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ARSENIC MOVEMENT IN THE PROFILES OF SOME BANGLADESH SOILS

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ABSTRACT

Study on the seasonal movement of arsenic and its retention in the profiles of some selected soils (Aeric Endoaquept) within a catena in the Old Meghna Estuarine Floodplain-a geologic formation having arsenic contaminated aquifers-reveals that arsenic accumulates both in irrigated and in non-irrigated lands to different extent during the dry season. Land types (based on inundation depth during monsoon) and duration of seasonal flooding were found to have a bearing on the movement and accumulation of arsenic in the soil profile. At the same time, internal drainage condition of the soils and intensity of rainfall may also direct the fate of arsenic in soils. Noticeable accumulation of arsenic was evident in all soil horizons of highland and medium highland after irrigation. But in irrigated medium lowland, arsenic accumulated in surface horizons (Ap1g and Ap2g) and deeper C2 horizon (below 0.9 m) only. A remarkable variation in leaching and accumulation of arsenic in the horizons of different irrigated and non-irrigated land was observed after monsoon. Variation in the duration and depth of submergence of soil in the same land type either by irrigation or by natural water might play an important role in determining the movement and retention of arsenic in soils due to their influence on soil properties like the iron, clay and organic matter contents.

Keywords: Arsenic, movement, soil profile and land type.

INTRODUCTION

Millions of people in Bangladesh are dangerously exposed to arsenic contaminated drinking water extracted through shallow tube wells. A considerable number of shallow wells are also used for irrigating agricultural land for rice culture in the dry season (Imamul Huq and Naidu, 2005). The use of groundwater irrigation increased from 30 to 72 percent of total irrigated area during the period 1981 to 2002, while the area irrigated by using shallow tube well increased from 12 to 58 per cent during the same period (Ministry of Agriculture, 2004).

Arsenic occurs naturally in soils with location-specific variability in concentration (Adriano, 1986; Chu, 1994). However, there is a tendency of soil build-up of As in areas where As-contaminated groundwater is used for irrigation with subsequent accumulation of this As in different parts of plant grown on As-contaminated soils (Sanyal and Nasar, 2002; Imamul Huq *et al.*, 2003) albeit different crop plants exhibit different tendencies to accumulate and tolerate As (Adriano, 1986). Sources (shallow aquifers) of irrigation water underlying the Holocene Floodplain are contaminated with arsenic to variable extent (BGS/DPHE, 2001). Although a small portion of the As in the irrigation water does find its way to the growing crops yet, what happens to the rest of the As is a question to be answered. Whether portion of the As is returned to the aquifer or is retained in the soil profile needs to be assessed.

Higher As content has been found in irrigated soils with a very strong relationship between surface and subsoil As, indicating that regions with high surface As would be expected to have high sub-surface As. This may indicate possible leaching of As from surface soils irrigated with ground water containing high level of As into subsurface soils (CSIRO Land and Water, 2002). Rainfall during the dry season as well as the monsoon might also influence As leaching from surface to sub-surface.

Groundwater recharge from rainfall is considerably supplemented by the seasonal flooding (Brammer, 1997). This phenomenon may cause leaching of As from different soil horizons to variable extent. The leaching possibility of As through soil profiles therefore, may have implication on the possible recharging of As in groundwater. As soil is regarded as a sink of arsenic (Ahmed, 2003) and soils in floodplain develop some characteristic morphological features in their profiles due to seasonal flooding, concern about possible accumulation of arsenic in different soil horizons and subsequent leaching of arsenic through soil profiles both in the dry season and in the monsoon to understand the ultimate fate of As in floodplain soils has therefore, come forward (UNICEF, 2001). The accumulation and movement of arsenic in the soil profile again are likely to be varied in a catena (toposequence). The soils, from the context of soil genesis, differ because of variations in relief and drainage in a catena (Plaster, 2003) and such variations are of significance in determining the fate of As particularly due

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Table 1. Flooding Land Type Depth (FAO-UNDP 1988)

Land Type	**Depth of Flooding in Monsoon**
Highland (HL)	Above normal flood level
Medium Highland (MHL)	Flooded up to about 0.9 m
Medium Lowland (MLL)	Flooded up to between 0.9m and 1.8 m
Lowland (LL)	Flooded up to between 1.8 m and 3.0 m
Very Lowland (VLL)	Flooded deeper than 3.0 m

