samples were collected from different depth i.e. surface and 10-40 cm depth below surface, also from the middle and each sides of river banks. Sediment samples were collected with a bottom sampling. Samples from rivers were collected from several points, before (upstream) and after (downstream) the gold mining machines locations. Plant samples for screening were collected as fresh materials from abandoned tailing dams, around PETI ponds, along the contaminated river banks and paddy fields.

The samples were taken to Research Center for Biology for plant identification and to the laboratory belongs to The Agency of Agro Industry (BBIA) and The Agency of Soil Research for characterisation for analysis of mercury and cyanide contents. Mercury analysis was conducted by using AAS and cyanide content analysis was conducted by using spectrophotometry methods. Some selected plants (that indicating high Hg tolerance i.e high biomass production and high Hg content in roots and above ground portions) were collected for planting and to be used for further studies.

RESULTS

Mercury and Cyanide Contaminations. The results showed that most of the rivers and other aquatic environments over both areas of interest, Bogor and Cikotok, were affected by gold mine activities. Six rivers were surveyed in Pongkor and all of them were found to be affected by mining activities and indicated either mercury and/or cyanide contaminations. Cikaniki River, which is the main river in the area, was contaminated by 0.1 ppm of Hg and 0.15 ppm of CN in its sediment. Other river, Cipanas, where some active illegal mines located, was contaminated by 27.61 ppm of Hg in its sediment. Whereas Ciberantas River, which flows near tailing dam, contained 0.32 ppm of CN (Table 1).

Most PETI have waste ponds but some others simply dispose their waste to the environment such as rivers and paddy fields. The waste that directly comes out of the machine was detected to contain up to 62.27 ppm of Hg in its liquid and 598.14 ppm of Hg in its sediment. Inevitably, some rivers and paddy fields around the area were also affected. Paddy fields in two locations (Nunggul and Leuwijamang, Pongkor) were contaminated 22.68 and 7.73 ppm of Hg respectively. Even ground water, which is utilized as drinking water was detected containing 0.014 ppm of Hg (Table 1).

Four rivers in Cikotok area were examined. The main river in the area is Cimadur, which is located near to tailing dams belong to PT. Antam, the river where the tailing waste from the spillway flows. This river indicated contamination up to

Table 1. Mercury and cyanide contaminations in Tailing Dams, rivers and paddy fields around gold mines in Pongkor

Sampling Sites	Mercury (Hg) (ppm)		Cyanide (CN) (ppm)		GPS data
	Water	Sediment	Water	Sediment	
Cikaniki River 1 (upstream)	0.0005	0.1000	0.001	0.150	S: 06^{o} 39’ 41"E: 106^{o} 33’59"
Cikaniki River 2 (downstream)	na	na	0.014	0.030	S: 06^{o} 38’ 40"E: 106^{o} 34’16"
Cipanas River	0.0047	27.6100	0.004	0.004	S: 06^{o} 38’ 51"E: 106^{o} 34’05"
Ciberantas River (Tailing pond area)	0.0015	0.0060	0.014	0.320	S: 06^{o} 38’ 40"E: 106^{o} 34’16"
Tailing Dam 1	na	na	0.288	0.480	S: 06^{o} 38’ 45"E: 106^{o} 34’18"
Tailing Dam 2	na	na	0.030	0.770	S: 06^{o} 38’ 39"E: 106^{o} 34’17"
Tailing Dam 3	na	na	0.020	0.270	S: 06^{o} 38’ 39"E: 106^{o} 34’17"
IPAL Cikaniki	na	na	0.017	0.090	S: 06^{o} 39’ 41"E: 106^{o} 33’59"
IPAL Waste goes to Cikaniki River	na	na	0.014	0.030	S: 06^{o} 38’ 40"E: 106^{o} 34’16"
Public mine 1 (P Sahali)	0.2120	569.6300	na	na	S: 06^{o} 39’ 12"E: 106^{o} 34’11"
Public mine 2 (P Abih)	0.2430	212.8400	na	na	S: 06^{o} 39’12"E: 106^{o} 34’12"
Public mine 3 (P Suminta)	0.3020	598.1400	na	na	
Public mine 4 (P Andung)	0.0362	130.2400	na	na	S: 06^{o} 39’13"E: 106^{o} 34’14"
Public mine 5 (P Sahun)	0.3920	22.6700	na	na	S: 06^{o} 38’ 48"E: 106^{o} 34’02"
Public mine 6 (P Sukarman)	62.270	61.540	na	na	S: 06^{o} 39’12"E: 106^{o} 34’11"
Public mine 7 (P Rahmat)	0.0370	0.0005	na	na	S: 06^{o} 38’ 51"E: 106^{o} 34’05"
Public mine 8	0.0243	43.5000	na	na	
Fish pond Nunggul	0.0044	na	na	na	
Paddy Field Nunggul	na	22.6800	na	na	
Leuwijamang (inside of Halimun-Salak National Park) 2004					
Cibuluh river 1	2.0350	10.8300	na	na	
Cibarengkok river	0.0620	178.7500	na	na	
Ciberang river 10 k from machines	0.0080	nd	na	na	
Paddy field in Ciberang river	nd	7.7300	na	na	
Public mine 1	2.5790	5.4200	na	na	
Public mine 2	8.2350	11.4300	na	na	
Public mine 3	5.1680	33.6900	na	na	
Ground water	0.0140	nd	na	na	
Drinking water	0.0140	nd	na	na	

