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Arsenic Dynamics within Rice Production Systems in the Mekong Delta, Viet Nam

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ABSTRACT

Arsenic is highly toxic and widely occurred in the Mekong delta of Viet Nam. The delta is also known as one of the three deltas in the world that is likely to suffer extreme weather conditions such as flooding, drought, sea level rise, saline intrusion resulting from the variations of climatic conditions. Under changing climate, environmental conditions have been changed. As a result, agricultural practices have also been modified to adapt with changing new circumstances. The shifting in environmental conditions and adaptation practices could result in enhancing mobilization of arsenic in environments thus increasing exposure pathways of arsenic to human health. This paper will discuss the source of arsenic in the Mekong Delta, arsenic mobilization, and potential impact of climate change and adaption strategies on arsenic mobilization within rice production systems. Future research will be recommended to address the knowledge gaps when considering adaptation strategies and the impacts of climate changes in the Mekong delta context.

***Keywords**: Arsenic mobilization; Mekong delta. Climate change, adaptation strategy.*

1. Introduction

The mobilization of naturally occurring arsenic within many Asian mega-deltas, such as the Ganges and the Mekong, has occurred unintentionally through the development of farming systems and water abstraction networks. It is estimated that tens of millions of people in Asia routinely consume groundwater that has unsafe arsenic levels (>10 µg/L) (Polizzotto et al., 2008) and population at risk of chronic arsenic poisoning estimated up to one million in the Mekong delta (Berg et al., 2007).

Climate change could further alter arsenic dynamics within the Mekong delta through hydrological adjustments caused by sea-level rise and rainfall and indirectly via temperature and human adaptations. Human adaptations through increased groundwater abstraction for irrigation and domestic supply, farm system modifications such as dyke construction and alternate wetting and drying rice cultivation techniques and the construction of upstream dams may also change arsenic dynamics.

This review will investigate the source of arsenic in the Mekong Delta and soil pedogenesis, current arsenic mobilization, and the likely impact of climate changes and adaption strategies on arsenic mobilization within rice production systems. Recommendations will be made about pertinent knowledge gaps that need to be addressed when considering adaptation strategies and the potential impacts of climate change.

2. Formation of arsenic rich sediments in the Mekong delta

The Mekong Delta of Viet Nam is located at southernmost part of the Indochina Peninsula, from 8°30' to 11° North in latitude and from 104°30' to 106°50' East in longitude. It is bordered the East Sea in the East, the gulf of Thailand in the Southwest and Cambodia in the Northwest.

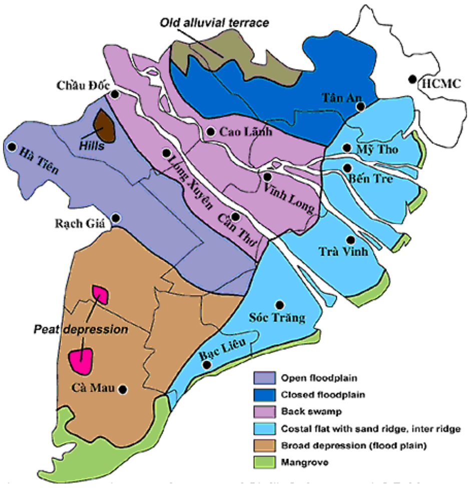

Figure 1. Topographic distribution of the Mekong Delta (Akira and Chiem, 2005).

Basically, the delta was divided into five landform units (**Figure 1**), namely, floodplain, coastal complex, broad depression, ancient alluvial terrace and hills-mountains based on topography, water regime and agro-ecology (Chiem, 1993). Chiem (1993) also stated that there was only old alluvial soil formed during the Tertiary to late Pleistocence period while the other landforms shaped in the Holocence period through transgression and regression. According to Chiem (1993) the foundation layers of the delta are the bedrock and the old alluvial soil which later overlaid by mangrove, marine, transitional, tidal flat, and intertidal sediments formed during marine regression. After the sea had regressed, the topsoil has been deposited with recent freshwater sediments from natural rivers.