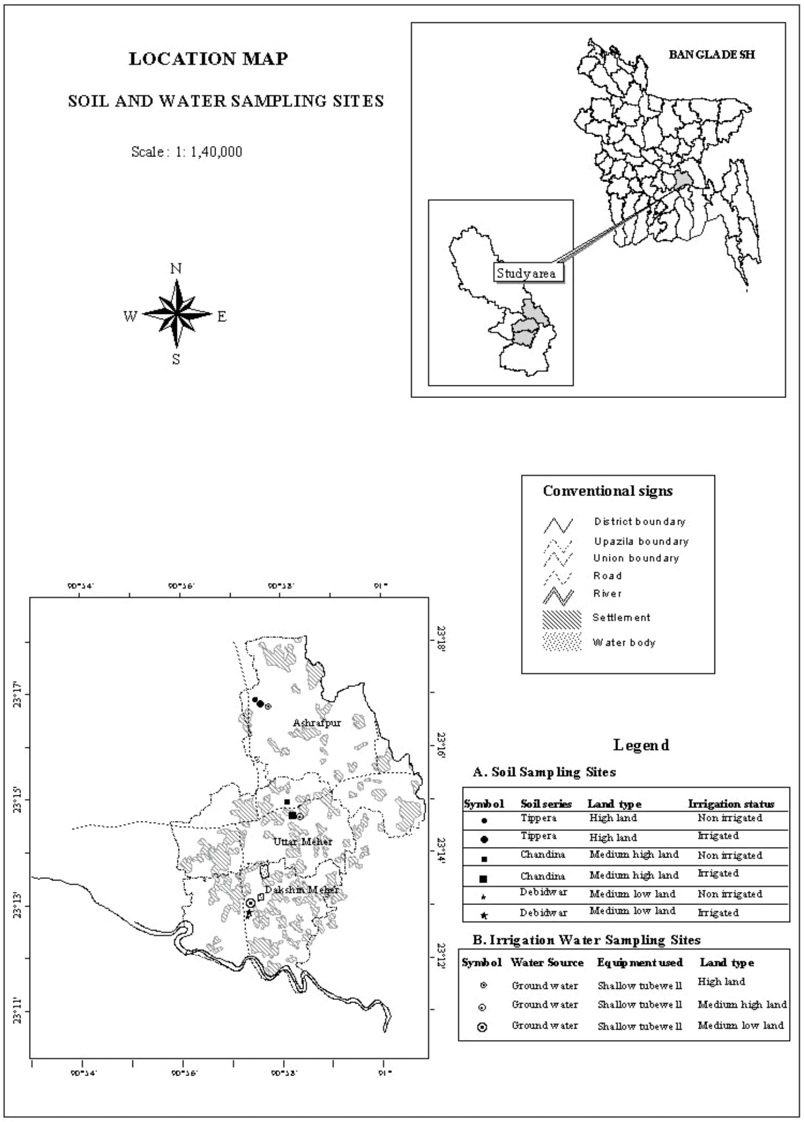

Fig. 1. Map showing GPS-GIS based location of soil and water sample collection sites.

to the changes of their properties induced by irrigation and rainfall.

From this viewpoint, a field based study was undertaken to figure out the extent of leaching and accumulation of As in horizons of the soil profiles of a catena belonging to three different land types (high land, medium high land, medium low land) (Table 1) where irrigation using shallow tube wells prevails in the dry season and submergence of lands occurs during the monsoon for different periods of time.

MATERIALS AND METHODS

Study area

The study area belonging to the Meghna estuarine floodplain is located between $23^0 12.680^/$ to $23^0 16.845^/$N and $90^0 57.146^/$ to $90^0 58.320^/$E (Fig. 1) in the southeastern part of Kachua upazila (sub-district) that continues to the adjoining south-central part of Shahrasti upazila under Chandpur district, - one of the high risk arsenic contaminated areas in Bangladesh (BGS/DPHE, 2001).

