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Phytoremediation of arsenic from geothermal power plant waste water using *Monochoria vaginalis, Salvinia molesta* and *Colocasia esculenta*

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Abstract

The aim of the research was to identify the ability of *Monochoria vaginalis, Salvinia molesta* and *Colocasia esculenta* to decrease Arsenic pollutant from thermal energy waste water through phytoremediation process. An experimental pool was made in field and filled with waste water of geothermal power plant in Lahendong, North Sulawesi. Arsenic content in root and leaf tissue was observed by *Atomic Spectrophotometer Atomic Adsorption* (ASS). The result of the study showed that there was no significant difference of As absorption among *Monochoria vaginalis, Salvinia molesta* and *Colocasia esculenta*. There were two models of As absorption as follows: the As absorption in root followed exponential asymptotic, while absorption by leaf was exponential growth. This research confirmed that *Monochoria vaginalis, Salvinia molesta* and *Colocasia esculenta* are the potential species for phytoremediation program.

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Introduction

Recently, water pollution becomes significant issue in environmental across the world. In many developing countries, besides water scarcity, the water quality issues have received a lot of attention and debates. Water pollution has been identified to decrease the quality of water ecosystem, water biodiversity and its terrestrial associated species, and cause many species extinct. The relationship of water pollution with recent rapid development has been reported in many documents and scientific literatures. Human activity has released many hazardous substances to the environment. According to many scholars, water pollution occurs when hazardous substances are dissolved into water and lead to numerous negative impacts to water biodiversity and human health (Bhattacharya *et al.,* 2007; Baldwin and Butcher, 2007).

Arsenic (As) is one of important pollutants in water. In many developing countries, such cases of water contamination consisting As in drinking water have been reported (Bhattacharya *et al.,* 2007). The danger of Arsenic pollution can be numerous, including induced skin, bladder and lungs cancer. A large amount of As in human body can lead to gastrointestinal problems (Duker *et al.,* 2005). Naturally, the concentrations of As in environmentis low. For instance, the concentration of As in rocks is~2 mg kg^{-1}, while in soilsis~2 mg kg^{-1}. Similarly, the concentration of As in freshwater is about ~1 mg dm^{-3} and in seawater~2 mg dm^{-3} (Tanaka, 1988). In geothermal fluid, the ranges concentration of As are from 0.1 to 50 ppm. The pyrite reaction in high temperature reservoir fluid leads to As release (Ballantyne and Moore, 1988).

The issues of As pollution and rapid industrial development have been widely recognized in developing countries, including in Indonesia. It is particularly important in the discussion of As pollutant due to geothermal power plant operational (Webster and Nordstrom, 2003).In Indonesia, the energy from geothermal power plant has been developed in many places where there are potentials of geothermal. Geologically, Indonesia is a hot spot for active volcanic mountainsand, therefore, provides significant resources for thermal energy. North Sulawesi is one of the areas in Indonesia where the abundant thermal energy has been identified and able to promote energy production. One of the geothermal power plants in North Sulawesi is located at Lahendong. The significant problem of thermal energy in Lahendong, however, is the release of Arsenic into water environment. The Arsenic is released into environment as an impact of thermal energy process as widely reported (Mungkono and Corie, 2006).

In Lahendong geothermal power plant, the occurrence of As isproduced and released from every stage of thermal energy process, including operation, separation and condensation. An official report of geothermal power plant in Lahendong shows that, from January to June 2012, the amount of As in waste water has fluctuated. In some point checks (i.e. *Cluster* 4 and *Cluster* 7), As has been monitored under the standard quality, while in some points (i.e. *Cluster* 5, *Cluster* 13, and *Cluster* 24), the content of As exceeded the standard quality (PGE Area Lahendong, 2012ab). According to Indonesian Ministry of Environment Law No. 19/2010 about geothermal plant operation, the Arsenic quality standard should be 0.5 mg/L. According to Indonesian Ministry of Environment Law No. 82/2001 about the water management and water pollution mitigation, the Arsenic content should be below 0.05 mg/L.

Various attemptsin order to eliminate hazardous pollutant in water environment have been introduced, one of which is phytoremediation techniques. Phytoremediation offers land managers to clean up hazardous contaminant from land and water ecosystem which are heavily contaminated (Bhattacharya *et al.,* 2007). Economically, phytoremediation is low-cost as it is compared to other techniques. These techniques are environmentally friendly. Widely, such techniques have been applied in environmental management, particularly to minimize hazardous particle in water and soil environments (Baldwin and Butcher, 2007).

