Phytoaccumulation of Arsenic from Arsenic Contaminated Soils by Eichhornia Crassipes L., Echinochloa Crusgalli L. and Monochoria Hastata L. in Bangladesh

Subtitle: Phytoaccumulation of As by E. Crassipes, E. Crusgalli and M. Hastata

Md. Shariful Islam[*1], Md. Wahid-Uz-Zaman[2], Md. Mokhlesur Rahman[2]

[1]Department of Agricultural Chemistry, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh
[1]Graduate School of Environmental Science, Hokkaido University, Sapporo 060-0810, Japan
[2]Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh, Bangladesh

*sharif@ees.hokudai.ac.jp; sharifpstu@gmail.com

***Abstract*-Arsenic (As) phytoaccumulation study was conducted with three plant species namely *Eichhornia crassipes* L. (water hyacinth), *Echinochloa crusgalli* L. (barnyard grass) and *Monochoria hastata* L. (water taro) in crop land soils contaminated by naturally and artificially from sodium arsenite ($NaAsO_2$). Phytoaccumulation of As increased significantly with increasing soil As levels. In artificially As contaminated soils, highest As concentration was recorded in water hyacinth (67.9 and 46.83 mg kg^{-1} root and shoot, respectively) followed by water taro and barnyard grass at 100 mg As kg^{-1} treated soil. For naturally As contaminated soils, the highest accumulation of As in barnyard grass (56.93 and 26.50 mg kg^{-1} root and shoot, respectively) followed by water taro and water hyacinth in *Paranpur* soils (116 mg As kg^{-1} soil). The enrichment factor of arsenic in both artificially and naturally arsenic contaminated soils, root and shoot parts of these plant species were found to be in the sequence of soil>root>shoot. In most cases, arsenic translocation factor of soil to root and root to shoot is 0.5 to 1.0 indicated that main application of these plants is for arsenic phytoaccumulation from soil. Highest bio-concentration factor (2300) values were found in barnyard grass root than water taro (2184.55) and water hyacinth (1336.36) and this values always ≥10 times higher (293-2300) in the plant parts grown in the contaminated site compare to uncontaminated site. Current study revealed that, these plant species can be used as arsenic accumulator in arsenic contaminated soils.**

Keywords- Arsenic; Contamination; Bio-concentration Factor; Phytoaccumulation; Soil.

I. INTRODUCTION

Arsenic (As) pollution in ground water has become a major public concern in many countries especially in Bangladesh. Approximately 35–77 million people out of 125 million populations in Bangladesh have faced the risk of exposure to As in their drinking water (Smith et al. 2000). The As contaminated areas in Bangladesh have shown as more than 20 mg As kg^{-1} soil (Zaman *et al*., 2008). High concentration As in surface soil was detected to depend on As contaminated ground water irrigation (Mandal et al. 1996), application of As-based herbicides and pesticides, fertilizers such as chicken manure from Roxarsone fed chiken and mining activities (Onken and Hossner,1996; Christen Kris, 2001). These pollutions could pose a serious threat to plants, human health and the environment through the food chain pathways (Arif, 2001; Bruce et al., 2003; Duxbury et al., 2003; Williams et al., 2006; Zhu et al., 2008). Arsenic is classified as Group-1 carcinogen to humans based on strong epidemiological evidence (Tchounwou *et. al*., 2003). There were about more than fifty arsenicosis patients identified in *Nalitabari* upazila (total population 0.27 million) under *Sherpur* District of Bangladesh due to drinking of As contaminated water (The Daily Amar Desh, December, 2011). According to WHO, the mean daily intake of As through food by adults is in the range of 17-129 µg. Average As concentration in rice grain produced in different parts of Bangladesh is 480 µg kg^{-1}. Considering average consumption of rice grain 454 gm/capita/day average As intake by a Bangladeshi people through only rice grain is 218 µg d^{-1} (SOS-arsenic.net, 2005). Arsenic toxicity depends on its speciation, and generally inorganic As species are more toxic than as compared with those of organic species (Meharg and Hartley-Whitaker, 2002; Jack, 2005). As(III) is more toxic as compared with As(V), and dimethylarsinic acid (DMAA) and monomethylarsonic acid (MMAA) are more toxic than their parent compounds (Petrick et al., 2000). Arsenic remediation technologies from soils include excavation, immobilization, vetrification, soil washing/flushing and phytoremediation (Rahman and Hasegawa, 2011). Phytoremediation is a low cost and eco-friendly technology for cleaning up the contaminated sites (Vamerail *et. al*., 2010). Phytoaccumulation is one of the phytoremediation processes that plant uptake contaminants from the environment and stored in their body. Some terrestrial plant species such as *Agrostis castellana*; *Agrostis delicatula* (Koe, 1994), *Bidens cynapiifolia* (Bech et al., 1997), *Pteris vittata* L. (Ma et al., 2001) and *Pityrogramma calomelanos* L. (Gulz et al., 2005) have been reported to accumulate As from soils. Among them *Pteris vittata* L. accumulates a formidable amount of As from soil (Ma et al., 2001) and stored in the fronds (Tu et al., 2002).

Aquatic macrophytes have ability to concentrate heavy metals in their roots, shoots as well as leaves. However, the accumulation of heavy metals is much higher in roots of these plants (Mishra et al. 2009; Paiva et al. 2009; Mufarrege et al. 2010). Mishra and Tripathi (2008) compared the phytoremediation potential of three aquatic macrophytes and concluded that *Eichhornia crassipes* was more efficient in removal of heavy metals (Fe, Zn, Cu, Cr, and Cd) followed by *Pistia stratiotes* and *Spirodela polyrrhiza*. Rahman et al. (2007) performed a hydroponic experiment with *Spirodela polyrrhiza* L. and found that it uptake about 0.353 µM As g^{-1} from 4.0 µM arsenate solution. Rahman et al. (2008) also reported that external supplementation of ethylene diamine tetra acetic acid (EDTA) in the growth medium of *Spirodela polyrhiza* increased the uptake of As(V) and As(III).

Many researches were conducted on phytoremediation of As using hyper accumulator. There are some problems of the application of hyper accumulators to contaminated soils such as a small biomass and a limited adaptation capacity to the growth condition and cultivation. The selection of plants having strong metal-accumulating ability and being compatible with local weather conditions might yield more immediate practical results than that based solely on a high tolerance to the toxic metal (Murakami and Ae, 2009). So the current research focused on phytoremediation of crop land surface soils using adaptable and high biomass content plants, where As built up by using As contaminated irrigation water, fertilizers, manures and pesticides; and artificially from $NaAsO_2$. Plant species used in this study were common in Bangladesh and can easily grow on the crop land in moist or submerged condition especially in rice field. To study remediation of As contaminated crop land surface soils, these plant species can be used for the phytoaccumulation of As and clean up the soil environment in a eco-friend way.