The catena selected for the study comprises the *Tippera-Chandina-Debidwar* soil association located in a sequence of land types (Fig. 2) i.e. *Tippera* soil series in the highland, *Chandina* in the medium highland and *Debidwar* in the medium lowland (SRDI Staff, 1965). For a better understanding of the movement and retention of As, soils *(Aeric Endoaquept)* of both irrigated and non-irrigated phases in the same land type were considered. GPS (Geographical Positioning System) was used to locate the soils for reference.

Soil and water sampling

Soil samples were collected separately from depth ranges covering vertically an individual horizon delineated from the adjoining horizons. The samplings were done during the dry, pre-monsoon and post-monsoon periods of 2004 and 2005. Delineation and identification of the soil horizons for the three soil series were accomplished by digging a 1.2 m × 1.2 m × 1.2 m pit. The soil profiles were described following the guideline of Schoeneberger *et al.* (2002) and the nomenclature of the identified horizons was made after SRDI Staff (1965) and was further correlated for standardization with those described by the Soil Survey Staff (2003). Three replicates of sample from each of the horizons of all the profiles were collected.

Groundwater samples were also collected from shallow tube wells installed on different land types following the procedure and precautions as described in Imamul Huq and Alam (2005). Sampling in different phases was done within a fixed timeframe protocol considering the period of dry season irrigation and submergence of soil in the monsoon (Table 2).

After sampling in every phase the soils were air dried followed by breaking down of the large aggregates and removal of root fragments. Air-dried soils were then ground and passed through a 0.5 mm sieve. Bulk of the individual samples was thoroughly mixed and stored for specific laboratory analysis.

Analysis of samples

Soil properties like Fe, clay and organic matter contents were determined following the methods as described in Imamul Huq and Alam (2005). The total soil arsenic was

Table 2. Soil and ground water sampling phase with timeframe and perspective considered for sampling

Sampling phase	Sampling time	Sampling perspective
Phase - 1	January 16-17, 2004 Beginning of dry season (for non-irrigated land) and before the start of irrigation (for irrigated land)	To determine background level of arsenic in soil and ground water.
Phase - 2	May 1-2, 2004 End of dry season (for non-irrigated land) and after irrigation (for irrigated land)	To determine the fate of As in soils under non-irrigated and irrigated condition and to asses the retention of As in soils before flood. Ground water samples were collected to know the change in As concentration in ground water after extraction for irrigation.
Phase - 3	January 15-16, 2005 After monsoon of 2004 i.e. at the start of dry season (for non-irrigated land) as well as before irrigation (for irrigated land).	To determine the consequence of submergence of land in monsoon on the fate of As and to find out the persistence of As in soils. Ground water samples were collected to know change in As concentration in terms of its recharge in ground water after monsoon
Phase - 4	May 1-2, 2005 End of dry season (for non-irrigated land) and after irrigation (for irrigate land)	To make inferences about the fate of As in soils under non-irrigated and irrigated condition in floodplain environment. Ground water samples were collected to find out the trend of changes of As concentration in ground water after extraction for irrigation

Land type	Soil association
Highland (HL)	Settlement
Highland (HL)	Tippera
Medium Highland (MHL)	Chandina
Medium Lowland (MLL)	Debidwar

Fig. 2. Schematic diagram showing the typical position of soils in the catena

extracted by aqua-regia (Portman and Riley, 1964) and the water soluble As was extracted by shaking 10g soil samples with 50 ml distilled water at a 1:5 soil-water ratios for 24 hours. The arsenic in the extracts was estimated by Hydride Generation–Atomic Absorption Spectrophotometer (HG-AAS) with the help of potassium iodide (KI) and urea following calibration of the equipment. With every set of digestion a certified reference material (CRM) was included to ensure the QA/QC. Water samples were analyzed for determining the arsenic concentration by using the same procedure as used for soil-As determination.

RESULTS AND DISCUSSION

Fate of As in soils in the dry season

In all land types of both non-irrigated and irrigated phases, there was a variable increase in the As content in different horizons of the soil profiles during the dry season. The mean aqua-regia extractable (Fig. 3a, 3b, 3c) and the corresponding water extractable As contents (Table 3) in the individual horizons of different non-irrigated lands indicated an increase of As in almost all the horizons. This could happen due to capillary rise of

Table 3. Mean concentration of water extractable As in different soil horizons of different land types under non-irrigated and irrigated phase.