Many plants have potentiality as As accumulator and, therefore, provide opportunities to develop low cost and eco-friendly technology to remove As, including Water hyacinth, Duckweed, Water fern (*Azolla*), Butterfly fern (*Salvinia*), Water lettuce (*Pistia stratiotes*), Watercress, Esthwaite waterweed (*Hydrilla verticillata*), Waterweed (*E. canadensis*) and Needle spike rush (*Eleocharis acicularis*) (Rahman and Hasegawa, 2011). The As absorption by Pteridophytes reports that *Pteris biaurita* L., *Pteris quadriaurita*, *Pteris ryukyuensis* and *Pteris cretica* as a hyper-accumulator (Srivastava *et al.,* 2006*)*. From wetland environment, some species such as *Canna glauca* L., *Colocasia esculenta* L. *Schott, Cyperus papyrus* L. and *Typha angustifolia* L. are recognized as potential plant to eliminate As in wetland ecosystem (Jomjun *et al.,* 2010).

There are opportunities to use plants species for remediation agents in Geothermal Power Plant in Lahendong.The area surrounding Lahendong is home for numerous plants which are able to prove as bioaccumulation of As in polluted land and water. However, so far, there are no assessments on the effectiveness of such plants in absorbingthe As. The aim of the research was to identify the ability of *Monochoria vaginalis* Burm F.L. Presi *,Salvinia molesta* Mitchell and *Colocasia esculenta Schott Var. Aquatilis* Hassk as As biacumulator, and determine the mathematical models of As absorption in root and leaf of *Monochoria vaginalis* Burm F.L. Presi*, Salvinia molesta* Mitchell dan *Colocasia esculenta Schott Var. Aquatilis* Hassk.

Material and methods

The research was conducted in sub-district Lahendong, North Sulawesi. The experimental plot for plants observation was set up at waste water outlet at Cluster LHD-13 of the Lahendong Geothermal Power plant. The research was conducted in June to August, 2012.

For the observation of the plants' ability to absorb the dissolved As in Geothermal Power Plant, a 3x4-meter water pool was build. The pool has ± 25 cm in depth. As mall number of soils which was collected from paddy field was dumped into pool as a plant media to grow. The pool was filled by waste water about ±1000 liter from waste water as well as LHD-28. Experimental pool was divided into three sections; as a control, about 25 liter waste water was transferred into the experimental pools.

Three species, namely *Monochoria vaginalis* Burm F.L. Presi, *Salvinia molesta* Mitchell and *Colocasia esculenta* (L.) Schott Var. and *Aquatilis* Hassk were used as an experimental plant to absorb As. These species were acclimatized for seven days prior to plant in experimental pool. Arsenic in plants tissues was observed in every week. The first week observation was on the seventh day, second observation was on the fourteenth day, third observation was twenty-first day and the last observation was twenty-eighth day. In every week, pH and media temperature were measured.

In each period of As absorption measurement, about 100 mg of root and leaf tissues were collected from such plants and transferred into laboratory for further analysis. Roots and leaves were washed to eliminate the contaminants and dried in room temperature. About 100 mg sample was blended using 500 ml H_2O_2. The digestion by H_2O_2enabled to release As in liquid. Liquid contains As was collected and As was analyzed in *Atomic Spectrophotometer Atomic Adsorption* (ASS) WLN-ML-WI-01, APHA-3125-B. In the similar techniques, about 100 ml of waste water was collected and transferred into bottle containing HNO_3. The experiment was conducted in a completely randomized design with three replications. Data were analyses using one way ANOVA. The modeling of As absorption was modeled by using Origin Pro 8.0 software.

Result and discussion

As absorption in tissue culture

The ability of *Monochoria vaginalis*, *Salvinia molesta* and *Colocasia esculenta* to absorb water pollutant has reported widely. Previous survey by Rompas (1995) shows *Monochoria vaginalis* was able to absorb Mercury and metal in waste water in Manado. This research provides opportunities that basically such species was able to absorb other hazardous metal, including As.

Table 1. As in roots and leaf in different times of measurement.

