

Distribution of arsenic in water and sediment in Mekong and Bassac River, Cambodia

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Abstract: Report of UNICEF, 2009 has shown that region along Mekong River in Cambodia has arsenic (As) pollution in groundwater. The major cause of As pollution was attributed to natural process such as the dissolution of As-containing minerals and anthropogenic activities such as percolation of water from mining waste. Cambodia has been recorded a higher concentration of arsenic in groundwater of several provinces including Kandal, Kampong Cham, Prey Veng, Kratie, and Steung Treng. Some studies have pointed out that the presence of arsenic in this groundwater might source from Mekong River. For this reason, this study aims to assess the distribution of arsenic in river and sediment of the Mekong and Bassac River, Cambodia. The water sample was collected from the surface, middle and bottom of the river in Kratie, Kampong Cham, and Kandal Province. The water samples ($n=45$) were analyzed for the physical and chemicals quality including As and Iron. Same analysis of Sediment samples ($n=11$) from the River of Kandal Province were also assessed for the concentration. The study found that the arsenic content in water samples of the Mekong River, Cambodia ranged from 2.75 $\mu\text{g/L}$ to 4.14 $\mu\text{g/L}$ in Kratie and Kampong Cham Province. In Kandal Province, the high concentration ranged from 10.16 $\mu\text{g/L}$ to 15.64 $\mu\text{g/L}$. The arsenic concentrations in water in Kratie and Kampong Cham Province were generally below the environmental standard of Sub Decree On Water Pollution Control, 1999. On the other hand, the arsenic concentration in water from the study site of Kandal Province was not in the permitted standard. Sediment sample contents arsenic is ranged from 1.05 mg/Kg to 1.70 mg/Kg. It was found a high concentration of arsenic in sediment and bottom water. The result has shown that a good correlation through some literatures point out a high concentration of As in the groundwater of Kandal Province. This could be a reason and source of the presence of a high concentration of arsenic in groundwater of Kandal province.

Keywords: Arsenic, distribution, surface water, sediment

1. INTRODUCTION

Arsenic is the poisoning component, has probably influenced human history more than any other elements or toxic compound (William and Frankenberger, 2002). It belongs to Group VA of the Periodic Table and can exist in four oxidation states: -3 , 0 , $+3$, and $+5$. Arsenite (As^{3+}) is usually more toxic than arsenate (As^{5+}) (Azizur Rahman *et al.*, 2012). From biological and toxicological perspective, there are three major groups of arsenic compounds: inorganic, organic, and volatile. (WHO, 2000). Inorganic arsenic is more toxic than organic arsenic (Rudnick and Gao, 2003; ATSDR, 2007). It is a proven carcinogen to human and strongly associated with lung, liver, bladder, and skin cancer (ATSDR, 2007).

Actually, the arsenic is an element found everywhere in the atmosphere, natural water, soils, rocks, and organisms. It is

gathered via a combination of the natural process such as biological activities, volcanic, weathering reactions and human activities (Thornton, 1999; Smedley and Kinniburgh, 2002). Sources of drinking water could come from different places based on available water sources such as surface water (ponds, rivers, and lakes), groundwater (aquifers) and rainwater. Some sources might pose a risk of arsenic contamination (Smedley and Kinniburgh, 2002).

The environmental problem of arsenic is the result of mobilization under natural condition (Smedley and Kinniburgh, 2002). Such conditions, the arsenic mobilization into the water will depend on its form in the soils and sediments, mainly the stability of solid phases in the face of reducing conditions (Ladeira *et al.*, 2001; Redman *et al.*, 2002). Arsenic mobilization is controlled by Fe oxyhydroxide and reduction of Fe released arsenic to solution or water (Sun *et al.*, 1996; Bhattacharya *et al.*, 1997; Nickson *et al.*, 2000; Ladeira *et al.*, 2001; Meng *et al.*, 2001; Rudnick and Gao, 2003; Nollet and De Gelder, 2014) and including the processing of microbial and

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chemical activities (Islam *et al.*, 2004 and Mladenov *et al.*, 2010). Several studies have shown that the distribution of arsenic between the liquid and the solid phase depend on the pH and oxide reduction potential of system (Nollet and De Gelder, 2014), arsenic concentration, arsenic speciation, competing irons, adsorption properties of the solid surface (Bissen and Frimmel, 2003; Wang *et al.*, 2009; Fendorf *et al.*, 2010; Azizur Rahman *et al.*, 2012). The consequent release of arsenic to the soil solution and watercourse some factors, such as grain size distribution, low pH values, heat, and exposure to water and oxygen, may favor mineral oxidation (Andrade *et al.*, 2008).