Soils in the Mekong delta of Vietnam have been formed and developed through various processes. First soil type in the Mekong delta is the fresh alluvium soil forming from receiving sediments brought by Tien and Hau rivers and their branches originated from Mekong River. This type of soil is very good for agriculture and is accounted for 28% of the whole Mekong delta of Vietnam (approximate to 1,110,000 ha).

Another soil type found in the delta is saline soils where soils are influenced by both marine and riverine environments. These are found along the coast forming the existing saline soil belt in the Mekong delta. They cover an area of 808,749 ha (21% of the delta).

Acid sulphate soils (ASS) are commonly discovered in alluvium soils and saline soils in the Mekong delta. In alluvium soils, ASS found in the Dong Thap Muoi and Long Xuyen quadrangle, in low-lying areas along the Hau River and in parts of the lowlands between the Tien and Hau rivers. This covers an area of 510,027 ha (13% of the delta).

These soils have very high concentrations of sulphate and low pH values ranging from 2.26 to 3.54. In saline soils, ASS found in Ca Mau and along the shores of the Gulf of Thailand covering an area of 1,080,236 ha (28% of the delta).

The other soil types with smaller proportions such as sandy, peat land, the gray soil on old alluvium, mountainous soils are also found in the Mekong delta. Soil distribution of the Mekong delta is shown in **Figure 2**.

In general, soils in the Mekong delta are medium in fertility; high organic matter, low availability phosphorus compared with other paddy soils in other Asian countries; and high capacity of nutrient retention (Pedro et al., 2002).

The arsenic (As) is derived from the weathering of the Himalayas which has been deposited within the Mekong delta floodplain over geological time. A similar source, transport and depositional history has been identified in the Ganges-–Brahmaputra–Meghna River system (Nickson et al., 1998; Harvey et al., 2002; Anawar et al., 2003; van Geen et al., 2003; Islam et al., 2004; Dowling et al., 2002) and is in likely operation in the Irrawaddy River system. Therefore, the Mekong delta was probably supplied by As-bearing sediments from the Upper Mekong basin and also from the fertilizer inputs (Nguyen and Itoi, 2009). Additionally, ASS in the Mekong delta is enriched with As due to the sulphide digenesis during soil pedogensis (Gustafsson and Tin, 1994).

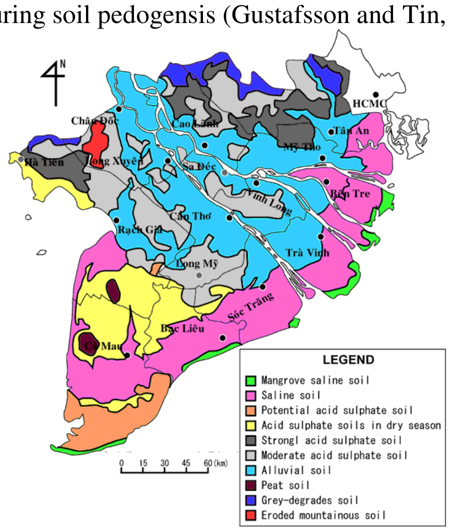

Figure 2. Soil distribution map of the Mekong Delta (Akira and Chiem, 2005).

3. The distribution of naturally occurring arsenic

3.1 Arsenic in soils in the Mekong delta

Several studies have shown that arsenic is naturally present in many soils of the Mekong delta, for example Gustafsson and Tin's study (1994) showed that the arsenic concentration in some acid sulfate soils was between 10-30 mg/kg. According to Vietnamese regulations, soil contaminated by arsenic when its concentration exceeds 5 mg/kg and many ASS soil areas are defined as being "contaminated" with arsenic.

Prior studies indicated that soil in Dong Thap province is slightly contaminated with arsenic. In Cao Lanh district belong to Dong Thap province, soil profile was collected for analysis of arsenic, and the results showed that different depths exhibited different arsenic concentrations (Nhanh et al., 2008) in which surface layer (0-1m) had the lowest arsenic concentration (2.06 µg/kg), the deeper layer (1-6m) had the highest arsenic concentration (118.24 µg/kg) while the layers with the depth of 26-32m and 32-50m had the arsenic concentration of 25,28 and 11,02 µg/kg, respectively. Topsoil samples at four hamlets of Thap Muoi district were collected for arsenic determination and the results revealed that the average concentration of arsenic in this layer is not significantly different with concentrations in the ranges of 0.74-2.15 mg/kg (Mai et al., 2006).