nd: not determined, na: no avaible data.

Table 2. Mercury and cyanide contamination in tailing dams, rivers and paddy fields around gold mines in Cikotok

Sampling sites	Mercury (Hg) (ppm)		Cyanide (CN) (ppm)		GPS data
	Water	Sediment	Water	Sediment	
Tailing dam	0.004	1.69	na	0.12	S: 06^{o} 51’652"E: 106^{o} 16’690"
Cipamancalan River (upstream)	0.169	2.94	na	na	
Cipamancalan River (downstream)	0.170	23.41	na	na	
Cimadur River (upstream)	na	na	<0.001	0.11	S: 06^{o} 51’58"E: 106^{o} 16’659"
Cimadur River (downstream)	na	na	<0.001	0.72	S: 06^{o} 51’58"E: 106^{o} 16’579"
Ciawitali River (upstream)	0.257	61.52	na	na	
Ciawitali River (downstream)	0.198	44.42	na	na	
Cierang (upstream)	0.520	101.37	na	na	S: 06^{o} 51’686"E: 106^{o} 17’545"
Cierang (downstream)	0.148	99.40	na	na	S: 06^{o} 51’686"E: 106^{o} 17’655"
Public mine 1	1.230	29.45	na	0.12	S: 06^{o} 51’331"E: 106^{o} 18’251"

na: no avaible data.

0.72 mg ppm CN. Other rivers, Cierang, Ciawitali and Cipamancalan, where some active PETI were located indicated Hg contamination up to 101.37, 61.52, and 23.41 ppm respectively in the sediments and 0.15, 0.26, and 10.17 ppm of Hg respectively in the waters (Table 2).

There was an indication that the closer the sample site to mine machines, the higher the Hg concentrations. Concentration of Hg in Cibarengkok and Cibuluh Rivers, the nearest rivers from the mining activity in Leuwijamang, contained the highest level of Hg which was up to 178.75 and 10.83 ppm of Hg respectively (Table 1). Some rivers in Cikotok such as Cierang and Ciawitali, which are the nearest rivers to mine machines, also contained the highest level of Hg in their sediments which were up to 101.37 and 61.52 mg ppm of Hg respectively (Table 2).

Different characteristics were detected between waste media of industrial scale (PT. Antam) and small-scale public mines (PETI). Beside some differences in physical properties, differences in important heavy metal contaminants were also found. Antam waste contains high CN while PETI contains high Hg contaminant. Heavy metal content (Pb, Fe, Cd, dan Zn) of both mines were considerably high compared to uncontaminated media (garden top soil). Lead (Pb) contents of PT. Antam and PETI waste were respectively 20 and 30 times higher that Pb content of uncontaminated soils. Iron (Fe) content of Antam and PETI waste were respectively 50 and 120 times higher than uncontaminated soils. Cadmium (Cd) of Antam and PETI waste were 40 times higher, and Zink (ZN) were 3 times higher compared to uncontaminated garden soils (Table 3).