II. MATERIAL AND METHODS

A. Study Area, Sample Collection and Preparation

Soils were collected from Bangladesh Agricultural University, Mymensingh (Latitude: 24.75° N, Longitude: 90.4° E, Altitude: 17 m), campus at 0-15 cm depth for artificial As contamination. Naturally As contaminated soil was collected from the three As contaminated sites (*Paranpur, Kamorpur and Dholdi*) of *Faridpur* Sadar Upazilla under *Faridpur* district (Latitude: 23.6° N, Longitude: 89.83° E, Altitude: 11 m), Bangladesh, which was known as severely As contaminated area (Hossain et al., 2001). Soil characteristics of control, artificial and naturally As contaminated soil, were given in the Table I. Exactly 5.0 kg soil was taken in a series of plastic pots. The pots were maintained in neutral condition (Table I). The experiment was laid out in a Completely Randomized Design (CRD) with three replications. For artificial As contamination of soil, there were four treatments of As *viz*., 30, 50, 70 and 100 mg As kg^{-1} (ppm) soil from sodium arsenite ($NaAsO_2$) with control soil (Table I) and three replications in both for artificially and naturally As contaminated soils were done. Initially required amount of As dissolved in de-ionized water and mixed properly with soil then 20 mg N from urea and P from triple super phosphate were also added per kg soil before planting. Plant seedlings were collected from Agronomy field of Bangladesh Agricultural University, Mymensingh. Three plants were grown on each pot. The plants were irrigated daily with arsenic free tap water. Plants were uprooted at 45 days after transplanting. Plant height was measured from the ground level to the top of the plants and number of leaves for each plant was recorded at full maturity. Then about 2-3 g air dried plant samples were oven dried at 65ºC temperature for 48 hrs (Rahman et al., 2007). The oven dried samples were cooled and weighed (by digital balance) separately for root and shoot. This procedure was repeated until constant weight was obtained.

TABLE I AGRO-ECOLOGICAL ZONE (AEZ), SOIL SERIES, NAME OF SOIL, ARSENIC CONTENT AND PH VALUE OF THE FARIDPUR SOILS AND BANGLADESH AGRICULTURAL UNIVERSITY (BAU) FARM SOILS

Experiment	AEZ	Soil Series	Name of soils	As (ppm)	pH
Control	Brahmaputra- Jamuna Floodplain	Sonatala	BAU Farm soil	4.3	6.7
Faridpur soil (Naturally As contaminated soils)	Low Ganges River Floodplain	Ishurdi	*Paranpur* Soil	116.0	7.5
			Kamorpur Soil	47.3	7.4
			Dholdi Soil	22.0	7.5
Artificially As contaminated soil	Brahmaputra- Jamuna Floodplain	Sonatala	Soil 1	30.0	6.7
			Soil 2	50.0	6.7
			Soil 3	70.0	6.5
			Soil 4	100.0	6.8

B. Arsenic Analysis

Exactly 0.5 g (oven dry basis) for plant and soil samples was taken into a digestion tube. Five mL of 65% HNO_3 (analytical reagent grade) were added and samples were kept under fume hood for 12 hrs. Then the samples heated on a digestion chamber at 95ºC temperature for 2 hrs. After cooling to room temperature, 3 mL of 30% hydrogen peroxide were added to the digests and the samples were heated again at 120ºC for 20 min and then diluted to 10 mL using de-ionized water and filtered with the help of Whatman No. 42 filter paper and stored in 15 mL plastic bottles. Arsenic contents in the plant and soil was determined with a hydride generator Atomic Absorption Spectrophotometer (Varian, UK), as described by Welsch *et al.* (1990).

C. Enrichment Factor (EF)

The EF has been calculated to derive the degree of soil contamination and heavy metal accumulation in soil and in plants growing on contaminated site with respect to soil and plants growing on uncontaminated soil (Kisku et al., 2000).

EF = Concentration of As in soil or plant parts at contaminated site/ Concentration of As in soil or plant parts at uncontaminated site.

The enrichment factor in the plant parts is an important criterion for the selection of suitable crop species which can be selected for cultivation in a field having higher level of metal contamination or receiving industrial effluent (Barman and Bhargava, 1997).

D. Translocation Factor (TF)

TF or mobilization ratio was calculated to determine relative translocation of metals from soil to other parts (root and shoot) of the plant species (Barman et al., 2000; Gupta et al., 2008).

$$TF = \frac{\text{Concentration of As in plant tissue (parts)}}{\text{Concentration of As in corresponding soil or root}}$$

E. Bio-Concentration Factor (BCF)

The BCF provides an index of the ability of the plant to accumulate the metal with respect to the metal concentration in the substrate. The result of BCF was calculated (L kg^{-1}) as follows (Snyder, 2006).

$$BCF= \frac{\text{Concentration of As in plant tissue (mg kg}^{-1}\text{)}}{\text{Initial concen.of As in external solution (mg L}^{-1}\text{)}}$$

F. Statistical Analysis

The data were statistically analyzed. For each pot, the mean values, standard deviations (SD) and confidence ranges were calculated at the 0.05 probability level as per Duncan's Multiple Range Test (DMRT). Significance of differences between the means was checked by least significant difference (LSD) test. Statistical analysis was performed by MSTATC program and as outlined by Gomez and Gomez (1984).

III. RESULTS AND DISCUSSION

A. Effects of As on Leaves Production

Increasing dose of As decreased significantly the number of leaves of 3 plants in artificially As contaminated soil. Water hyacinth showed the maximum number of leaves in the artificially soil contained 30 ppm As (Fig. 1A). In cases of barnyard grass and water taro, the highest number of leaves per plant was observed in control group. The number of leaves varied from 16-5, 11-5 and 10-6 in water hyacinth, barnyard grass and water taro, respectively (Fig. 1A) due to different As treatments. In naturally As contaminated soil, the highest number of leaves (32) was found in the water hyacinth at 22 mg As kg^{-1} soil and the lowest number of leaves (9) was found in the barnyard grass at 116 mg As kg^{-1} soil shown in Fig. 1D. Similar results were also observed by Mitra (2004) and Sultana (2006) who reported that the number of leaves in some weed species decreased with the increase of soil As concentration.

B. Effects of As on Plant Height

Increasing levels of As decreases the plant height from 30 ppm to onwards (Fig. 1B, 1E). The maximum height was obtained at 30 ppm As treatment for barnyard grass (85 cm) and minimum height was obtained at 100 ppm As for water hyacinth as presented in Fig. 1B. In naturally As contaminated soil, the highest plant height was obtained in barnyard grass (85 cm) at 22 ppm and lowest was at 116 ppm As for water hyacinth (17 cm) shown in Fig. 1E. Arsenic can help the growth of these plants at certain lower level but in excess amount of As, plant growth was decreased. It might suggest that calcium content in leaf and stem was reduced by As treatment (Patrick et al., 2007). Bindu et al. (2010) reported that significant decrease in the relative growth, biomass productivity, and total chlorophyll content were noticed in the taro plant (*Colocasia esculenta*) with an increase in Pb and Cd concentration in the solution and exposure time.