In An Giang province, the investigation of soil arsenic concentrations in four hamlets (namely An Tuc, O Lam, Luong Phi and Luong An Tra in Tri Ton district) was also conducted. The findings demonstrated that arsenic concentrations in soil surface layer (20-25cm) varied from 1.0 to 8.3 mg/kg (Hoa et al., 2006) and there were 12% samples having the arsenic concentrations over the acceptable level at 5 mg/kg. This proved that topsoil layers in these four hamlets have been contaminated by arsenic. The study reported that the topography has effect on the arsenic concentration; for example, there was a significant difference in concentration of arsenic between lower and upper areas. The arsenic concentration in the low-lying area was found to be higher than that of upper area. This is probably because the low-lying areas can store water and materials containing arsenic transported downward. Arsenic was also found at high concentration (5.1 to 9.3 mg/kg) in soil in another district (An Phu) in An Giang province (Nhi et al., 2008).

In Soc Trang province, the arsenic concentrations were reported in the ranges of 1.1- 4.7 mg/kg found in ASS in My Tu district while found to be 1.2-3.5 mg/kg in sandy soil in Vinh Chau district. These concentrations were lower compared to those found in Dong Thap district.

One of the reasons why concentration of arsenic concentration in soil is high is because groundwater highly contaminated with arsenic is used for irrigation. For example, in An Giang, soil contaminated with arsenic up to 33.5 mg/kg when groundwater used for irrigation contaminated with arsenic of 200 µg/L. In contrast, the soil was not contaminated with arsenic when groundwater was not utilized for irrigating (Thu et al., 2011). Similarly, Nhi et al. (2008) found that there was a remarkable correlation (r=0.57) of arsenic concentration between groundwater and topsoil. Other studies found that the arsenic contaminated in soil then could be transferred to biomass. For instance, rice and corn could accumulate arsenic in stem and grain up to 8 mg/kg and 1.8 mg/kg, 1.9 mg/kg and 1.5 mg/kg, respectively (Nhi et al., 2008).

Arsenic contamination in different soils and sediments has also been studied. It was found that arsenic in sulfidic layer in ASS was higher than that of potential ASS and alluvial soil which was found to be 1.023 µg/kg, 635 µg/kg, respectively. Several studies proposed that arsenic is enriched in the ASS because of ASS containing abundance of pyrites (Gustafsson and Tin, 1994). There was an increase trend of sediment-bound arsenic from inland to estuary with the concentration ranged from 3.23 - 14.97 mg/kg and this is because estuarine areas are places where all the materials being transported to and deposited (Nga et al., 2011). It is clearly indicated that arsenic is being circulated in different environmental places and compartments.

3.2 Arsenic in surface waters in the Mekong delta

Arsenic is also found in the surface waters but it is generally very low concentration compared to groundwater. Nga et al. (2011) carried out a study on the assessment of arsenic in surface waters in the Mekong delta. The research results showed that arsenic concentrations increased from inland rivers to estuaries and from the upstream to the downstream of Tien and Hau Rivers. This is consistent with the previous discussion section that low-lying areas contain higher concentrations of arsenic. The arsenic concentrations in saline areas was found to be 4 times higher than permissible level for coastal water quality regulated in Vietnamese National Technical Standards for coastal areas. Arsenic concentrations in saline areas were significant differences from those in brackish and freshwater areas, which averaged concentrations were 49.47 µg/l, 8.51µg/l, and 1.48 µg/l, respectively. It is found from the research that arsenic concentrations had a positive correlation with pH, EC (electrical conductivity) and SS (suspended solids) in brackish areas (Nga et al., 2011). It could be possibly that SS might have carried arsenic to the coastal areas. However, further investigation is needed to conclude the transport of arsenic by sediments.

Arsenic concentrations in surface waters were investigated at the Long Xuyen Triangle, An Giang province. The results showed that arsenic concentrations in surface waters in alluvial soil, heavy and potential ASS areas were 6.49 µg/l, 3.40 µg/l, and 2.29 µg/l, respectively. The concentration of arsenic in surface water of alluvial soil was high due to the concentration of arsenic in the groundwater in the same area was high (Nhe and Hoa, 2006) as previously reported by Thu et al. (2011).