Arsenic is one of the most hazardous pollutant in groundwater and drinking water in some countries including Bangladesh, West Bengal, Nepal, China, Vietnam, India, Myanmar and many other countries across the world (Winkel *et al.*, 2008). Arsenic is appearing problem in natural contamination of water in Cambodia (UNICEF, 2009). The similar environmental condition is found in Cambodia where it lies in continental Southeast Asia, between the latitudes 10.5 and 14.5 north. Geographically the country is mainly flat in the central area and bordered by Thailand and Laos to the West and North by Vietnam on the East and South, and the Gulf of Thailand on the southwest. Cambodia is dominated by the two great lakes of the Tonle Sap Lake and the Mekong River. The Mekong River flows southward through the country from the border of Laos, and westward through Phnom Penh to join the Tonle Sap River. This Mekong River has its water sourced from Tibet where this Himalaya Mountain has a high content of arsenic in the mountain. The Mekong and Bassac River flow southward from Phnom Penh to the border of Vietnam, passing the Mekong Delta on its way to the South China Sea (UNICEF, 2009). Actually, Cambodia has known through huge literature by UNICEF, 2009 that region along the Mekong River presents a significant amount of arsenic in the groundwater. The confirmation of arsenic and health contamination was found through the research of Hashim *et al.*, 2013. The work emphasizes on the groundwater and hair samples of humans lived in Kandal, Kratie and Kampong Cham Province. Results showed highly contaminated by As in the sample. Kandal province which is highly contaminated area than another province. Kandal and Kratie had an arsenic concentration in well higher than the standard of Cambodia Drinking water quality standard of 50 $\mu\text{g/L}$ excepted Kampong Cham province less than WHO standard (Phan *et al.*, 2010). Sample of hair, fingernail, and toenail of individual from Kandal province had given a high concentration of As of more than 1 $\mu\text{g/L}$. The authors had concluded that it might be because of arsenic toxicity. Sample from Kampong Cham and Kratie Provinces had an arsenic concentration in hair higher arsenic than 1 $\mu\text{g/L}$ but fingernail and toenail was not high. So it is possible arsenic toxicity in hair but

fingernail and toenail were impossible arsenic toxicity (Phan *et al.*, 2011).

The purpose of the present study is to investigate arsenic distributions in water and sediment in the Mekong River and Bassac River of Cambodia. The specific objectives were set as follows: (1) To determine and compare a distribution of water chemistry parameters including total arsenic concentration in water of Mekong River from three sampling sites of Kratie, Kampong Cham, and Kandal Province of Cambodia, (2) To check the concentration of arsenic in the sediment of Bassac River and Kandal Province, (3) To assess the possible source of arsenic existence in groundwater for regions along Mekong and Bassac River.

2. METHODOLOGY

2.1 Sample collection

The study area is along the Mekong River to Bassac River of Cambodia. The water samples were collected from the surface, middle, and bottom of the river during dry season at the three provinces of Lower Mekong Cambodia (Figure. 1.). The sampling was in Mekong River at Kratie Province starting at the riverside of Ta Lus village, Bos Leav commune of Chetborei district to another riverside at Preaek Prolung village, Saob commune of Preaek Prasab district. Another three sampling points at Kampong Cham Province was made at the riverside of Phum 10 village, Veal Vong Commune, Kampong Cham city to another side of the river at Tbong Khmum Province of Chirot I village, Tonle Bet commune of Tbong Khmum district. Lastly, the sampling sites downstream of the Mekong River were chosen at Bassac River. Sampling points nearby Kaoh Thom Bridge were conducted for three cross-sections of the Bassac River at Preaek Thon village, Preaek Thmey continues, Kaoh Thom district. Kratie and Kampong Cham Province are located along the Mekong River upstream of Phnom Penh, whereas Kandal Province is located between the Mekong River and the Bassac River, downstream of Phnom Penh. Nine water samples were collected from the Mekong River in Kratie Province and another 9 water samples were collected from Kampong Cham Province. The water samples were reached to 27 in Bassac River in Kandal Province. Eleven sediment samples were collected at Kandal Province due to the accessibility and safety point of consideration. Kr, Kc, Ka represents sample notation as Kratie, Kampong Cham, and Kandal province, respectively. Notation for sediments sample is KA. Surface water samples were collected by hand with pail before pouring to sample storage bottle. The water from the middle and bottom of the river was collected by polyethylene bottle bounding with Nilong wire. The sampling bottle was attached heavily enough with concrete to make sure water sample can be collected the water at the bottom of the river.