No	Plant species	Control		1st week		2nd week		3rd week		4rt week	
		Root (mg/kg)	Leaf (mg/kg)	Root (mg/kg)	Leaf (mg/kg)	Root (mg/kg)	Leaf (mg/kg)	Root (mg/kg)	Leaf (mg/kg)	Root (mg/kg)	Leaf (mg/kg)
1	*Monocharia vaginalis*	0.5183	0	14.5551	0.5792	12.6640	1.2933	22.289	0.9073	17.567	2.5833
2	*Salvinia molesta*	0.1898	0	17.7706	0.4229	19.2335	2.7047	17.705	1.9100	17.233	4.2100
3	*Colocasia esculenta*	0.8717	0	6.5717	0.1670	19.3574	0.2937	26.474	0.0460	14.230	0.4333

The research confirmed that waste water prior to the remediation contains As about 3.83 mg/L, pH 2,8-3,0, and temperature was 34-36 °C in range. Prior to the experiment, such species principally contains As particularly in roots (Table 1). Geological background of Tomohon area seems to contribute a lot to the existence of As in plant tissue, particularly on the roots. The soil in Tomohon was dominated by vulcanic. Naturally, As is found as common minerals such as Sulfides (i.e Realgar AsS, Orpiment As_2S_3, Arsenophyrite FesAsS), Sulfosalts (i.e. Tennantite $(CuFe)_{12}As_4S_{13}$, Enargite Cu_3AsS_4), Arsenates (i.e. Scorodite $FeAsO_42H_2O$, Mimetite $Pb_5(AsO_4)_3Cl$, and Arsenites (i.e. Trippkeite $CuAs_2O_4$) (Thornton and Farago,1997). Moreover, such plants from mining area often contain significant amount of Arsenic. An observation by Essumang *et al.* (2007) shows that *Xanthosoma sagititolium* and *Colocasia esculenta* which grow in mining area contain Arsenic, cadmium and mercury beyond the recommended level by WHO.

Roots absorbed As higher that leaves in the three species (Table 1). This data seemed to be similar with many previous study related to As absorption in plant tissue. Tlustos *et al.* (2008) asserts that root was the dominant tissue to take As in spinach, radish, carrot. Similarly, an experiment by Bindu *et al.,* (2010) shows that the roots of *Colocasia esculenta* are able to absorb lead (Pb) and Cadmium (Cd) than leaf tissue. Root tissue is one of the significant plants tissues which are responsible to absorbs water and nutrient from plants media growth, both water and soil. The direct absorption and material storage in the root tissues lead to high material accumulation, while less absorption in leaf is affected by plant ability to transport mineral from the roots to the leaves.

Jomjun *et al.,* (2010) confirm that *C. esculenta* is able to remove As about 68 mg As/m²/day and this species is considered as one of the species with fastest ability to absorb As in wetland environment. A study by Tambamroong (2007) on the ability of *C. esculenta* also shows that such plant is able to accumulate As maximally about 40.34 mg in cultivated *C. esculenta* and 46.79 mg for wild *C. esculenta*. Taro, *C. esculenta*, is aquatic and semi aquatic Aroids which are able to grow in both open and shadow area. *C. esculenta* is native to tropical Asian species and the edible cultivar nowadays cultivated in northern Africa, Japan, Northern America and Caribbean. Nowadays, *C. esculenta* was reported as an invader in the Iberian Peninsula (Gracia-de-Lomas *et al.,* 2012).

Fern is one of the important plant groups that are able to absorb pollutant. Previous survey shows that

Pityrogramma calomelanos and *Pteris vittata* was fern with ability to accumulate As up to 8350 µgg^{-1}. Visoottiviseth *et al.* (2002). Another floating fern *Salvinia molesta* has been known as an effective plant to absorb As in roots (628±5 mgKg^{-1}dw^{A}), and decrease in shoots (110±1 mgKg^{-1}dw^{A}), and leaves (128±1 mgKg^{-1}dw^{A}) (Ashraf *et al.,* 2013). In this study, *Salvinia molesta* showed its ability to absorb As in significant amount and therefore led such species as a potential bio-accumulator. In Indonesia, however, *S. molesta* is an exotic plant species which recently contributes to the many lakes degradation (Hakim *et al.,* 2011). *S. molesta* is one of the floating ferns with ability to spread fast in aquatic ecosystem. Therefore, the application of *S. molesta* as As accumulator in aquatic environments should be controlled systematically.

Table 2. Mathematical models of As absorption.