In Ca Mau province, arsenic in surface water was measured at the concentrations of 1.9 µg/l, 6.6 µg/l, 2.13µg/l, 23.3µg/l, 17.7 µg/l at main channels of Phung Hiep, Tac Van, Ganh Hao, and Bay Hap, respectively (Nga et al., 2011). It is obviously that these concentrations were much higher than those found in the inland rivers.

Arsenic in surface waters are sometimes higher than the acceptable level regulated by EU and WHO. This may pose a serious threat to human health and other organisms in aquatic environments.

3.3 Arsenic in groundwater in the Mekong delta

In the last decades, a rapidly growing in rural population has forced people in the Mekong delta to shift from using surface water to groundwater use. With the rapidly economic development, surface water quality is getting worse because of pollution thus tube-wells drilling for primary and additional water supply is of a good choice. Groundwater is mainly used for domestic use accounting for 76% including cooking, bathing and washing, for irrigation (43%) and for other purposes such as industry and rice production (35%). However, groundwater arsenic pollution has been becoming major health risk in the Mekong delta (Berg et al., 2007; Winkel et al., 2011). Previous study showed that groundwater arsenic concentrations in the Mekong delta ranged from 1 to 845 µg/L and averaged at 39 µg/L (Berg et al., 2007). This concentration was higher than the safety level for arsenic concentration in drinking water as recommended by World Health Organization and Vietnamese government.

Arsenic contamination in tube-wells has been detected in many provinces in the Mekong delta. Hai (2006) found that there were approximately 60 to 80% of groundwater wells in Dong Thap province contaminated by arsenic with the concentrations ranged from 100 to 500 µg/l. The study also indicated that high concentration of arsenic in groundwater was commonly found in the shallow tube-wells of 60-m depth. Arsenic concentration of greater than 50 µg/l was found in Thanh Binh, Cao Lanh, Tam Nong, Tan Hong, and Sa Dec districts while arsenic concentration in between 11-50 µg/l found in Hong Ngu and Lai Vung (Nhanh et al., 2008). Furthermore, more than 30% of tube-wells have been contaminated with arsenic at the concentration of greater than 10 µg/l in Thap Muoi district, Dong Thap province (Mai et al., 2006).

Among 3,000 groundwater wells in An Giang province, there were 40% of wells contaminated with arsenic at the concentration greater than 50 µg/l and 16% of wells had arsenic concentration lower than 50 µg/l (UNICEF and Vietnam Public Health Institute, 2006). In Tri Ton district of An Giang province, the study of Hoa (2006) revealed that the mean arsenic concentration in groundwater is still under the standards of 50 µg/l for arsenic affected areas in developing countries including Vietnam. However, there were 15% of groundwater wells having the arsenic concentration of greater than 10 µg/l exceeding minimum allowable level for drinking water according to regulations of EU and WHO. The over standard groundwater samples were commonly seen at wells aged 8-10 years with the depth of 14-40m. Additionally, the study also reported that there was insignificantly different in the concentrations of arsenic between rainy season and dry season. However, there was noticeable difference between upper and lower lying areas of groundwater wells. Arsenic in groundwater samples in the higher areas was found to be higher than that of in lower lying area due to difference in geological materials containing arsenic.

An Phu, is another district of An Giang province, is highly contaminated with arsenic in groundwater. The concentration of arsenic in three villages including Quoc Thai, Phuoc Hung and Khanh An were 230, 302, and 139 µg/l, respectively (Nhi et al., 2008). Previous studies at the same place also indicated that the arsenic concentrations in groundwater ranged from 100 to 751 µg/l (An Giang Medical Center, 2005) and from 100 to 845 µg/l (Thu et al., 2011). There is some certain level of difference in the reported results of arsenic contamination in An Phu but one thing should be noted that the arsenic concentration is very high and far exceeds the safety levels regulated by Viet Nam, EU and WHO. This poses a serious threat to human health if the contaminated water is frequently consumed.