Soil series and Land type	Horizon	Phase	Depth (m)	Mean As concentration (ppm)			
				ASD 2004	AD 2004	ASD 2005*	AD 2005
Tippera, Highland	Ap1g	N.Irr.	0-0.1	0.007	0.002	0.003	0.004
		Irr.	0-0.1	0.005	0.006	0.004	0.007
	Ap2g	N.Irr.	0.1-0.14	bdl	0.004	0.004	0.005
		Irr.	0.1-0.15	0.004	0.007	0.005	0.008
	Bw1g	N.Irr.	0.14-0.29	0.003	0.006	0.003	0.006
		Irr.	0.15-0.28	0.004	0.006	0.004	0.007
	Bw2g	N.Irr.	0.29-0.40	0.004	0.009	0.004	0.007
		Irr.	0.28-0.40	0.003	0.005	0.003	0.007
	B3	N.Irr.	0.40-0.64	0.002	0.006	0.004	0.006
		Irr.	0.40-0.65	0.008	0.009	0.006	0.012
	C1	N.Irr.	0.64-0.88	0.003	0.008	0.004	0.006
		Irr.	0.65-0.90	0.009	0.009	0.008	0.009
	C2	N.Irr.	0.88-1.20	0.003	0.007	0.004	0.007
		Irr.	0.90-1.20	0.007	0.008	0.005	0.009
Chandina, Medium highland	Ap1g	N.Irr.	0-0.14	0.002	bdl	Bdl	bdl
		Irr.	0-0.12	0.006	0.005	Bdl	0.002
	Ap2g	N.Irr.	0.14-0.18	0.002	bdl	0.002	0.002
		Irr.	0.12-0.17	0.002	0.002	Bdl	0.003
	Bw1g	N.Irr.	0.18-0.37	0.009	0.002	Bdl	0.003
		Irr.	0.17-0.36	bdl	bdl	Bdl	0.006
	Bw2g	N.Irr.	0.37-0.67	0.003	bdl	0.002	0.003
		Irr.	0.36-0.60	bdl	bdl	0.003	0.006
	C1	N.Irr.	0.67-0.95	0.004	0.003	0.004	0.003
		Irr.	0.60-0.90	0.003	0.003	0.005	0.007
	C2	N.Irr.	0.95-1.20	0.004	0.003	0.004	0.003
		Irr.	0.90-1.20	0.005	0.005	0.007	0.008
Debidwar, Medium lowland	Ap1g	N.Irr.	0-0.10	0.004	0.003	Bdl	0.003
		Irr.	0-0.12	0.002	0.004	Bdl	0.003
	Ap2g	N.Irr.	0.10-0.15	0.003	0.002	Bdl	0.004
		Irr.	0.12-0.18	0.002	0.006	0.003	0.004
	Bw1g	N.Irr.	0.15-0.35	0.004	0.003	0.002	0.002
		Irr.	0.18-0.35	0.004	0.004	0.003	0.003
	Bw2g	N.Irr.	0.35-0.65	bdl	bdl	Bdl	0.004
		Irr.	0.35-0.58	0.005	0.004	0.005	0.003
	C1	N.Irr.	0.65-0.90	0.005	bdl	0.002	0.003
		Irr.	0.58-0.90	0.007	0.003	0.007	0.004
	C2	N.Irr.	0.90-1.20	0.005	bdl	0.002	0.003
		Irr.	0.90-1.20	0.006	0.007	0.003	0.004

ASD = At the start of dry season, AD = After dry season, N.Irr. = Non-irrigated, Irr. = Irrigated
*After monsoon of 2004; bdl = below detectable level of the machine (0.002 ppm)

water in these soils indicating the fact that As could act as a soluble salt. Exceptions occurred in the soil profile of the non-irrigated medium highland where mean concentration of As decreased in Ap1g horizon. This could happen due either to leaching (by the sporadic rainfall) or to volatilization loss of As in the dry season. The decrease in the C1 and C2 horizons could be due either to capillary movement of water extractable As to the adjoining upper Bw2g horizon or to leaching loss that was not supplemented.