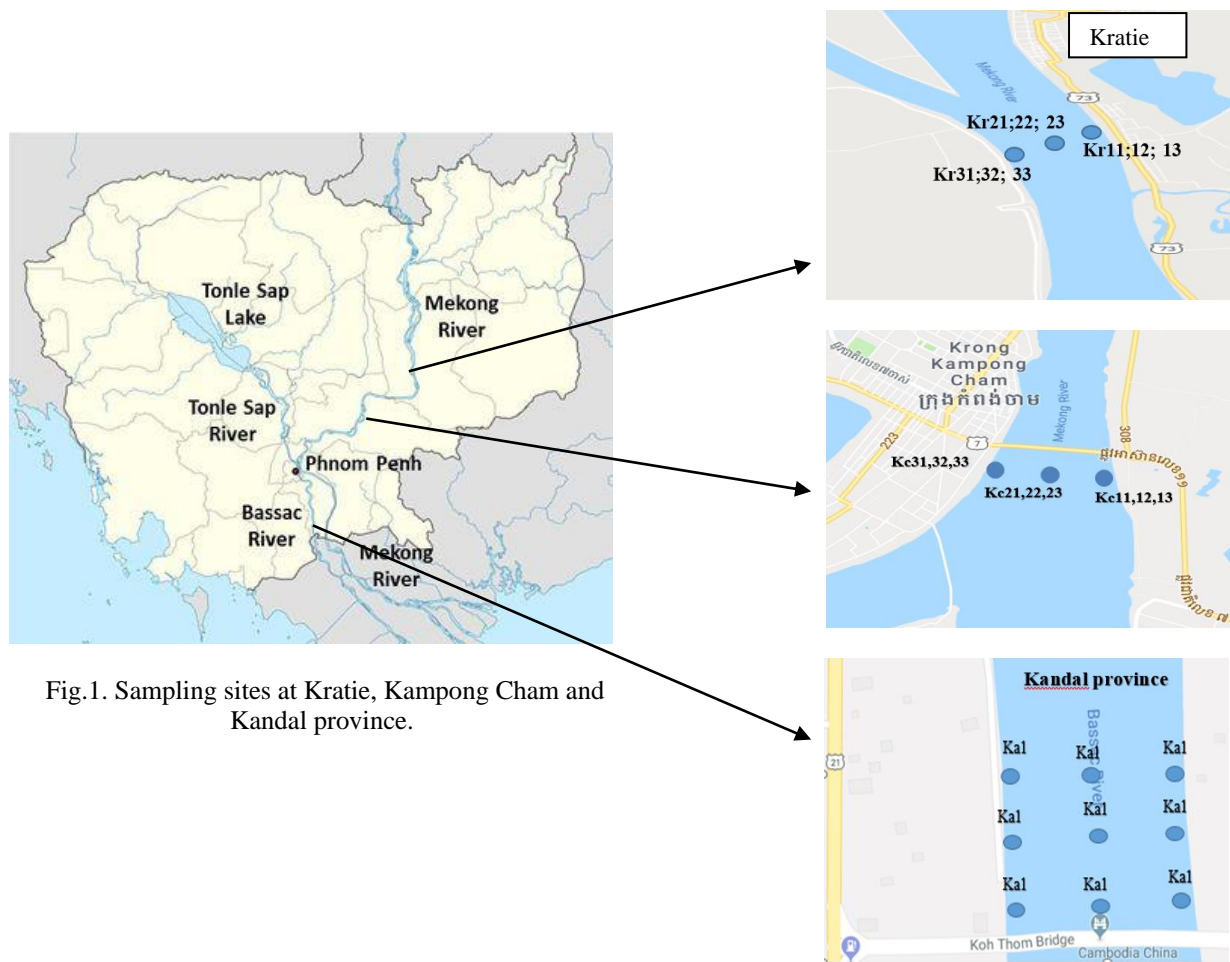


Fig.1. Sampling sites at Kratie, Kampong Cham and Kandal province.