Arsenic concentrations in groundwater vary according to different soil types. One study showed that arsenic concentration in groundwater of alluvial soil is higher than that of heavy acid sulfate soil (ASS) and potential ASS. For example, arsenic concentrations of 36.39 µg/l, 11.34 µg/l, and 2.53 µg/l were found in groundwater in alluvial soil, heavy ASS and potential ASS respectively (Nhe et al., 2006). The higher concentration of arsenic in groundwater in alluvial soil is because the affinity between arsenic and ferrous oxides is low when pH increased and thus arsenic is easier to be dissolved in alluvial soil and the reduction of hydrous ferric oxides in alluvial sediments (Nga et al., 2011).

In Can Tho city, there were several studies on certain districts indicated that concentrations of arsenic in groundwater were high in Binh Thuy (36.39 µg/l) and Cai Rang (224.62 µg/l) (Nhe and Hoa, 2006), Vinh Trinh (42 µg/l), Long Tuyen (1.51µg/l), Thot Not (1.61µg/l) (Chi et al, 2009).

It could be concluded that groundwater in the Mekong delta was heavily contaminated with arsenic and the magnitude of concentration varied depending on geological materials exposing to groundwater. The frequent use of groundwater for daily activity could be resulting in high risk level for human health.

3.4 Plant uptake of arsenic in the Mekong delta

As previously mentioned, it has been proven that irrigation of arsenic-contaminated groundwater for rice cultivation has resulted in high deposition of arsenic in topsoil layers. The uptake of arsenic into rice grain has been well documented around the world. For example, total concentration of arsenic in raw rice in Australia has been recorded at the concentration in the ranges of 0.02-0.04 $\mu g.g^{-1}$d.wt, in China the arsenic concentration varied from 0.14-0.93 $\mu g.g^{-1}$d.wt, in the United States 0.25-0.30 $\mu g.g^{-1}$d.wt, in West Bengal (India) 0.08-0.33 $\mu g.g^{-1}$d.wt, in Tawan 0.05-0.76 $\mu g.g^{-1}$d.wt and in Europe 0.13-0.20 $\mu g.g^{-1}$d.wt (Rahman and Hasegawa, 2011).

In Vietnam, arsenic in raw rice has also been reported in the ranges of 0.03-0.47 $\mu g.g^{-1}$d.wt (Rahman and Hasegawa, 2011). For the Mekong delta, data of arsenic accumulation in plants is still limited. However, a preliminary study revealed that rice and other crop cultivation by using arsenic contaminated groundwater could trigger accumulation of arsenic into rice and corn. In An Giang province, it was found that soil contaminated with arsenic up to 33.5 mg/kg where As contaminated groundwater (200 µg/l) was used for irrigating the crop (Thu et al., 2011). Practical experiments have showed that the arsenic contaminated in soil then could be transferred to biomass. For instance, rice and corn could accumulate arsenic in stem and grain up to 8 mg/kg and 1.8 mg/kg, 1.9 mg/kg and 1.5 mg/kg, respectively (Nhi et al., 2008).

It is clear that arsenic is being mobilized in the groundwater, surface water and soils and up taken in rice plants under current conditions. In the future the mobilization of arsenic could be enhanced under climate change. Key factors which are likely to influence on arsenic circulation should be identified.

4. Factors effect on arsenic concentration and its mobilizations

As desorption/dissolution is generally considered to be mediated by ligand exchange reactions

The major mineral binding arsenic in sediments are metal oxides particularly those of Fe, Al, and Mn (Smedley and Kinniburgh, 2002). Clays also absorb arsenic because of the oxide-like character to their edges. For arsenic adsorption, uncertainties still remain in relation to the interactions of As^{3+} and As^{5+} in the presence of other interacting ions. For example, Fe oxides are probably the most important adsorbents in sandy aquifers because of their greater abundance and the strong binding affinity. Nevertheless, Al oxides can also be expected to play a significant role when present in significant quantity (Smedley and Kinniburgh, 2002).

Competing species such as phosphorus also has effect on arsenic release. Nhi et al. (2008) found there is a strong correlation between dissolved phosphorus and total phosphorus and arsenic concentration with correlation coefficients of 0.5 and 0.52, respectively. Smedley and Kinniburgh (2002) also reported that phosphate also has great effect on the transport of arsenic in the environment. The correlation is explained because phosphorus and arsenic have the similar structure and phosphorus may replace arsenic when phosphorus is introduced into the environment through fertilization. As a result, more phosphorus fertilizer applied, more arsenic will be released into the environments.