C. Effects of As on Biomass Production

Results shown in Fig. 1C and F indicated that shoot and root biomass production was affected by increasing the As levels. It was significantly ($p<0.05$) reduced the water hyacinth root, barnyard grass shoot and water taro shoot and root biomass content (Fig. 1C). In most cases the biomass content was increased at 30 ppm As and then decreased with increasing As level (Fig. 1C, 1F). The highest biomass (root and shoot combined) was found in water hyacinth (48.43 g) at 22 ppm As (Fig. 1F) and lowest biomass (root and shoot combined) found in barnyard grass (5 g) at 100 ppm As (Fig. 1C). Sultana and Kobayashi (2011) found that, little growth inhibition and biomass production of *barnyard grass* occurred with increasing As concentration. Ebel et al., (2007) have been reported that water hyacinth (*E. crassipes*) grow very fast, enormous biomass production rate and high tolerance to heavy metals polluted wastewater. Giraldo and Garzon (2002) also told that water hyacinth represents a reliable alternative for arsenic bioremediation in aquatic system even though the plant may cause severe water management problems because of its huge vegetative reproduction and high growth rate.

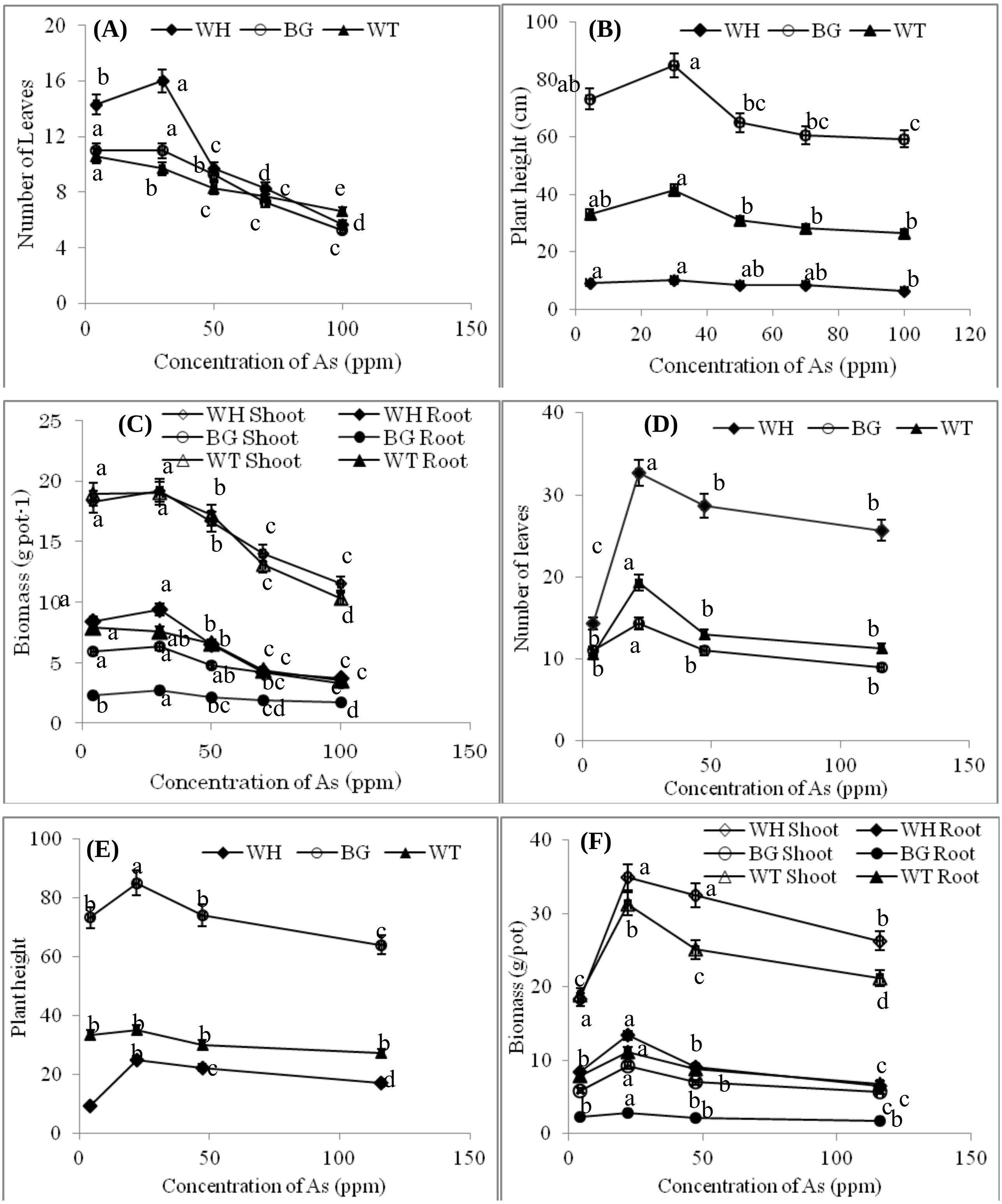


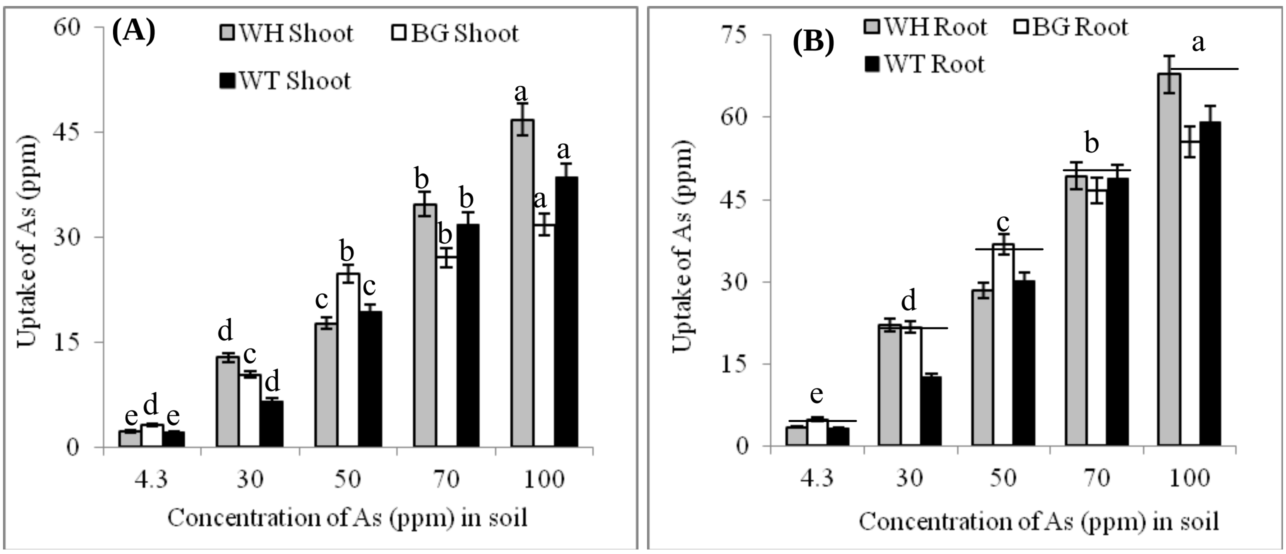
Fig. 1 Effect of different concentration of As (ppm or mg As kg^{-1} soil) on the production of leaves [(A), (D)], plant height [(B), (E)] and biomass production [(C), (F)] of Water hyacinth (WH), Barnyard grass (BG) and Water taro (WT) in artificially [(A),(B),(C)] and naturally [(D),(E),(F)]As contaminated soils Common letter did not differ at 5% level of probability as per DMRT. (n=3)