Two years (2004 and 2005) data revealed that the mean concentration of As was noticeably increased in all the soil horizons of the highland and the medium highland after irrigation (Fig. 4a, 4b). But in the irrigated medium lowland, As increase was evident in the surface horizons (Ap1g and Ap2g) and in the deeper (C2) horizons only below a depth of 0.9 m (Fig. 4c). Very little accumulation was noticed in the Bw2g horizon of the irrigated medium lowland soil profile. It needs to be mentioned here that, the Bw2g horizon of the medium lowland is a compact clay horizon consisting of 55.55% clay. This compactness might have played a role in restricting upward or downward movement of water extractable As.

In the irrigated lands, application of groundwater containing variable concentration of As was the main cause for As increase in different soil horizons. This was the consequence of As accumulation in the surface horizon and a subsequent leaching of this As to the lower

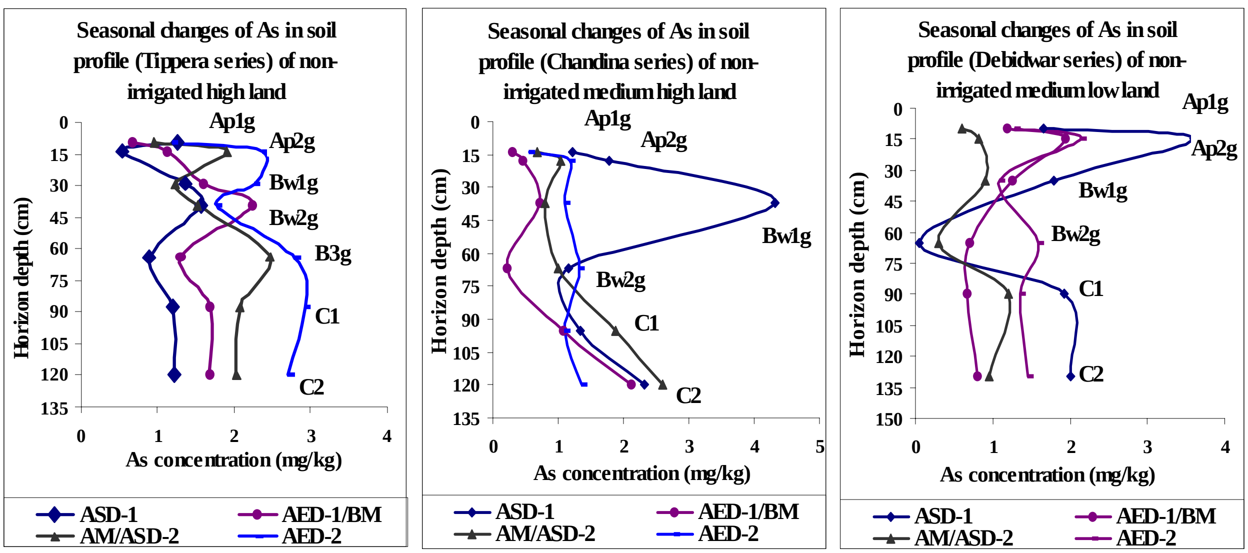

Fig. 3. Seasonal changes in As contents at different horizons of different non-irrigated soils.