Table 3. Physical and chemical characteristic of gold mines waste media

Components	Tailing dams Antam samples			PETI samples		
	Cikotok 2006	Pongkor		Cikotok 2004	Pongkor	
		2004	2006		2004	2006
Texture (%)						
Sand	22	64	67	7	40	45
Dust	57	17	26	82	50	40
Clay	21	19	7	11	10	15
pH						
H_2O	8.0	7.9	8.3	7.5	7.9	7.9
KCl	7.4	7.8	8.2	7.3	7.8	7.5
Organic matter (%)						
C	0.29	0.35	0.22	0.47	0.51	0.25
N	0.03	0.06	0.02	0.04	0.08	0.02
C/N	10	6	11	12	6	13
P_2O_5 (ppm)	43	10	30	125	17	8
P_2O_5 (mg/100 g)	33	52	44	15	73	103
K_2O (ppm)	na	46.3	53	na	124.5	139
K_2O (mg/100 g)	na	26	9	na	29	57
Ca (cmol(+)/kg)	na	na	24.59	na	na	9.85
Mg (cmol(+)/kg)	na	na	0.63	na	na	0.74
K (cmol(+)/kg)	na	na	0.10	na	na	0.26
Na (cmol(+)/kg)	na	na	0.30	na	na	0.26
KTK (cmol(+)/kg)	na	na	2.36	na	na	5.18
KB^+ (%)	na	na	>100	na	na	>100
Al^{3+} (cmol(+)/kg)	na	na	0.00	na	na	0.00
H^+ (cmol(+)/kg)	na	na	0.00	na	na	0.00
Fe (ppm)	na	16854	14353	na	43035	30207
Zn (ppm)	20	656	169	36	1612	225
Pb (ppm)	63	128	668	164	201	30
Cd (ppm)	0.6	2.62	2.82	1.7	3.09	0.06
CN (mg/kg)	0.43	0.155	0.28-0.77	0.12	0.022	0.04
Hg (mg/kg)	1.69	0.293	0.0005	29.45	239.38	61.54-598.14

na: no avaible data.

Mercury and Cyanide Phytoextraction of Some Tolerant Plants. Some plant species from PETI were found to have potency as Hg hypertolerant, such as *Lindernia crustacea* (L.) F.M. which accumulated up to 89.13 ppm of Hg, *Digitaria radicosa* (Presl) Miq accumulated which up to 50.93 ppm of Hg and *Zingiber* sp which accumulated 49.33 ppm of Hg (Table 4). Sample collected in 2006 i.e. Paku (local name), accumulated 10.79-16.18 ppm of Hg and *Paspalum conjugatum* which accumulated 1.78 ppm of Hg (Table 5 & 6).

Meanwhile plants from tailing dam were found potentially tolerant to CN, such as *Ipomoea* sp. that was abble to accumulate up to 35.70 ppm of CN, *Limnocharis flava* accumulated 9.59 ppm of CN (Table 4); *Mucuna pruriens* accumulated up to 42.40 ppm of CN, *Mikania cordata* accumulated up to 23.10 ppm of CN, *Cyperus* sp. accumulated 21.17-33.16 ppm of CN (Table 5 & 6).

Some plants were detected tolerant to both PETI and PT. Antam waste. These palnts showed considerably high accumulation of Hg and CN, i.e *Paspalum conjugatum* which accumulated up to 16.52 ppm of CN and 1.78 ppm of Hg, *Cyperus* sp accumulated up to 33. 16 ppm of CN and 0.77 ppm of Hg and *Caladium* sp. accumulated 17.11 ppm of CN and 9.12 ppm of Hg. *Mikania cordata* that predominated both mine sites, accumulated up to 23.10 ppm of CN (Table 5 & 6).