D. Arsenic Accumulation in Plant Parts

Phytoaccumulation of As was significantly increased in these plant species with increasing soil As levels (Fig. 2). Arsenic accumulation was determined both in root and shoot separately (Tables II and III). In artificially As contaminated soil, highest amount of As accumulation was found in 100 ppm As treatment. The relative distribution of As in shoot and root has been presented in Fig. 2 (A, B). The highest As concentration in shoot was found in case of water hyacinth (46.83 mg As kg^{-1} shoot) followed by barnyard grass (31.77 mg As kg^{-1} shoot) and water taro (38.63 mg As kg^{-1} shoot) (Fig. 2A). Considering the root, the highest As concentration was found in case of water hyacinth (67.90 mg As kg^{-1} root) followed by water taro (59.12 mg As kg^{-1} root) and barnyard grass (55.64 mg As kg^{-1} root) (Fig. 2B). Alvarado et al. (2008) showed that water hyacinth have high As removal efficiency (removal rate of 600 mg As ha^{-1} d^{-1}) from water due to its high biomass production and favorable climatic conditions under field environment and a removal recovery of 18% under laboratory conditions. In naturally As contaminated soil, highest amount of As accumulation was in the root of barnyard grass (56.93 mg As kg^{-1} root) at 116 ppm As containing soil and minimum uptake occurred at 22 ppm As treatment (Table II) in the shoot of water hyacinth (6.17 mg As kg^{-1} shoot). In both shoot and root, the arsenic concentration increased progressively with increased levels of arsenic (Figs. 2C and D). The highest concentration of As in shoot was found in case of barnyard grass (26.50 mg As kg^{-1} shoot) at 116 ppm As treatment (Fig. 2C) followed by water taro (19.77 mg As kg^{-1} shoot) and water hyacinth (17.03 mg As kg^{-1} shoot) shown in Table II. The highest As removal efficiency was found in water hyacinth than other plants due to high biomass production (Fig. 1C). Mishra et al. (2008) also compared As removal efficiency of *Eichhornia crassipes*, *Lemna minor* and *Spirodela polyrhiza* from tropical opencast coalmine effluents and observed that *E. crassipes* had the highest removal efficiency (80%) as compared to other aquatic macrophytes. This study showed that root accumulated higher amount of As than shoot (Fig. 2). Tlustos *et al.*(1998), Mitra (2004) and Sultana (2006) also expressed similar views that some weeds like *joina, water cress* etc. accumulate higher amount As in root than in shoot. Sultana and Kobayashi (2011) found that barnyard grass accumulated more As in root than shoot. According to Hoffmann et al. (2004), As uptake by *Salvinia minima* was increased with increasing As exposure time and concentration in the growth solution. Arsenic accumulation in brake fern (*Pteris vittata*) also increased by increasing As in soils (Ma et al., 2001). High concentration of As (138 mg kg^{-1} fresh wt) has also been found in naturally grown watercress (*Nasturtium microphyllum*) in Taupo Volcanic zone, New Zealand (Robinson et al., 2006) which also supported this study.

E. Enrichment Factor (EF)

EF in naturally and artificially As contaminated soil, root and shoot parts of three plant species were shown in Tables II and III. All values of EF were greater than one which indicates higher availability and distribution of arsenic in soil contaminated by irrigation water or As containing pesticides, fertilizers etc. and added As from $NaAsO_2$ and thereby increasing the metal accumulation in plants species grown on the contaminated soil (Kisku et al., 2000; Gupta et al., 2008). In most cases the sequence of EF is soil>root>shoot. The EF increases in different plant parts with increasing the As concentration in soil. The EF values indicate higher accumulation of As by roots than shoot for all plant species from naturally (Table II) and artificially (Table III) As contaminated soil hence they are suitable for As phytoaccumulation and both root and root can be harvested to clean up arsenic. Ramesh et al. (2010) investigated the accumulation of Cd, Zn, Cr, Pb, Cu, Ni, Mn and Fe in fields contaminated with fly ash from a thermal power plant and subsequent uptake in different parts of naturally grown 11 plants species. From the results, among the eight metals, the maximum EF was found in case of Cd followed by Fe for soil, root and shoot part but in overall, the sequence did not follow any specific pattern – some are more than one and in some cases less than one.



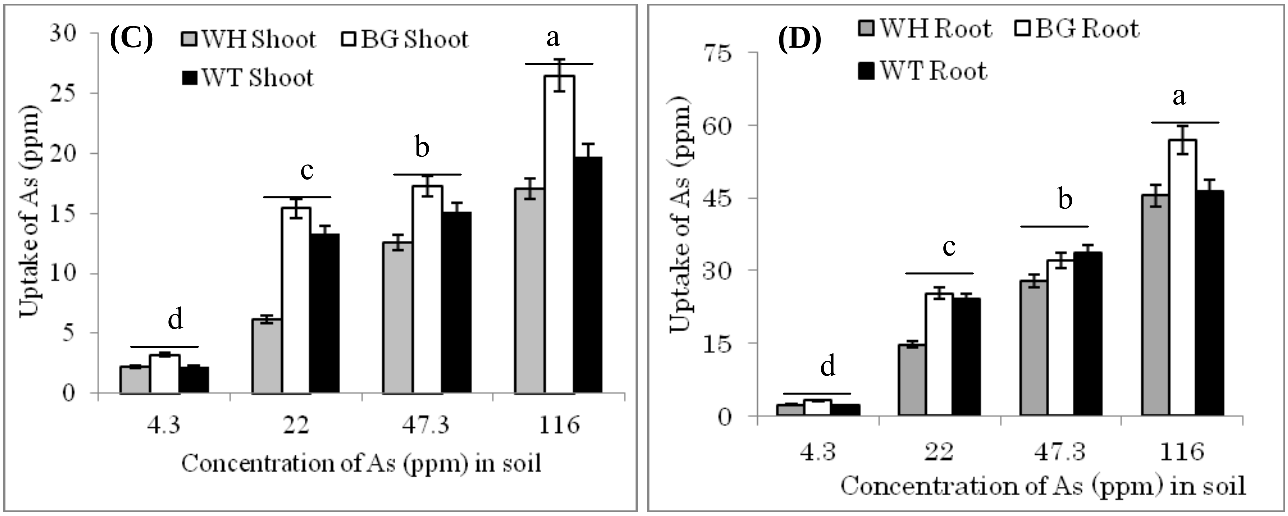


Fig. 2 Arsenic uptaken (ppm or mg As kg^{-1} biomass, oven dry basis) by Water hyacinth (WH), Barnyard grass (BG) and Water taro (WT) shoot (A, D) and root (B, C) from artificially (A, B) and naturally (C,D) As contaminated soil. Common letter did not differ at 5% level of probability as per DMRT (n=3)