One part of all sample includes surface, middle, and bottom of water sample were tested in situ for physical properties at the field (Rezende *et al.*, 2015). The samples were acidified with concentrated HNO_3 . They were stored in high-density polyethylene bottles and maintained frozen until analysis at laboratory (Rezende *et al.*, 2015). Sediment samples were collected by a PVC tube. The tube was vertical straight then use strong power pushed the tube into the sediment and closed tube. The sediment samples were stored in plastic buckets and kept at 4°C then carried to laboratory for analysis (Chapagian *et al.*, 2009).

2.2 Chemical analysis of Fe and As

20 ml of water samples after filtered with glass fiber filter of 0.45 micrometer pore size were analyzed with an Atomic Absorption Spectrophotometer (AAS) method model (AA-7000) (Berg *et al.*, 2007). Sediment samples were dried in oven at 105°C than taken out mass measurement until constant weight. 1 gram of dry sediment sample was digested with 10mL of nitric acid-

65%, mix and cover with a watch glass. Then, the sample was heat to $95^\circ\text{C} \pm 5^\circ\text{C}$ for 10 to 15 minutes. Next, the sample was kept to cool down to room temperature and added 5mL of concentrated HNO_3 following by another cycle of digestion. This digestion process requires to repeat till no appearance of brown fume. Then, the digested sample was cooled down to room temperature prior to addition of 2 mL distilled water and 3mL of 30% hydrogen peroxide (H_2O_2). Then, the solution was reheat at $95^\circ\text{C} \pm 5^\circ\text{C}$ without boiling for two hours. After cooling, the solution was diluted to 100mL with water then removed the particulate in the digested sample by filtration with filter paper 0.45 μm (METHOD 3050B, 1996). The sample was then ready for analysis by AAS method (Berg *et al.*, 2007). Overall processes of the experimentation is shown in Figure 2.



Fig.2. Sample treatment and analysis.

3. RESULTS AND DISCUSSION

3.1 Physicochemical properties

The results of physicochemical characteristic of water sample were compared with standard of UNESCO, WHO,

UNEP, 1996 and Sub Decree On Water Pollution Control (Sub-decree,1999) in Table 1.

Table1. Standard of water river UNESCO, WHO, UNEP, 1996 and Sub-decree, 1999

Parameters	Standard
Turbidity (NTU)	-
DO (mg/L)	7.5-2.0 ^b
pH	6.5 -8.5 ^b
TDS (mg/L)	-
Conductivity (µs/cm)	≤300 ^b
Temperature (°C)	<45 ^b
Iron(mg/L)	≤ 3.0 ^a
Arsenic (µg/L)	< 10 ^b

^a: UNESCO/WHO/UNEP, 1996

^b: Sub-decree, 1999

According to Table.2. show that all water samples had pH levels close to neutrality, the temperature had values < 45°C, conductivity had values <300 µs/cm, dissolved oxygen (DO) values were compliant values of Sub-decree, 1999 standard but Kratie and Kampong Cham Province had only DO parameter are non-compliant values of standard. The turbidity had values range from 5.97 to 62.76 NTU. The value of total dissolved solids was from 76.33 to 125.33 mg/L.

Table2. The results of physicochemical characteristic of water sample in Kratie, Kampong Cham and Kandal location.

Parameter	Unit	Kratie (average)			Kampong Cham			Kandal		
		Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
Turbidity	NTU	9.990	9.547	30.300	5.977	9.013	62.767	27.633	28.233	25.000
pH	None	8.063	8.200	8.103	8.226	8.313	8.306	7.674	7.692	7.706
Temperature	°C	27.633	28.233	25.000	28.200	28.267	27.367	27.356	27.378	27.389
Conductivity	(µs/cm)	163.833	164.100	152.767	194.867	172.900	170.867	111.011	103.122	101.856
DO	mg/L	8.720	8.130	7.733	8.567	8.657	8.467	3.218	3.174	3.089
TDS	mg/L	125.333	114.333	114.687	114.667	114.677	112.000	76.667	76.444	76.333

3.2 Iron and Arsenic concentration in water

3.2.1 Iron concentration

The results are shown in Figure 3, iron concentration in surface and middle of the water in Kandal location was high, whereas that in Kratie is moderate and lowest concentration of 0.011 mg/L was found in Kampong Cham. The concentration of iron in the bottom of the river in Kampong Cham was high, whereas medium concentration in Kandal, and lowest in Kratie province.