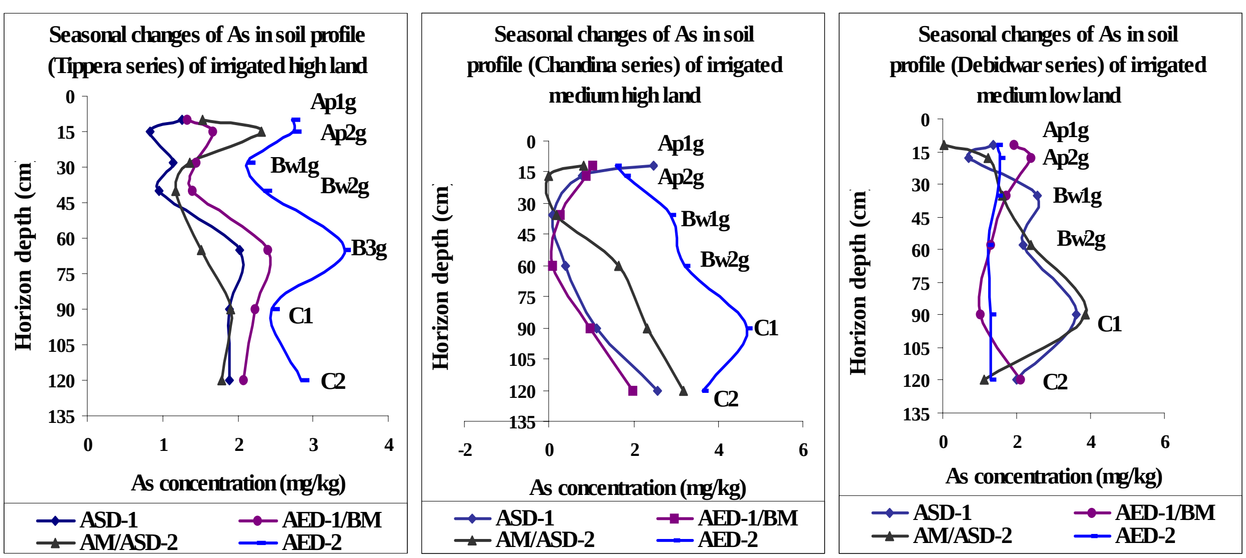

Fig. 4. Seasonal changes in As contents at different horizons of different irrigated soils.

horizons from the adjoining upper horizon due to continuous irrigation.

In the irrigated highland, increase in As concentration was observed to be erratic and insignificant, particularly in the Ap1g from where As could not only be volatilized but also be transferred to rice plants which might be the reason for insignificant accumulation and leaching in Ap2g as well as in Bw1g horizons. On the other hand, a significant ($p = <0.05$) accumulation of As was observed in the Bw2g, B3g, C1 and C2 horizons extending a depth of 0.28 – 1.2 m during the period of irrigation in the dry season. The existence of deeper and more compact plough pans formed due to continuous transplanted rice cropping (rice-rice-rice) prevailing in the irrigated lands might control leaching and accumulation of As in the surface horizons as well as in the subsoil horizons. Soil porosity of individual horizons might be another important factor controlling As leaching and accumulation.

Highly significant ($p = <0.01$) increase of As was observed in almost all the soil horizons of both irrigated and non-irrigated medium highlands and medium lowland during the dry season.

Fate of As in soils in monsoon

The pre- and post-monsoon soil samples from different horizons of both the non-irrigated and the irrigated lands (*i.e*. in between the dry seasons of the two years, 2004 and 2005) showed varying phenomenon in the As retention. It was found that the mean As concentration apparently increased in the upper and lower parts (Ap1g, Ap2g, B3g, C1 and C2 horizon) and decreased in the subsoil horizons (Bw1g and Bw2g) at 0.15-0.65 m depth in the non-irrigated highland (Fig. 3a). But in the irrigated highland, the mean As concentration showed an increasing trend in the upper (surface) horizons (Ap1g and Ap2g) with concomitant decrease in the lower (subsoil) horizons (Bw1g, Bw2g, B3g, C1 and C2) (Fig. 4a). Although both non-irrigated and irrigated highlands are usually submerged during the monsoon for not more than 15 days (SRDI Staff, 1999) yet, remarkable differences in leaching and accumulation of As in different horizons of the soil profiles of non-irrigated and irrigated highlands were observed. In the imperfectly drained highlands where the study was carried out, the groundwater table characteristically remains static within 1.0 m depth from the surface for certain period of time during monsoon (SRDI Staff, 1999). With the recession of this groundwater table, certain amount of As could leach or wash out from the subsoil horizons. Irrigated highlands clearly exhibited the evidence of this attribute as a consequence of remaining wet or saturated permanently. But in the case of non-irrigated highland, the phenomenon takes place only temporarily. Besides, soils of irrigated highlands used for rice culture during the dry season characteristically possess different inherent morphological, chemical and biochemical properties than the non-irrigated highlands that are never used for rice cultivation (Kyuma, 2004). This could have implications on the variability in leaching and accumulation of As although both lands are in the same position of the catena.