F. Translocation Factor (TF)

TF or mobilization ratio of metals from soil to root and root to shoot has been estimated (Tables II and III). In naturally As contaminated soil, soil to root and root to shoot TF increases with decreases As concentration in soil (Table II). In case of 22 ppm As treatment, the translocation of As from soil to root was found to be in the order of Barnyard grass (1.15) >Water taro (1.09) >Water hyacinth (0.67) and when this value was compared with control value it was observed to be higher in the contaminated site for barnyard grass and water taro (Table II). The same order was also found in root to shoot TF but in all cases TF become less than 1.0 indicated slow translocation of As from root to shoot that is, shoot contained lower arsenic than root. Marin et al. (1992) found TF of root to shoot for inorganic As of less than 0.2 for rice cultivars but in this study root to shoot TF for water hyacinth, barnyard grass and water taro ranges from 0.37-0.45, 0.47-0.61 and 0.43-0.55, respectively (Table II).

In artificially As contaminated soils, soil to root and root to shoot TF for each plant species was lower than the uncontaminated soil and in all cases TF less than 1.0 (Table III). Rabb et al. (2007) studied 46 plant species to determine uptake and translocation into shoot of arsenate, methyl arsonate and dimethylarsinate and found that none of the plant species had a shoot to root TF that exceeded 0.9 for arsenate (V), and ranges from 0.01 to 0.84. In this research, root to shoot TFs for water hyacinth, barnyard grass and water taro ranges from 0.58-0.70, 0.48-0.67 and 0.53-0.65, respectively (Table III) for 30, 50, 70 and 100 ppm As treatment. Ramesh et al. (2010) experimented with 11 plant species and average translocation of metals from soil to root was found to be in the order of Cu (1.03)> Ni (0.96) > Mn (0.85) > Zn (0.67) >Pb (0.58) > Cd (0.50) > Fe (0.48) and when this value was compared with control value it was observed to be higher in the contaminated site for Cd, Zn, Cu, Ni, Mn and Fe. In case of root to shoot TF was found in the order of Mn (1.38) > Fe (1.27) > Pb (1.03) > Ni (0.94) > Zn (0.85) > Cd (0.82) > Cr (0.73) and among the metals Mn, Fe, Ni and Pb translocation factor was found to be higher than the control value but Zn, Cd and Cr become lower than the control value. Comparatively the TF values from soil to root and root to shoot showed lower than EF values. One reason for slow translocation of As from root to shoot could be due to that trivalent arsenite are easily trapped in the root, but under anaerobic conditions, much of the As in the cells was a pentavalent arsenate and this arsenate again is partly reduced to arsenite due to the activity of endogenous arsenate reductase enzyme, conjugated with thiols, and sequestered in the root vacuole (Zhu and Rosen, 2009). To express the gene for arsenate reductases, Dhankher et al. (2002) found that over expressing the gene for the *Escherichia coli* arsenate reductase gene, *arsC*, in A*rabidopsis thaliana* under the control of a light-responsive transcription factor led to hypersensitivity to arsenic and arsenite formed $As(GS)_3$ conjugates. Other factor that influences the TF for the different As species is the ability of plants to complex inorganic arsenic as As–phytochelatin (PC) complexes. In experiments with *Helianthus annuus,* it was reported that the formation of these complexes

TABLE II ENRICHMENT FACTOR (EF), TRANSLOCATION FACTOR (TF) OF AS FROM SOIL TO ROOT (S→R), ROOT TO SHOOT (R→S) AND AS UPTAKE (PPM) BY WATER HYACINTH, BARNYARD GRASS AND WATER TARO IN NATURALLY AS CONTAMINATED AND UNCONTAMINATED SOILS

Plant	Treatment of As	Location	Naturally As contaminated soil			Uncontaminated soil			EF
			As uptake (ppm)	TF		As uptake (ppm)	TF		
				S→R	R→S		S→R	R→S	
Water Hyacinth	22 ppm	Shoot	6.17	0.67	0.42	2.23	0.80	0.65	2.77
		Root	14.7			3.44			4.27
		Soil	22			4.3			5.12

Water Hyacinth	47.3 ppm	Shoot	12.53	0.59	0.45	2.23	0.80	0.65	5.62
		Root	27.77			3.44			8.07
		Soil	47.3			4.3			11.00
	116 ppm	Shoot	17.03	0.39	0.37	2.23	0.80	0.65	7.64
		Root	45.5			3.44			13.23
		Soil	116			4.3			26.98
Barnyard grass	22 ppm	Shoot	15.4	1.15	0.61	3.2	1.14	0.65	4.81
		Root	25.3			4.89			5.17
		Soil	22			4.3			5.12
	47.3 ppm	Shoot	17.27	0.68	0.54	3.2	1.14	0.65	5.40
		Root	32.08			4.89			6.56
		Soil	47.3			4.3			11.00
	116 ppm	Shoot	26.5	0.49	0.47	3.2	1.14	0.65	8.28
		Root	56.93			4.89			11.64
		Soil	116			4.3			26.98
Water Taro	22 ppm	Shoot	13.27	1.09	0.55	2.17	0.74	0.68	6.12
		Root	24.03			3.18			7.56
		Soil	22			4.3			5.12
	47.3 ppm	Shoot	15.17	0.71	0.45	2.17	0.74	0.68	6.99
		Root	33.63			3.18			10.58
		Soil	47.3			4.3			11.00
	116 ppm	Shoot	19.77	0.40	0.43	2.17	0.74	0.68	9.11
		Root	46.4			3.18			14.59
		Soil	116			4.3			26.98

was predominantly in the root system (Raab et al., 2005). Since As–PC complexes seem not, as such, to be transport forms of As (none were found in sap samples of *H. annuus* and *B. juncea*), their formation might reduce the translocation of inorganic arsenic (Pickering et al., 2000 and Raab et al., 2005).