No	Total AS absorption	Model	Mathematic models of absorption
1.	Roots of Monocaria vaginalis	exponential asymptotic	y = a – bcx with a = 18.99521 b=18.23187 and c = 0.85584
2	Leaf of Monocaria vaginali	exponential growth	y = yo + Aex/t with yo =-0.07207 A=0.30884 and t = 13.33919
3	Roots of Salvania molesta	exponential asymptotic	y = a – bcx with a = 18.04781 b= 17.85823 and c = 0.54182
4	Leaf of Salvania molesta	exponential growth	y = yo + Aex/t with yo =-6.72911 A=6.71001 and t = 60.28505
5	Root of Colocasia esculenta	eksponensial asymptotic	y = a – bcx with a = 26.8423 b= 27.2402 and c = 0,9255
6	Leaf of Colocasia esculenta	exponential asymptotic	y = a – bcx with a =21.98703 b =22.27684 and c =0.89945.

Previous research confirmed that *M. vaginalis* is one of the potential bio-accumulator of Cd and Pb (Liu *et al.,* 2007). While there are few studies having been conducted to observe the ability of *M. vaginalis*as bio-accumulator flora, this study confirmed that *M. vaginalis*is one of the promising plant species in As phytoremediation. As absorption by roots particularly shows that such species is the significant As bio-accumulator. Geographically, *Monochoria vaginalis* is a native to Malaysia, Japan and Taiwan regions. This species is noxious weed which is often found in flooded paddy field.

There are no differences on the amount of As absorption among three species, indicates that such species have potential as bio-accumulator of As in wetland environment. Amount of As accumulation in roots of three species in first week not significant (Sig. F = 0.392), as well as in second week (Sig. F = 0.338), third week (Sig. F = 0.550), and fourth week (Sig. F = 0.473). Similarly, the amount of As accumulation in leaf of three species in first week was not significant (Sig. F = 0.763), as well as in second week (Sig. F = 0.750), third week (Sig. F = 0.638), and fourth week (Sig. F = 0.784). During observation waste water pH was monitored about 3-4 times with range temperature was 22-26^{o}C.

Mathematical models of As absorption

Based on analysis of As absorption by using Origin Pro 8.0 software, there were two mathematical models which were given in Table 2 and illustrated in Fig. 1-6. Absorption by roots in three species was *exponential asymptotic* while absorption by leaf *was exponential growth.*

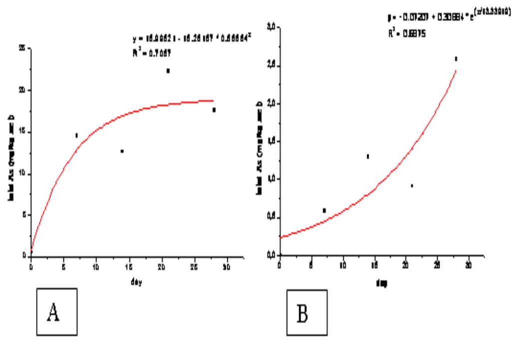

Fig. 1. Total As Absorbion in roots (A) and leaf (B) of *Monocaria vaginalis*.

Modeling results with regression by using Origin Pro 8.0 program, in total arsenic absorption patterns obtained at the root of *Monochoria vaginalis* (Figure 1) modeled by *asymptotic exponential* equation (y = a - BCX) showed that as increasing the day, the value of total arsenic in the roots *M. vaginalis* also tend to be higher but would be constant at a certain point. For total arsenic absorption on leaf of *M. vaginalis* (Figure 1), total inclination arsenic on the leaf of *M. vaginalis* would also increase with each passing day but there was not any tendency to any decrease. In this model, the distribution tend to follow polynomial. As the highest absorption on the root of *M. vaginalis* was obtained at the time of measurement at the third week for a total of absorption was as much as 22. 289 mg / kg, while the highest As content in the leaves was found in measurements on the fourth week, at which time the resulting As measurement was as much as 2.5833 mg / kg .

In general, the results of modeling of total As in the roots and leaves of *Salvinia molesta* were the same with the modeling results on *M. vaginalis* which follow an exponential distribution where as the growing day, the value of the measured parameters would tend to grow taller and be constant at a certain point. However, in contrast to the results of the modeling for total Arsenic in *Salvinia molesta* leaves that would tend to follow the distribution of increasing the polynomial which would further increase the value of total arsenic and would not be constant at a certain point. As absorption on *Salvinia molesta* was in the highest in the roots obtained at the time of measurement at second week with a total of absorption as much as 19.2335 mg / kg, while the highest As content in the leaves was found in measurements to fourth weeks, at which time of the measurements resulting as much as 4.2100 mg / kg