Table 4. Mercury and cyanide accumulation of tolerant plant species growing in Pongkor gold mine (collected in 2004)

Species	CN (ppm)	Hg (ppm)
Plants from PETI		
Zingiber sp.	nd	49.33
Colocasia sp.	nd	9.12
Digitaria radicosa (Presl) Miq	nd	50.93
Commelina nudiflora	nd	30.37
Lindernia crustacea (L.) F.M.	nd	89.13
Plants from Tailing dam Antam		
Ipomoea sp.	35.700	nd
Limnocharis flava	9.590	nd
Echinochloa colona Link	6.130	nd
Salvinia molesta	4.630	nd
Scoparia dulcis L.	4.720	nd

nd: not determined.

DISCUSSION

Besides a better understanding on the effects of mine activities on the environmental degradation, it is urgently needed to conduct a serious study to obtain alternative solutions to overcome the problems. Following evidences reveal the impacts of the environmental degradation to the plants and the ability of these affected plants to remediate their contaminated environments, as one alternative solution.

Most of the rivers and other aquatic environments under study were affected by gold mine activities. Most water and sediment samples from some rivers and paddy fields were detected containing mercury in considerably high levels above the maximum tolerable concentration of the water standard in Indonesia which is 0.002 ppm.

The results of the study revealed that contamination of mercury increases with the increase of gold mine activities. There were some positive relationships between the Hg concentration in water or the Hg concentration in sediment

Table 5. Mercury and cyanide accumulation of tolerant plant species growing in Pongkor gold mine (collected in 2005 & 2006)

Plant species	Cyanide (ppm)		Mercury (ppm)	
	Root	Shoot	Root	Shoot
Samples collected from Cikaniki River 1				
Crotalaria juncea	8.65	7.95	0.0005	0.04
Paspalum conjugatum	na	16.52	na	0.0005
Jali (local name)	na	14.11	na	0.0005
Centrosema pubescens	na	8.62	na	0.0005
Samples collected from tailing dam				
Eleusine indica (L.) Gaertn	4.2	4.98	nd	nd
Cyperus kyllingia	13.65	7.52	nd	nd
Rhynchospora corymbosa (L.) Britton	9.82	8.4	nd	nd
Salvinia molesta	4.64	na	na	na
Calopogonium mucunoides Desv	6.16	na	na	na
Cynodon dactylon	1.05	na	na	na
Cyperus compactus Retz	2.91	na	na	na
Echinochloa colona Link	6.13	na	na	na
Eulisine indica (L.) Gaertn	4.67	na	na	na
Fimbristylis miliacea (L.) Vahl	4.93	na	na	na
Limnocharis flava	9.59	na	na	na
Ipomoea sp.	35.70	na	na	na
Ischaemum timorense	0.63	na	na	na
Limnocharis flava	9.59	na	na	na
Mikania cordata (Burm.f.) B.L.Robinson	11.65	na	na	na
Scoparia dulcis L.	6.13	na	na	na
Sonchus arvensis L.	3.46	na	na	na
Samples collected from public mines Nunggul				
Zingiber sp.	nd	nd	0.0005	0.78
Paku (local name)	nd	nd	na	10.79
Paspalum conjugatum	nd	nd	na	0.03
Colocasia sp.	nd	nd	0.0005	0.25
Pogonatherum paniceum Hack.	nd	nd	na	0.25
Samples collected from public mines Tugu				
Paspalum conjugatum	nd	nd	na	1.78
Cyperus kyllingia	nd	nd	na	0.77

nd: not determined, na: no avaible data.

and the number of the mining machine in the rivers, suggesting that the Hg concentrations directly related to the mining activity. This finding agrees with the results reported by Yamada *et al*. (2005) that Hg concentration in Kahayan River was positively correlated with the number of gold mine machines which was fluctuated from year to year.