TABLE III ENRICHMENT FACTOR (EF), TRANSLOCATION FACTOR (TF) OF AS FROM SOIL TO ROOT (S→R), ROOT TO SHOOT (R→S) AND AS UPTAKE (PPM) BY WATER HYACINTH, BARNYARD GRASS AND WATER TARO IN ARTIFICIALLY AS CONTAMINATED AND UNCONTAMINATED SOILS

Plant	Treatment of As	Location	Artificially As contaminated soil			Uncontaminated soil			EF
			As uptake (ppm)	TF		As uptake (ppm)	TF		
				S→R	R→S		S→R	R→S	
Water Hyacinth	30 ppm	Shoot	12.8	0.64	0.58	2.23	0.80	0.65	5.74
		Root	22.12			3.44			6.43
		Soil	34.3			4.3			7.98
	50 ppm	Shoot	17.7	0.52	0.62	2.23	0.80	0.65	7.94
		Root	28.5			3.44			8.28
		Soil	54.3			4.3			12.63
	70 ppm	Shoot	34.7	0.66	0.70	2.23	0.80	0.65	15.56
		Root	49.35			3.44			14.35
		Soil	74.3			4.3			17.28
	100 ppm	Shoot	46.83	0.65	0.69	2.23	0.80	0.65	21.00
		Root	67.9			3.44			19.74
		Soil	104.3			4.3			24.26
Barnyard grass	30 ppm	Shoot	10.37	0.63	0.48	3.2	1.14	0.65	3.24
		Root	21.68			4.89			4.43
		Soil	34.3			4.3			7.98
	50 ppm	Shoot	24.73	0.68	0.67	3.2	1.14	0.65	7.73
		Root	36.83			4.89			7.53
		Soil	54.3			4.3			12.63
	70 ppm	Shoot	27.07	0.63	0.58	3.2	1.14	0.65	8.46
		Root	46.63			4.89			9.54
		Soil	74.3			4.3			17.28
	100 ppm	Shoot	31.77	0.53	0.57	3.2	1.14	0.65	9.93
		Root	55.64			4.89			11.38
		Soil	104.3			4.3			24.26
Water Taro	30 ppm	Shoot	6.6	0.37	0.53	2.17	0.74	0.68	3.04
		Root	12.54			3.18			3.94
		Soil	34.3			4.3			7.98
	50 ppm	Shoot	19.33	0.56	0.64	2.17	0.74	0.68	8.91
		Root	30.15			3.18			9.48
		Soil	54.3			4.3			12.63
	70 ppm	Shoot	31.9	0.66	0.65	2.17	0.74	0.68	14.70
		Root	48.84			3.18			15.36
		Soil	74.3			4.3			17.28
	100 ppm	Shoot	38.63	0.57	0.65	2.17	0.74	0.68	17.80
		Root	59.12			3.18			18.59
		Soil	104.3			4.3			24.26

G. Bio-Concentration Factor (BCF)

BCF is a useful parameter to evaluate the potential of the plants in accumulating metals and this value was calculated on a dry weight basis. The BCF values of root and shoot of each plant were calculated separately for naturally and artificially As contaminated soil (Table IV). BCF was always higher in root than in shoot. The highest BCF value (2300) was recorded in barnyard grass root at 22 ppm As treatment and lowest in water hyacinth shoot at 116 ppm As treatment (293.62) for naturally As contaminated soil (Table IV). In case of artificially As contaminated soil from $NaAsO_2$, highest BCF found in water hyacinth root (1474.67) at 30 ppm As whereas lowest in water taro shoot (440) at 30 ppm As concentration in soil (Table IV). In all cases, BCF was 10-40 times higher than in control or uncontaminated site for shoot and root of all plants. Anwar et al. (2006) conducted an experiment about exposure and bioavailability of As in contaminated soils from the La Parrilla mine, Spain using *Pteridium aquilinum*, *Erica australis*, *Juncus effuses*, *Phalaris caerulescens* and *Spergula arvensis,* plant species and measured BCF 3.2 to 593.9 for one site and 2.1 to 20.7 for other As contaminated site. Giri and Patel (2011) also found the maximum values of BCF for Cr (VI) and Hg (II) were found to be 413.33 and 502.40 L/kg respectively in water hyacinth where the initial concentration was 0-4 ppm Cr and 0-20 ppm Hg in hydroponic culture and this result was supported our current research. This study showed highest BCF value which indicated that these plants might have the great potentiality for using As phytoaccumulation in As contaminated crop land soils for future applications.

TABLE IV BIO-CONCENTRATION FACTOR (BCF) OF SHOOT AND ROOT OF WATER HYACINTH, BARNYARD GRASS AND WATER TARO FOR AS ACCUMULATION IN NATURALLY AND ARTIFICIALLY AS CONTAMINATED SOILS

Plant	Naturally As contaminated soil			Artificially As contaminated soil		
	As treatment (ppm)	Plant parts	BCF	As treatment (ppm)	Plant parts	BCF
Water hyacinth	4.3 (Control)*	Shoot	38.45	30	Shoot	853.33
		Root	59.31		Root	1474.67
	22	Shoot	560.91	50	Shoot	708.00
		Root	1336.36		Root	1140.00
	47.3	Shoot	529.81	70	Shoot	991.43
		Root	1174.21		Root	1410.00
	116	Shoot	293.62	100	Shoot	936.60
		Root	784.48		Root	1358.00
Barnyard grass	4.3 (Control)*	Shoot	55.17	30	Shoot	691.33
		Root	84.31		Root	1445.33
	22	Shoot	1400.00	50	Shoot	989.20
		Root	2300.00		Root	1473.20
	47.3	Shoot	730.23	70	Shoot	773.43
		Root	1356.45		Root	1332.29
	116	Shoot	456.90	100	Shoot	635.40
		Root	981.55		Root	1112.80
Water taro	4.3 (Control)*	Shoot	37.41	30	Shoot	440.00
		Root	54.83		Root	836.00
	22	Shoot	1206.36	50	Shoot	773.20
		Root	2184.55		Root	1206.00
	47.3	Shoot	641.44	70	Shoot	911.43
		Root	1421.99		Root	1395.43
	116	Shoot	340.86	100	Shoot	772.60
		Root	800.00		Root	1182.40

*Control is both for naturally and artificially contaminated soils.

IV. CONCLUSIONS

Water hyacinth, barnyard grass and water taro were efficient for phytoaccumulation of As in contaminated soils. These plants showed good growth parameter like height, leaves and biomass production upto 25-30 ppm As concentration in soil and then gradually decreased. The highest recovery was recorded in water hyacinth due to higher biomass production. The weather of Bangladesh is very suitable to grow these plants spontaneously in moist and submersed soil condition, so this plant might be considered for cleaning up As contaminated surface soils in Bangladesh. From the enrichment factor, translocation factor and bio-concentration factor, it can be concluded that accumulation of As in roots was always higher than the shoots, and we can easily uproot the plant during moist or submersed soil condition. So all of these are suitable for As phytoaccumulation in crop land soil and have the great potentiality for future applications as an As accumulator in the As contaminated area.

REFERENCES

[1] Alvarado, S., Guedez, M., Lue-Meru, M.P., Nelson, G., Alvaro, A., Jesus, A.C., Gyula, Z. Arsenic removal from waters by bioremediation with the aquatic plants water hyacinth (Eichhornia crassipes) and lesser duckweed (Lemna minor). Bioresour. Technol. 99, 8436–8440(2008).

[2] Anawar H.M., Sanchez A.C., Murciego A. and Buyolo T. Exposure and bioavailability of arsenic in contaminated soils from the La Parrilla mine, Spain. Environ Geol, 50:170-179(2006).