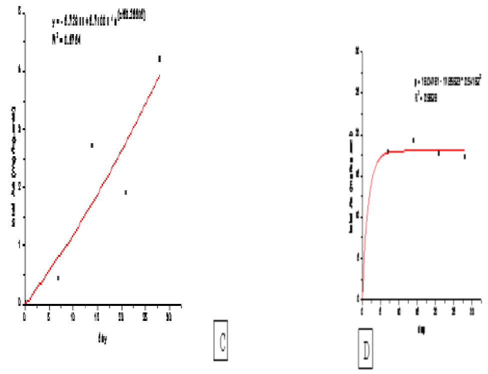

Fig. 2. Total AS absorbion in leaf (C) and roots (D) of *Salvinia molesta*.

The total absorption of As in the roots of *Colocasia esculenta* (L.) Schott var. *Aquatilis Hassk* is shown in (Figure 3). In contrast to the two previous cases, for the models created on the total arsenic roots of *Colocasia esculenta* (L.) Schott var. *Aquatilis Hassk* tended to follow the pattern of distribution of total arsenic polynomial which would increase in a few days to find the highest point (extreme point) and then would decline after that point. In contrast to the modeling leaves which followed an exponential distribution patterns of increasing the total asen would further increase and would be constant at a certain point. The highest As absorption in the roots of *Colocasia esculenta* was obtained at the time of measurement at the third week with a total absorption of as much as 26. 474 mg / kg, while the highest As content in the leaves was found in measurements to fourth weeks, at which time the resulting measurements of As was much as 0.4333 mg / kg.

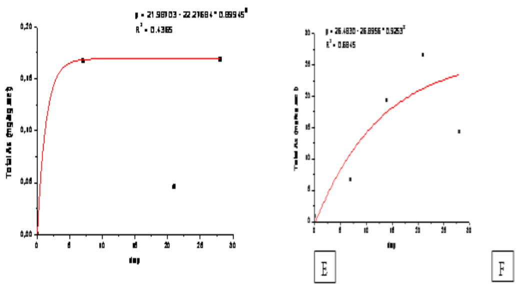

Fig. 3. Total As in root (E) and leaf (F) in *Colocasia esculenta*.

Conclusion

The *Monochoria vaginalis, Salvinia molesta* and *Colocasia esculenta* have ability to absorb As in waste water of Geothermal Power Plant. There are two mathematical models which of AS absorption. The absorption by roots in three species was *exponential asymptotic* while absorption by leaf was *exponential growth*.The highest As content in the root of *Monochoria vaginalis* (22. 289 mg / kg) was occurred in the third week while the highest As content in leaves was obtained at the day of measurement in the fourth week (2.5833 mg / kg). The highest As absorption in the roots of *Salvinia molesta* (19.2335 mg / kg) was obtained at the time of measurement at the second week, while the highest As content in the leaves was found in measurements of the fourth week (4.2100 mg / kg). The highest As absorption in the roots of *Colocasia esculenta* (26. 474 mg / kg) was obtained at the time of measurement at the third week while the highest As content in the leaves (0.4333 mg / kg) was found in measurements in the fourth week.

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References

Ashraf MA, Maah MJ, Yusoff I. 2013. Evaluation of natural Phytoremediation process occurring at Ex-tin Mining Catchment. Chiang Mai Journal Science **40(2)**, 198-213.

Baldwin PR, Butcher DJ. 2007. Phytoremediation of Arsenic by two hyperaccumulators in a hydroponic environment. Microchemical Journal **85(2)**, 297-300.
http://dx.doi.org/10.1016/j.microc.2006.07.005

Ballantyne JM, Moore IN. 1988. Arsenic geochemistry in geothermal systems. Geochimica et Cosmochimica Acta **52(2)**, 475-483.
http://dx.doi.org/10.1016/0016-7037(88)90102-0

Bhattacharya P, Welch AH, Stollenwerk KG, McLaughlin MJ, Bundschuh J, Panaullah G. 2007. Arsenic in the environment: biology and chemistry. Science of the Total Environment **379(2)**, 109-120.
http://dx.doi.org/10.1016/j.scitotenv.2007.02.037

Bindu T, Sumi MM, Ramasamy EV. 2010. Decontamination of water polluted by heavy metals with Taro (*Colocasia esculenta*) cultured in a hydroponic NFT system. The Environmentalist **30(1)**, 35-44.
http://dx.doi.org/10.1007/s10669-009-9240-6