Reduction–oxidation (redox) processes

The mobility of arsenic depends the aerobic and anaerobic conditions of the soil. In anoxic conditions (soils, sediment, aquifers) a series of reduction reactions may occur causing changes in Fe redox chemistry and affect the mobility of arsenic. One of the principal causes of high concentrations in subsurface waters is the reductive dissolution of hydrous Fe oxides and the release of adsorbed or combined arsenic (Smedley and Kinniburgh, 2002). Nguyen and Itoi (2009) studied the release mechanism of arsenic and concluded that there are two mechanisms. Firstly, arsenic released when $Fe(OH)_3$ containing arsenic dissolved under reducing conditions. Secondly, FeS_2 containing arsenic is oxidized under oxidizing condition. Nguyen and Itoi (2009) also found that there is a positive correlation of As with Fe and Mn oxides in the Mekong delta core samples.

Dissolution of As-bearing solid phases

Kocar et al (2008) state that the release of As during the onset of reducing conditions and ensuing reductive dissolution of As-bearing Fe (hydr)oxides is generally ascribed as the dominant means of displacement from the solid phase (McArthur et al., 2001; Ahmed et al., 2004). This hypothesis is supported by correlations between As and oxalate (solid phase) extractable Fe(III) in the aquifer sediments, as well as correlations between Fe(II) and soluble As in well waters (McArthur et al., 2001; Ahmed et al., 2004).

The above discussion showed that occurrence of arsenic concentrations and its mobility are dependent on ligands exchange reactions and the redox conditions in the environments.

5. Arsenic dynamics in future

5.1. Climate change and arsenic dynamics

The water level in the Mekong Delta is influenced by water discharge of the Mekong River as well as the tidal variations in the East Sea and the West sea (Gulf of Thailand). The Mekong delta is predicted to suffer excessive flooding in the tidally inundated areas and longer flooding periods (Wassmann et al., 2003). Consequently, these adverse impacts could affect all three cropping seasons, Autumn-Winter, Winter–Spring, and Summer–Autumn in the Mekong delta.

It is predicted that by 2100 in Viet Nam, sea level rise [according the scenarios of low emission (B1), average emission (B2) and the highest emission (A1F1)] will have risen 65 cm to 100 cm compared to the period 1980-1999 (MONRE, 2012). Under the worst-case scenario of 100 cm sea level rise (SLR) by 2100, the area of the Mekong Delta seriously inundated (Deltares, 2010; MONRE, 2012). The sea level rise could cause impact on inundation and drainage of the Mekong delta because it is a low land area. Most natural area of the delta has an elevation of +2.0m while water level of the East Sea tide could rise up to +2.14m. Thus, under high tide of the East and West Seas, the Mekong Delta would suffer great harm under the effect of sea water rising in the future (Van, 2010). Sea level rises-up to 1m, 39% natural area of the Mekong Delta would be flooded (MONRE, 2012).

The sea level rising obstructing directly flood discharge to sea would make water levels in main rivers rise higher than it would be causing flooding in a wider area and longer flooding duration. The early flood would be higher in the future and duration of the ending flood drainage for the entire delta would be longer affecting directly the cultivation of winter-Spring crop cultivation in the Delta. It is likely that height of the present dyke for residential areas would be threatened when water level rising higher than planned. Water level in rivers and canals rising high would also result in drainage of local rain-water, particularly in urban and residential areas (Van, 2010).

As discussed previously, the Mekong delta has dense river systems and under strong tidal effect of the Seas, once sea level rises sea water could be conveyed further in main rivers.

There are some ways that sea level rise could have effect on arsenic dynamics. *Firstly*, flooding due to sea level rise could change redox conditions resulting in changing reduction and oxidation states of arsenic thus changing its mobility. *Secondly*, saline intrusion due to sea level rise, fresh water will become scarce for domestic use and agricultural production and this could lead to intensively abstract underground water for those activities. In some areas, intensive pumping arsenic contaminated groundwater for irrigation could move arsenic from underground to topsoil then arsenic could find its way to surface waters and may be to biomass.