Different characteristics between waste media of industrial scale (PT. Antam) and small-scale public mines (PETI) brought about the differences in species diversity in both mine sites. Different characteristics of mine waste might result in different response in physiological adaptability of the plants. Plants that are growing in PETI area, showed high tolerance toward Hg and tend to accumulate considerably high levels of Hg in their roots and above ground portion, while those which grow in tailing dam showed tolerance to CN and tend to accumulate higher CN compare to Hg in their tissues. Table 3, 4, and 6 represent accumulation of Hg and CN in plant roots and shoots.

The results also indicated that plants growing in contaminated sites tend to accumulate higher metal contaminants. Rodriguez *et al*. (2007) reported that Hg accumulation in some plants growing in uncontaminated media was not more than 0.1 microg/g, however Hg accumulation in plants growing in Hg contaminated site was found to be higher. Mercury content of 0.37-3.10 microg/g was found in five wild plant species growing in Almaden mine that was contaminated with Hg. Mercury levels of 0.16-1.40 microg/g was detected in five herbs grown in liquid media contain 200 microg/g Hg. Mercury content in *Cyperus monocephala* and *Digitaria radicosa* increased with the increase of mercury content in media (Hidayati *et al*. 2009). Plants that were grown in cyanide contaminated media such as *Saccharum spontaneum* tend to accumulate higher cyanide in their shoot (Hidayati *et al*. 2008).

Some plants were able to produce high biomass as well as absorbing high contaminants such as *Saccharum spontaneum*. Some plats highly absorbed contaminants but producing low biomass such as *Lindernia crustacea* (L.) F.M. This phenomena were commonly found in the field and suggesting that plants response differently to environmental stress. Therefore continuous research is required to obtain ideal plant character for phytoremediation i.e combination of high biomass production and high metal accumulation.

There was a variation of physiolocigal adaptability amongs plant species growing in the contaminated areas. Some plants indicated high tolerance to toxic contaminants by showing high biomass production and high metal accumulation. Each plant responses in specific way to specific metal contaminants. The different tolerance may be due to the physiological differences in their responses to form stress protein (phytochelatins). It was observed that even low levels of heavy metal contamination in the soil lead to suppressed root and wood growth and reduce emmision and transpiration rates (Larsen *et al*. 2005).

Table 6. Mercury and cyanide accumulation of tolerant plant species growing in Cikotok gold mine (collected in 2005 & 2006)

Plant species	Cyanide (ppm)		Mercury (ppm)	
	Root	Shoot	Root	Shoot
Samples collected from tailing dam				
Cyperus rotundus	3.19	6.90	nd	nd
Ludwigia peruviana	9.04	9.95	nd	nd
Ludwigia peruviana (young plant)	4.30	2.49	nd	nd
Cyperus kyllingia	18.15	15.01	nd	nd
Paspalum conjugatum	10.30	3.4	na	na
Mikania cordata (Burm.f.)B.L.Robinson	na	23.10	nd	nd
Mucuna pruriens	22.67	19.73	nd	nd
Colocasia sp.	7.54	9.57	nd	nd
Saccharum spontaeum	na	10.25	na	na
Imperata cylindrica	9.36	10.844	na	na
Centrosema pubescens	na	22.09	na	na
Chromolaena odorata	na	26.33	na	na
Jussiena repens	na	22.11	na	na
Mucuna pruriens	na	23.35	na	na
Melastoma malabatricum	na	16.43	na	na
Hyptis capitata Jack	na	9.39	na	na
Samples collected from non contaminated soil 6 m distance from tailing dam				
Ludwigia peruviana	25.16	8.40	nd	nd
Mucuna pruriens	na	8.64	nd	nd
Mikania cordata (Burm.f.)B.L.Robinson	na	11.44	nd	nd
Cleome aspera	na	22.4	na	na
Abelmoschus cf angulosus	na	13.3	na	na
Paspalum conjugatum	na	9.82	na	na
Chromolaena odorata	na	8.91	na	na
Wedelia Montana	na	8.19	na	na
Chromolaena odorata	na	8.11	na	na
Leersia hexandra	na	7.43	na	na
Saccharum spontaneum	na	6.74	na	na
Christella	na	6.25	na	na
Ludwigia peruviana	na	5.14	na	na
Imperata cylindrica	na	4.69	na	na
Echinochloa colona	na	3.90	na	na
Samples collected from Ciawitali River				
Paspalum conjugatum	nd	nd	na	0.69
Caladium sp. 1	nd	nd	0.48	1.16
Caladium sp. 2	nd	nd	<0.0005	1.19
Paku (local name)	nd	nd	16.18	0.48
Samples collected from public mines				
Paspalum conjugatum	na	na	na	47.00
Ipomoea batatas	na	na	22.57	18.57
Ageratum conyzoides	na	na	na	3.57
Cyrtococcum accrescent	na	na	na	5.75
Artocarpus integra	na	na	na	13.46
Commelina nudiflora	na	na	na	12.05
Paku (local name)	na	na	na	2.28
Paspalum conjugatum	na	na	na	20.21
Borreria laevis Grisel	na	na	na	19.83
Commelina nudiflora	na	na	na	17.40
Bambusa sp.	na	na	na	15.20
Paspalum conjugatum	na	na	na	14.05
Cyperus kyllingia	na	na	na	13.05
Pityrogramma calomelanos	na	na	na	12.76
Paspalum conjugatum	na	na	na	11.80
Paspalum conjugatum	na	na	na	8.90
Cyrtococcum accrescent	na	na	na	6.05
Plantago major	na	na	na	6.01
Bambusa sp.	na	na	na	15.20