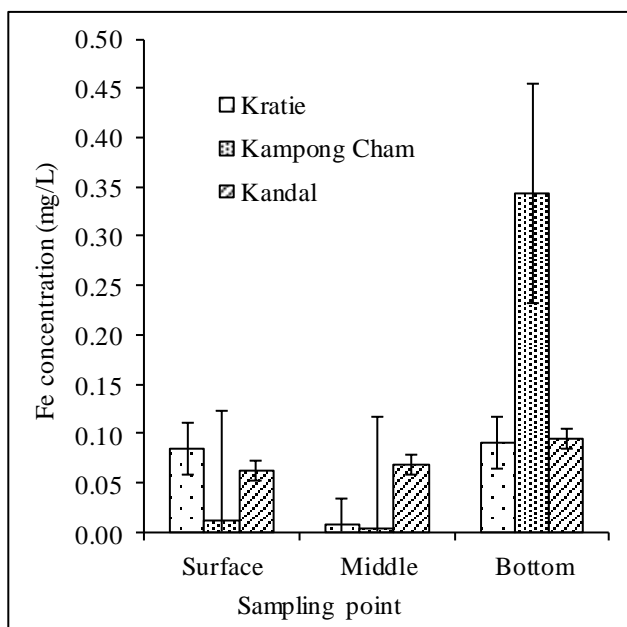


Fig. 3. Iron concentration in water samples.

The concentration of iron in water was highest than another point at the bottom of the Kampong Cham location (0.343 mg/L). According to the permitted UNESCO, WHO, UNEP, 1996, the concentration of iron in the river must be lower than 0.3mg/L. So all water sample had a concentration of Fe in standard permitted except for the concentration at the bottom in Kampong Cham Province. As the result, the concentration of iron does not increase by the water depth. Both arsenic species adsorb onto a variety of metal oxides. However, iron oxide (FeO) is the most adsorbent substrate because of chemistry and prevalence of iron oxide throughout the hydrogeologic environment (Hinkle and Polette, 1998).

3.2.2 Arsenic concentration

Fig.4. shows that arsenic concentration in the surface, middle and bottom of the water in Kandal location was

higher than Kampong Cham and lower in Kratie Province. The As concentration in water in Kampong Cham is similar with that in Kratie at each location and water depth. It is noted that the concentration of arsenic in water was highest in the bottom of Bassac River (15.64 µg/L). The high arsenic concentration is found for the sample at the bottom of the river. It is generally that the concentration of arsenic increase depends on the water depth.