Drought can be happened frequently and prolonged under changing climate. To maintain rice production, irrigation (using both surface and ground water) is obviously needed. If surface water is used for irrigation, it has increased annual recharge to aquifers, thus infiltrating irrigation waters leach arsenic from surficial sediment to the underlying aquifer (Polizzotto et al., 2008; Busbee et al., 2009). Moreover, long term irrigation can cause changes of biogeochemical and redox condition in the aquifer system. Consequently, the mobilization of arsenic can change following the change of biogeochemical and redox condition (Xie et al., 2012).

In case, groundwater is pumped for irrigation, additional source of arsenic added to the topsoil and surface waters then infiltrate to unsaturated zone or arsenic can be up taken to biomass creating a complex arsenic cycle.

In the dry season, flow in the Mekong is insufficient to prevent saline intrusion and extensive salinization of waterways occurs in the lower Delta. The effect of salt water intrusion on mobility of arsenic as that has just been discussed previously.

Trend analysis of the starting and ending days of rainy season shows that the rainy season has been elongated by 6 days over the period 1970 – 2007; starting overall 3 days earlier and lasting 3 days longer.

So, along with the lengthening of rainy season, the average rainfall in Mekong Delta increased considerably. With average annual rainfall of about approximately 1700 mm in Mekong Delta, the rate of rainfall increase over this 37-year period is 5.5% (Deltares, 2010). The increase of rainfall in a certain period of time may change the redox processes due to water stagnancy, submergence and cause change in arsenic mobility. The rainwater flow may also transport arsenic from topsoil to surface waters causing water pollution. In addition, the drainage of ponded water may cause quality of water contaminated with arsenic.

5.2. Climate change adaptations and arsenic dynamics

For some decades Vietnamese farmers have been adapting to the changing environmental conditions by modifying and diversifying their production systems and water management. One example of water management is water-saving technology that has been applied. With the best management, the technique can reduce the amount of water irrigated and does not reduce yield. This technique is therefore called safe alternate wetting and drying or safe AWD (Tuong and Macdonald, 2011). In brief, the safe

AWD is implemented in the way that irrigation is done when the water depth (from the soil surface) about 15cm at which soil water tension in the root zone is always less than 10 kPa. When the water level observed in the field drops to 15 cm below the soil surface, irrigation should be applied to re-flood the field up to 5 cm; field is kept flooded 10 days after transplanting (DAT) or 20 days after direct seeding (DAS), and most importantly flooded field is required at least a week after rice at flowering stage.

Water scarcity is becoming a constraint that is predicted to become more severity in future. In rice production in favorable provinces (An Giang, Can Tho), water scarcity is a major impediment in Winter-Spring and Summer–Autumn seasons. In Winter-Spring, water shortage occurs at the end of the season, during flowering and milky stages of the crop, while in Summer–Autumn, it occurs at the early stage of the crop. In unfavorable coastal province as Bac Lieu, water scarcity is more seriously. The winter – spring season is impossible for a large area due to shortage of irrigation water. The summer-autumn and autumn-winter have suffered freshwater and saline intrusion.

Several studies have proven that an appropriate AWD strategy will improve water use efficiency without reducing rice yield (Tuong and Macdonald, 2011). However, AWD exposes the soil to temporary aerobic and anaerobic conditions and this may rapidly change soil and water chemistry.

Exposure of paddy soil which is ASS to the air may cause acidity problem. Major soil types in the Mekong delta are classified as ASS and if AWD is applied in rice production in these ASS areas and water level in the “drying period” is lowered 15cm creating condition for air to expose to pyrite materials yielding iron sulphate and sulphuric acid. In some cases, pyrite is oxidized more rapidly by dissolved Fe (III) than by oxygen (Attanandana and Vacharotavan, 1986). Most of the iron (II), hydrogen, and sulphate ions released from pyrite oxidation will have further reactions in the soil and water (Attanandana and Vacharotavan, 1986). In saline areas, drying period in AWD may cause salinization due to capillary a process that brings salt up to the soil surface.

In contrast, preventing the air from contacting with the soil during the flooded period in AWD can create anoxic environment which is known is very favorable for release of As through reductive dissolution of hydrous Fe oxides and the release of adsorbed or combined As (Smedley and Kinniburgh, 2002; Nguyen and Itoi, 2009).