nd: not determined, na: no avaible data.

Phytoextraction involves the use of specialized physiological process that allow plants to accumulate metals during their complete growth cycle. This require high biomass plants capable of solubilizing metals ion in the soils, efficiently transporting them to the shoot, where the toxic metals are located and they accumulate high concentration. This type of metal uptake is optimized by hyperaccumulating plants that grow on soils and waters rich in metals and naturally accumulate these metals to between 0.1 to 3% of shoot dry biomass, depending on the availability of the contaminants in the media, genetic factors, including mass, and removal performance of the plant types (Gerth 2000; Prasat & Frietas 2003).

Gerth (2000) observed that there were no connection between the contaminant contents in the soils and those in the plants. This finding agrees with the results of this study that heavy metal content in the plants did not correlate with heavy metal content in the media (soils and waters).

It was obvious from phytoextraction study that some plants are able to survive under extreme environmental conditions. This characteristic make the plants organism convenient tools for remediation of soils and waters under difficult conditions.

This study shows that plants which accumulate cyanide above 20 ppm are *Centrocema pubescens*, *Cleome aspera*, *Jussiena peruviana, Mucuna pruriens, Solanum torvum, Ipomoea* sp., *Mikania cordata, Cromolaena odorata, Ludwigia peruviana, Cyperus monocephala*, *Paspalum conjugatum.* Plants which accumulate mercury above 20 ppm are *Paspalum conjugatum, Ipomoea batatas*, *Commelina nudiflora*, *Digitaria radicosa* (Presl) Miq, *Lindernia crustacean* (L.) F, *Zingiber* sp. Plant with high tolerance and high biomass production (rapid growth): *Saccharum spontaneum.* Plants that are dominant in the sites: *Mimosa pigra*, *Crotalaria juncea*, *Calopogonium mucunoides*, *Saccharum spontaneum.*

As we know that identifying or engineering a suitable plant species is only one step in developing a phytoextraction strategy for contaminaned site. Other important factors that may limit the potential success of phytoextraction are contaminant bioavailability and the poor understanding of molecular mechanism involved in metal hyperaccumulation. A better understanding of those factors may help in developing of superior plants for phytoextraction of pullutant metals. A series of research on this field is therefore required.

It can be concluded that most of the rivers and other aquatic environments under study were affected by gold mine activities. Some plant species growing on the contaminated aquatic environments were found to be potentially effective in accumulating heavy metals in their roots and above ground portions. These plants could be utilized as accumulators for cleaning up contaminated soils and waters.

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