In the non-irrigated medium highland, the mean concentration of As increased in all the horizons during monsoon (Fig. 3b). On the other hand, in the irrigated medium high land, the concentration of As decreased in the horizons (Ap1g, Ap2g, and Bw1g) occurring in the upper 0.36 m depth and increased in the Bw2g to deeper C2 horizon at 0.36-1.2 m (Fig. 4b). Both the non-irrigated and irrigated medium highlands are poorly drained. However, there is a variation in depth and duration of submergence due to their position in the catena. The non-irrigated medium highland is submerged with 0.3-0.6 m water column for 1-2 months, whereas the irrigated medium highland remains submerged with 0.6-0.9 m water for 2-3 months (SRDI Staff, 1997). On the contrary, in the poorly drained non-irrigated medium lowland, the decreasing trend of the mean As concentration (Fig. 3c) revealed the evidence of leaching in the upper 0.65 m with subsequent increase of As content in the deeper C1 and C2 horizons at 0.65-1.2 m depth. The irrigated medium lowland showed trends of changes in As concentration in different soil horizons similar to the irrigated medium highland except for C2 horizon where the concentration of As dropped. It needs to be mentioned here that the medium lowlands are usually inundated up to depth of 1.8 m for periods extending up to 6 months (SRDI Staff, 1997). It would therefore, be pertinent here to mention that drainage condition of the land along with its depth and duration of submergence in monsoon play an important role in As leaching and accumulation in different horizons of a soil profile. In the present case the intensity of rainfall in monsoon might be considered as one of the factors in determining the movement and retention of As in the profiles of soils.

Fate of As in relation to soil properties

Arsenic concentration in all the soil horizons was positively correlated with soil properties like Fe, clay and organic matter contents in most cases and followed the order: Fe > clay content > organic matter. This relationship in terms of its extent varied from horizon to horizon in both the non-irrigated and irrigated soils. It was also observed that there might be an interrelated or integrated influence of Fe, clay and organic matter contents of soils irrespective of horizons on the As concentration following an order: Fe + clay > Fe + organic matter > clay + organic matter. This relationship was more noticeable in the irrigated lands than in the non-irrigated lands irrespective of soils. It was also evident from the study that the changes in Fe, clay and organic matter content of different horizons resulting from rainfall and irrigation in the dry season might have influenced the magnitude of the movement and retention of As. Monsoon flooding also had influence on the occurrence of As, particularly in the poorly drained medium highland and medium lowland where finer clay particles are deposited and ultimately transported to the subsurface horizons. However, the fate of arsenic in soil environment is a multifaceted phenomenon in terms of its quantification because numerous factors are involved in retention and movement of As in the soil system. Arsenic can react with and become retained by the solid phase of the soil, be volatilized into the atmosphere as a result of various biological transformations, be taken up by plants or be leached out of the soil in drainage water (McLaren *et al.*, 2006).

Arsenic recharge in groundwater

In the study area, groundwater containing variable concentrations of As was used for irrigating different land types of the catena for rice cultivation in the dry season. It was observed from the two years (2004 and 2005) data that mean As concentrations in groundwater collected from the shallow wells decreased at the end of the dry season. This trend of decreasing As concentration in the groundwater was found to be almost similar (Fig. 5) irrespective of the position of the shallow tube wells in different land types even though the depth of aquifers varied from land type to land type. This could happen as a result of extraction of groundwater from the same aquifer system. But after monsoon, As concentration in groundwater increased following a unique trend irrespective of land types (Fig. 5, AM/ASD-2). Such increase in groundwater As gives an indication that a portion of the retained and accumulated As in soils of both irrigated and non-irrigated lands during dry season could be recharged to the aquifer system after monsoon. During monsoon the lands are usually submerged for certain period of time as a result of extensive rainfall (Fig. 5). When the rain water is drained out of the surface through the soil profiles, water extractable As could move downward and ultimately be added to the groundwater.

Our data revealed that in all cases, the level of As concentrations in groundwater of the different land types of the catena followed the order: Medium Highland > Highland > Medium Lowland. The groundwater movement and flow direction governed by internal drainage condition of water within the same aquifer system might have impact on As concentration in the extracted groundwater. It would therefore, be natural that higher As concentration might be present in groundwater collected from the aquifer of the medium highland where As containing groundwater could flow from aquifer of the highland. But long term submergence of the medium lowland with soils containing higher clay contents in all the horizons remain in a more reduced condition that probably limits the release of As to the aquifer in this land type.