Duker AA, Carranza EJM, Hale M. 2005. Arsenic geochemistry and health. Environment International **31(5)**, 631-641.
http://dx.doi.org/10.1016/j.envint.2004.10.020

Essumang DK, Dodoo DK, Obiri S, Yaney JY. 2007. Arsenic, cadmium, and mercury in cocoyam (*Xanthosoma sagititolium*) and watercocoyam (*Colocasia esculenta*) in Tarkwa a mining community. Bulletin of environmental contamination and toxicology **79(4)**, 377-379.
http://dx.doi.org/10.1007/s00128-007-9244-1

García-de-Lomas J, Dana ED, Ceballos G. 2012. First report of an invading population of *Colocasia esculenta* (L.) Schott in the Iberian Peninsula. Bioinvassion Record **1(2)**, 139-143.
http://dx.doi.org/10.3391/bir.2012.1.2.10

Jomjun N, Siripen T, Maliwan S, Jintapat N, Prasak T, Somporn C, Petch P. 2010. Phytoremediation of arsenic in submerged soil by wetland plants. International Journal of Phytoremediation **13(1)**, 35-46. http://dx.doi.org/10.1080/15226511003671320

Liu J, Dong Y, Xu H, Wang D, Xu J. 2007. Accumulation of Cd, Pb and Zn by 19 wetland plant species in constructed wetland. Journal of hazardous materials **147(3)**, 947-953. http://dx.doi.org/10.1016/j.jhazmat.2007.01.125

Mungkono SJ, Corie IP. 2006. Toksikologi Logam Berat B3 dan Dampaknya terhadap Kesehatan. Jurnal Kesehatan Lingkungan **2(2)**. (Online)

Peraturan Menteri Lingkungan Hidup Nomor 04 Tahun. 2007 Tentang Baku Mutu Air Limbah Bagi Usaha dan/atau Kegiatan Minyak dan Gas Serta Panas Bumi.

Peraturan Pemerintah Republik Indonesia Nomor 82 Tahun. 2001 Tentang Pengelolaan Kualitas Air dan Pengendalian Pencemaran Air.

PGE Lahendong. 2012a. Pemantauan Lingkungan Hidup Kegiatan PT. Pertamina Geothermal energy Area Lahendong Periode Bulan Januari-Maret 2012.

PGE Lahendong. 2012b. Pemantauan Lingkungan Hidup Kegiatan PT. Pertamina Geothermal energy Area Lahendong Periode Bulan April-Juli 2012.

Rahman MA, Hasegawa H. 2011. Aquatic arsenic: phytoremediation using floating floating macrophytes. Chemosphere **83(5)**, 633-646. http://dx.doi.org/10.1016/j.chemosphere.2011.02.045

Rompas RJ. 1995. Kemampuan Tumbuhan Tumpe *(Monocaria vaginalis)* Menyerap Logam Berat Hg dan Zn. Thesis. Universitas Gajah Mada Yogyakarta.

Srivastava M, Ma LQ, Santos JAG. 2006. Three new arsenic hyperaccumulating ferns. Science of the total environment **364(1)**, 24-31. http://dx.doi.org/10.1016/j.scitotenv.2005.11.002

Tambamroong W. 2007. Phytoextraction of arsenic from contaminated soil by Colocasia esculenta (L.) Schott; taro and wild taro. Chulalongkorn University. Graduate School.

Tanaka T. 1988. Distribution of arsenic in the natural environment with emphasis on rocks and soils. Applied Organometallic Chemistry **2(4)**, 283-295. http://dx.doi.org/10.1002/aoc.590020403

Thornton I, Farago M. 1997. The geochemistry of arsenic. In Arsenic. Springer Netherlands, 1-16. http://dx.doi.org/10.1007/978-94-011-5864-0_1

Tlustos P, Pavlikova D, Balik J, Szakova J, Hanc A, Balikova M. 1998. The accumulation of arsenic acid and cadmium in plants and their distribution. Rostlinna Vyroba-UZPI, 44.

Visoottiviseth P, Francesconi K, Sridokchan W. 2002. The potential of Thai indigenous plant species for the phytoremediation of arsenic contaminated land. Environmental Pollution **118(3)**, 453-461. http://dx.doi.org/10.1016/S0269-7491(01)00293-7

Webster JB, Nordstrom DK. 2003. Geothermal Arsenic, In: Welch AH, Stollenwerk KG, eds. Arsenic in Ground Water. Kluwer Academic Pub., 101-125.