[3] Arif, M. I. Arsenic in food chain due to arsenic contaminated groundwater, MS Thesis, Department of Agricultural Chemistry, BAU, Mymensingh, Bangladesh (2001).

[4] Barman, S.C. and S.K. Bhargava. Accumulation of heavy metals in soil and plants in industrially polluted fields, (In Paul N Cheremissinoff (Ed.), Ecological issues and Environmental Impact Assessment, Gulf Publishing Company, Houston, Texas, USA. pp. 289-314(1997).

[5] Barman, S.C., R.K. Sahu, S.K. Bhargava and C. Chatterjee, Distribution of heavy metals in wheat, mustard and weed grains irrigated with industrial effluents. Bull. Environ. Conta. Toxicol., 64, 489-496(2000).

[6] Bindu T, A M. M. Sumi and A E. V. Ramasamy. Decontamination of water polluted by heavy metals with Taro (Colocasia esculenta) cultured in a hydroponic NFT system. Environmnetalist, 30:35-44(2010).

[7] Bruce, S.L., Noller, B.N., Grigg, A.H., Mullen, B.F., Mulligan, D.R., Ritchie, P.J., Currey, N., Ng, J.C. A field study conducted at Kidston gold mine, to evaluate the impact of arsenic and zinc from mine tailing to grazing cattle. Toxicol. Lett. 137, 23–34(2003).

[8] Bech J. C., Poschenrieder, M. Llugany, J. Barcelo, P. Tume, F.J. Toloias. As and heavy metal contamination of soil and vegetation around a copper mine in Northern Peru. Sci. Total Environ. 203, 83–91(1997).

[9] Christen Kris. Chickens, manure, and arsenic Environ. Sci. Technol., 35 (9), pp 184A–185A (2001).

[10] Ebel, M., Evangelou, M.W.H., Schaeffer, A. Cyanide phytoremediation by water hyacinths (Eichhornia crassipes). Chemosphere 66, 816–823 (2007).

[11] D hankher O.P., Yujing Li, Barry P. Rosen, Jin Shi, David Salt, Julie F. Senecoff, Nupur A. Sashti & Richard B. Meagher. Engineering tolerance and hyperaccumulation of arsenic in plants by combining arsenate reductase andγ-glutamylcysteine synthetase expression. NatureBiotechnology 20, 1140 – 1145 (2002).

[12] Duxbury, J., Mayer, A., Lauren, J., Hassan, N. Food chain aspects of arsenic contamination in Bangladesh: effects on quality and productivity of rice. J. Environ. Sci. Health A Toxic/Hazard. Subs. Environ. Eng. 38, 61–69 (2003).

[13] Giraldo, E., Garzon, A. The potential for water hyacinth to improve the quality of Bogota River water in the Muna reservoir: comparison with the performance of waste stabilization ponds. Water Sci. Technol. 45 (1), 103–110(2002).

[14] Giri, A.K. and Patel, R.K. Toxicity and bioaccumulation potential of Cr (VI) and Hg (II) on differential concentration by Eichhornia crassipes in hydroponic culture. Water Science & Technology 63(5), 899-907 (2011).

[15] Gomez, K. A. and Gomez, A. A. Statistical Procedures for Agricultural Research. 2nd edn. John Wiley and Sons. New York, p. 680 (1984).

[16] Gulz P.A., S.K. Gupta, R. Schulin. Arsenic accumulation of common plants from contaminated soils. Plant soil 272, 337-347(2005).

[17] Gupta, S., S. Nayek, R.N. Saha and S. Satpati. Assessment of heavy metal accumulation in macrophyte, agricultural soil and crop plants adjacent to discharge zone of sponge iron factory. Environ. Geol. 55, 731-739(2008).

[18] Hoffmann, T., Kutter, C., Santamaria, J. Capacity of Salvinia minima Baker to tolerate and accumulate As and Pb. Eng. Life Sci. 4, 61–65 (2004).

[19] Hossain, M.M., Sattar, M.A., Hashem, M.A. and Islam, M.R. Arsenic contamination in some selected soils of Bangladesh. Online Journal of Biological Science. 1(10): 989-992 (2001).

[20] Jack C. N. Environmental contamination of arsenic and its toxicological impact on humans. Environ. Chem. 2, 146–160 (2005).

[21] Kisku, G.C., S.C. Barman and S.K. Bhargava. Contamination of soil and plants with potentially toxic elements irrigated with mixed industrial effluent and its impact on the environment. Water Air Soil Pollut., 120, 121-137(2000).

[22] Koe T. De. Agrostic castellana and Agrostis delicatula on heavy metal and arsenic enriched sites in NE Portugal. Sci. Total Environ. 145, 103–109(1994).

[23] Ma L.Q., K.M. Komar, C. Tu, W. Zhang, Y. Cai, E.D. Kennelley. A fern that hyperaccumulates arsenic. Nature. 409, 579 (2001).

[24] Mandal B.K., Chowdhury T.R., Samanta G., Basu G., Chowdhury P.P., Chanda R. et al. Arsenic in groundwater in seven districts of West Bengal, India – The biggest arsenic calamity in the world. Curr. Sci. 70, 976–986(1996).

[25] Marin A. R. , P. H. Masscheleyn and W. H. Patrick. The influence of chemical form and concentration of arsenic on rice growth and tissue arsenic concentration. Plant and Soil, 139 (2):175-183(1992).

[26] Mishra, V., Upadhyay, A., Pathak, V., Tripathi, B. Phytoremediation of mercury and arsenic from tropical opencast coalmine effluent through naturally occurring aquatic macrophytes. Water Air Soil Pollut. 192, 303–314 (2008).

[27] Mitra, N. Phytoremediation of arsenic contaminated soils by naturally grown weeds, M.S. Thesis, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh, Bangladesh (2004).

[28] Meharg, A.A., Hartley-Whitaker, J. Arsenic uptake and metabolism in arsenic resistant and nonresistant plant species. New Phytol. 154, 29–43 (2002).

[29] Mishra, V.K., and B.D. Tripathi. Concurrent removal and accumulation of heavy metals by the three aquatic macrophytes. Bioresource Technology 99: 7091–7097(2008).

[30] Mishra, V.K., B.D. Tripathi, and K.H. Kim. Removal and accumulation of mercury by aquatic macrophytes from an open cast coal mine effluent. Journal of Hazardous Materials 172:749–754 (2009).

[31] Mufarrege, M.M., H.A. Hadad, and M.A. Maine. Response of Pistia stratiotes to heavy metals (Cr, Ni, and Zn) and phosphorous. Archives of Environmental Contamination and Toxicology. 58: 53–61(2010).

[32] Murakami M. and Ae N. Potential of phytoextraction of copper, lead and zinc by rice (Oryza sativa L.), soybean (Glycine max [L.] Merr.), and maize (Zea mays L.). J. Hazard. Mater. 162, 1185–1192 (2009).

[33] Onken, B.M and Hossner, L.R. Determination of arsenic species in soil solution under flooded conditions. Soil Science Society of American Journal, 60, pp. 1385–1392 (1996).