Applying AWD brings economic benefits for rice producers but may destroy natural ecosystems and human health through oxidation of pyrite in ASS (drying period) and reductive dissolution arsenic (flooded period) because AWD expose agricultural soils to temporarily oxic and anoxic environments. In addition, in coastal areas where now is rice producing but previously saline is in the verge of salinization in the drying period of AWD application.

In the Mekong delta, groundwater provides water through groundwater wells (small, medium and large-scale) from five main aquifers namely Holocene; Upper-Middle Pleistocene; Lower Pleistocene; Pliocene; and Upper Miocene. Groundwater is mainly used for domestic use, urban water supply, irrigation, aquaculture and industrial areas (IUCN, 2011). In agricultural production in the Mekong delta, surface water from rivers, lakes and dams is the main source of water used for irrigation. However, in the dry season, as discussed previously, both favorable and unfavorable provinces face problems associated with water scarcity and groundwater will become a primary source for both irrigation and domestic use. In order to meet national food security, third crop has been proposed and implemented in favorable places with full dykes systems causing increasing water demand that require abstraction water from the ground for irrigation. As previously discussed, groundwater in the Mekong delta has a great potential risk of contamination with high level of arsenic and once pumped up for agricultural irrigation may transport arsenic to topsoil where it can be further propagated into surface water and taken up into plant biomass.

Major rice based farming systems in the Mekong delta are triple rice, double rice, mono rice production, rice cultivation in rotation with upland crops. In the coastal province like Bac Lieu, shrimp farming is also found integrated with rice production forming rice-shrimp farming system (Dung et al., 2011). Dung et al. (2011) also found that the main constraints for the main rice based farming systems are abnormal rains, big floods, droughts, high temperature, and salinity intrusion. The farming systems are expected to have relation with arsenic mobilization through using groundwater for irrigation. Rice intensification, cultivation of rice in drought period and in saline areas needs a significant abstraction of groundwater for irrigation. This abstraction will bring arsenic contaminated groundwater to surface soil and water and end up in biomass or transported into the environments where human may have more opportunities to get exposed.

From the main constraints such as abnormal rains, big floods, droughts, high temperature, and salinity intrusion as well as the expectation in increasing agricultural production primarily in production of rice, engineering measures have been taken into account. Eight crops per 3 years (it should be 9 crops/3 years but 01 crop is used for receiving flood water into the fields to improve soil quality, sediment brought into the field for fertile to increase productivity for the following crops in the following years) is the target of An Giang province (DARD, 2010). To obtain the goal, An Giang had proposed plan period 2010-2015 for development of full-dyke system construction for third crop production (Autumn-Winter season) in entire An Giang province. The shifting from double to triple crop per year may have constraints on the availability of fresh water in the rivers in the dry season and flooding in the wet season. The increasing demand of water for third crop production may result in increasing abstraction groundwater that was reported heavily contaminated with arsenic for irrigation. Canal dredging and enlargement as well as sluice construction and operation on the one side may increase capacity of water transport for irrigation which is contributing to higher agricultural production but on the other side it may also increase chance for pollutants such as arsenic to be more actively mobilized.

Climate change and adaption strategies influence on environmental conditions and water sources of use that could enhance dynamic of arsenic in the Mekong delta of Viet Nam. This issue is very challenging for human health in the future, thus effective measure should be planned.

6. Conclusion remarks

Climate change is happening and adaptation to changing environmental conditions is a must. However, adaptation strategies including application of AWD techniques, construction of full-dyke systems, and abstraction of groundwater for agricultural activities are believed to principally enhance cycling of arsenic in different environmental compartments and subsequently accumulate arsenic in certain living organisms. Understanding of mobilization and behavior of arsenic in various environments are essential to reduce potential risk to human health.

The future research should emphasize on dynamics and partitioning of arsenic through different environmental compartments, pathways of arsenic in food web and its accumulation in biomass. In addition, speciation and transport of arsenic in environments is complicated particularly under changing climate. Experimentation is needed to elaborate key factors which have significant impact on arsenic species and its movement in dynamic environments.

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