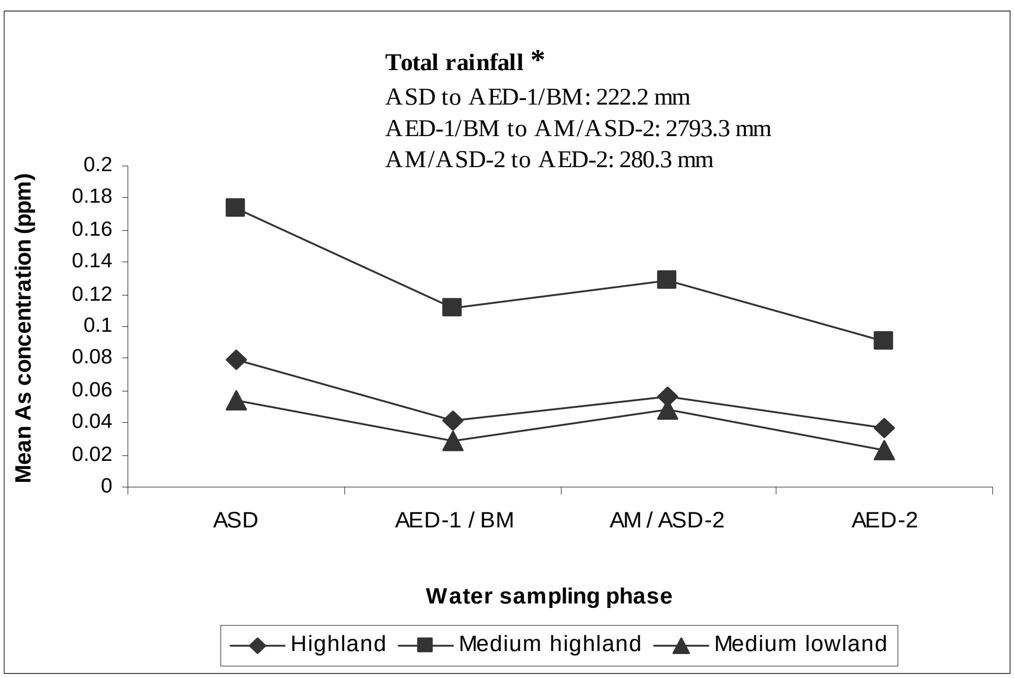

Fig. 5. Changes of As in ground water used for irrigating different land types.
Note: ASD: At the start of dry season, AED: At the end of dry season, BM: Before monsoon
AM: After monsoon, 1 indicates the year 2004 and 2 indicates the year 2005.
**Source:* Bangladesh Rice Research Institute, Regional Station, Comilla. 2005 (Personal communication)

Arsenic increase in the soil horizons resulting from its accumulation and decrease due to movement out of the soil horizons reflected the fate of As in the soils. The present study showed that accumulation and leaching phenomenon of As in soil horizons in both the non-irrigated and irrigated lands are governed by a number of environmental variables like the properties of individual soil horizons, position of the soil profile in the catena, depth and compaction of the plough pan (Ap2g horizon in the soil profile), rainfall intensity during the dry season, depth and duration of submergence of soils in the monsoon, internal drainage condition of the soils and seasonal movement of the groundwater table.

In the study area, like other floodplain areas of Bangladesh, the diversity and complexity of soils are predominantly due to variation in flooding depth (Brammer, 1997) which along with the topographical variations influences the internal drainage condition of the soils (Brammer, 1971). It is known that large amount of materials move from the surface horizon and is deposited in the subsoil horizon due to movement of water through soil horizons (Barshad, 1964). This downward movement of water carrying water extractable As along with clay particles from soil horizons could be one of the most important processes in the differentiation of As content in the soil profile as well as in determining the ultimate fate of As in soils. A thorough knowledge about the movement of arsenic and its subsequent retention in the soil profile could help plan a better management of the underground water for drinking or irrigation purposes to avoid arsenic poisoning among the populations in the affected regions. Area-specific long-term monitoring is indispensable to make a sustainable water resource management plan for the area of interest.

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