[34] Petrick, J.S., Ayala-Fierro, F., Cullen, W.R., Carter, D.E., Vasken Aposhian, H. Monomethylarsonous acid (MMA-III) is more toxic than arsenite in change human hepatocytes. Toxicol. Appl. Pharmacol. 163, 203–207 (2000).

[35] Pickering I. J., R. C. Prince, M. J. George, R. D. Smith, G. N.George, D. E. Salt. Reduction and coordination of arsenic in Indian Mustard. Plant Physiol. 122(4), 1171-1178(2000).

[36] Paiva, B.L., J.G. de Oliveira, R.A. Azevedo, D.R. Ribeiro, M.G. da Silva, and A.P. Vito´ria. Ecophysiological responses of water hyacinth exposed to Cr3+ and Cr6+. Environmental and Experimental Botany 65: 403–409(2009).

[37] Patrick R. Baldwin and David J. Butcher. Phytoremediation of arsenic by two hyperaccumulators in a hydroponic environment. Microchemical Journal, 85:297-300(2007).

[38] Raab A., H. Schat, A.A. Meharg and J. Feldmann. Uptake, translocation and transformation of arsenate and arsenite in sunflower (*Helianthus annuus*)–Part 1: formation of arsenic-phytochelatin complexes during exposure to high arsenic concentrations, *New Phytologist,* 168, 551-558(2005).

[39] Raab A., Willium N. P., A.A. Meharg and J. Feldmann. Uptake and translocation of inorganic and methylated arsenic species by plants. Environ. Chem. *4*:197-203(2007).

[40] Rahman, M.A. and H. Hasegawa. Review on Aquatic arsenic: Phytoremediation using floating macrophytes. Chemosphere 83: 633-646 (2011).

[41] Rahman, M.A., H. Hasegawa, K. Ueda, T. Maki, C. Okumura and M.M. Rahman. Arsenic accumulation in duckweed (Spirodela polyrhiza L.): A good option for phytoremediation. Chemosphere 69: 493–499(2007).

[42] Rahman, M.A., H. Hasegawa, K. Ueda, T. Maki, and M.M. Rahman. Influence of EDTA and chemical species on arsenic accumulation in Spirodela polyrhiza L. (duckweed). Ecotoxicology and Environmental Safety 70: 311–318 (2008).

[43] Ramesh Singh, D.P. Singh, Narendra Kumar, S.K. Bhargava and S.C. Barman. Accumulation and translocation of heavy metals in soil and plants from fly ash contaminated area. Journal of Environmental Biology, 31:421-430(2010).

[44] Robinson, B., Kim, N., Marchetti, M., Moni, C., Schroeter, L., van den Dijssel, C., Milne, G., Clothier, B. Arsenic hyperaccumulation by aquatic macrophytes in the Taupo Volcanic Zone, New Zealand. Environ. Exp. Bot. 58, 206–215(2006).

[45] Smith A.H., Lingas E.O. and Rahman M. Bull. World Health Organization 78, 1093 (2000).

[46] SOS-arsenic.net. 35 million (3.5 crore) people facing arsenic contamination-Poor Mitigation Activities. http://www.sos-arsenic.net/english/latest.html, (2005).

[47] Snyder, K.V.W. Removal of Arsenic from Drinking Water by Water Hyacinths (Eichhornia crassipes). J. U.S. S J W P, Volume 1. (2006).

[48] Sultana, R. and Kobayashi, K. Potential of barnyard grass to remediate arsenic-contaminated soil. Weed Biology and Management, 11: 12–17 (2011).

[49] Sultana, R., Zaman, M.W. and Islam, S. M. N. Interaction of arsenic with other elements in arsenic hyperaccumulating weeds. Journal of Bangladesh Agricultural University, 4(2):211-217(2006).

[50] The Daily Amar Desh, Nirapod panir obave Arsenic atonke Nalitabarir ordhek jonogosti-(Crisis of safe drinking water among the half population of Nalitabari upazila due to Arsenic contamination), The daily Bengali newspaper of Bangladesh. Amar Bangla Page (2nd December 2011).

[51] Tchounwou P.B., A.K. Patlolla, J.A. Centeno. Carcinogenic and systemic health effects associated with arsenic exposure-a critical review. Toxicol Pathol 31. 575-588 (2003).

[52] Tlustos, P., Balik, J., Szakova, J. and Pavlikova, D. The accumulation of arsenic in radish biomass when different forms of arsenic were applied to the soil. Rostlinna Vyroba Czech University of Agriculture, 44(1): 7-13(1998).

[53] Tu C., L.Q. Ma, B. Bondada. Arsenic accumulation in the hyperaccumulator Chinese brake and its utilization potential for phytoremediation. Environ. Qual. 31, 1671–1675 (2002).

[54] Vamerali, T., Bandiera, M., Mosca, G. Field crops for phytoremediation of metal-contaminated land: A review. Environ. Chem. Lett. 8, 1–17(2010).

[55] Welsch, F. P., Crock, J. G. and Sanzolone, R. Trace level determination of arsenic and selenium using continuous-flow hydride generator atomic absorption spectrophotometry (HG-AAS). In. B. F. Arbogast (ed.). Quality assurance manual for the Branch of Geochemistry, U. S. Geological Survey. U. S.A., pp.38-45(1990).

[56] WHO (World Health Organization). Arsenic in drinking water URL: http/www. who. Int/inf-fs/en/fact. 210. Hotmai1(1999).

[57] Williams PN, Islam MR, Adomako EE, Raab A, Hossain SA, Zhu YG, Feldmann J, Meharg AA. Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters. Environmental Science & Technology 40: 4903–4908(2006).

[58] Zaman, M. W., Shariful, I. M. and R. M. Mokhlesur. Remediation of arsenic contaminated soils by naturally grown weeds. J. Agrofor. Environ. 2 (1): 123-126 (2008).

[59] Zhu YG, Sun GX, Lei M, Teng M, Liu YX, Chen NC, Wang LH, Carey AM, Deacon C, Raab A et al. High percentage inorganic arsenic content of mining impacted and nonimpacted Chinese rice. Environmental Science & Technology 42: 5008–5013 (2008).

[60] Zhu Y.G. and Rosen B. Perspective for genetic engineering for the Phytoremediation of arsenic-contaminated environments: from imagination to reality? Current Opinion in Biotechnology, 20:220-224(2009).

Md. Shariful Islam, was born in Bangladesh on 25th September 1981. He completed his undergraduate (B.Sc.Ag. Hons.) and graduate (M.S. in Agricultural Chemistry) degree from Bangladesh Agricultural University, Mymensingh, Bangladesh during 2000-2006. After that he joined as a faculty member of Patuakhali Science and Technology University, Patuakhali, Bangladesh. Now he is doing his Ph.D. in the Graduate School of Environmental Science, Hokkaido University, Japan. Mr. Islam has 13 publications in different national and international journals on phytoremediation of heavy metals from environment, water quality assessment and environmental toxicology**.**