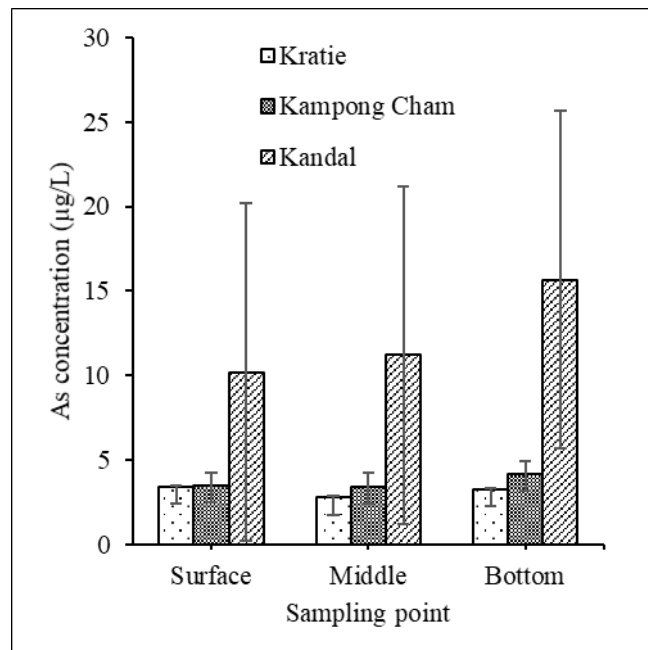


Fig.4. Arsenic concentration in water samples

Fig.4, shows in general that the concentration of arsenic in the bottom water is higher than the middle and surface of the water. For instance, arsenic concentration from Bassac River has arsenic content in surface water (10.16µg/L) lower than in the middle of the water (11.21 µg/L) and in middle of water lower than the bottom of the water (15.64 µg/L). The occurrence of arsenic in river water might be from the natural and human activity. This result could be explained by the oxidation of arsenic in the surface and flow into the bottom of the river (Hug *et al.*, 2001). A concentration of arsenic in freshwater change depends on the amount of arsenic, the source of arsenic, the biological and the local geochemical environment (Smedley and Kinniburgh, 2002). Arsenic used in pesticides for agriculture might be a contributor to the increase of arsenic in water followed by low-temperature volatilization and windblown dust from surface water flowed to bottom of the river (WHO, 2000; 2001). Arsenic from natural and anthropogenic sources are mainly transported in the environment by water to

sediment and penetrate into groundwater. The factors of this transport are oxygenated that arsenites predominate under reducing condition that found in deep well-water. The concentration of arsenic from Kandal Province is highest compared to the water samples from the river at Kratie and Kampong Cham Provinces.

3.3 Arsenic and Iron in sediment samples

3.3.1 Iron concentration in sediment samples

Fig.5, shows about the result of iron content ranged from 11.60 mg/Kg to 18.65 mg/Kg. The maximum (18.65 mg/Kg) iron concentration was observed in the sediment samples of KA1 lower layer of sediment. On the contrary, the minimum 11.60 mg/Kg of iron content was observed in the sediment of KA3 upper layer of sediment. Totally, all samples concentration of iron in sediments occurrence within each depth. In general, it is shown that the lower sediment sample has a higher concentration of iron. According to the result, the concentration of iron increase related to the increase of arsenic concentration in sediment in this area. A release of arsenic from iron oxide also results from the biologically mediated process of dissimilatory iron reduction, which happens in reducing environments with large amounts of decaying organic matter. Bacteria cause arsenic as arsenite to desorb from available iron oxide into groundwater during those conditions (Stollenwerk *et al.*, 2003).

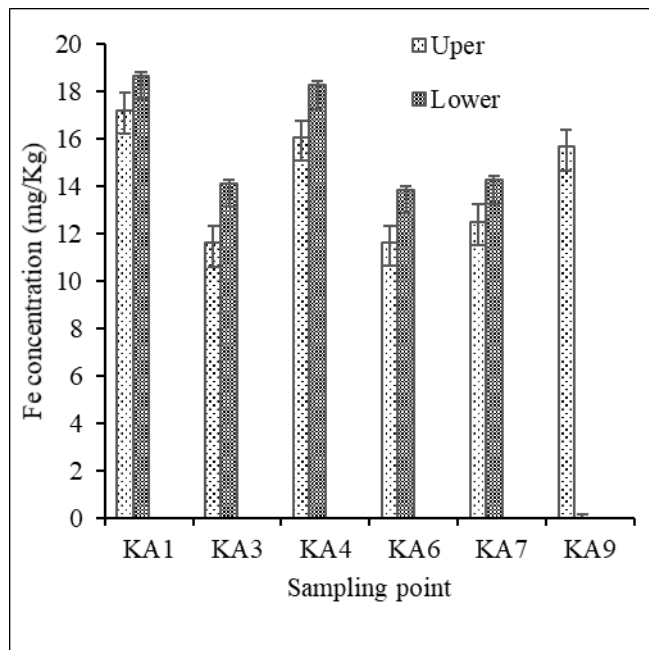


Fig.5. Iron concentration in sediments

3.3.2 Arsenic concentration in sediment samples

The arsenic content ranges from 1.05 mg/Kg to 1.70 mg/Kg. The maximum (1.70 mg/Kg) arsenic concentration was observed in the sediment samples of KA1 lower layer of sediment. On the contrary, the minimum (1.05 mg/Kg) arsenic content was observed in the sediment of KA3 upper layer of sediment. In general, all sediment samples of the lower side have a higher concentration of arsenic than the upper.

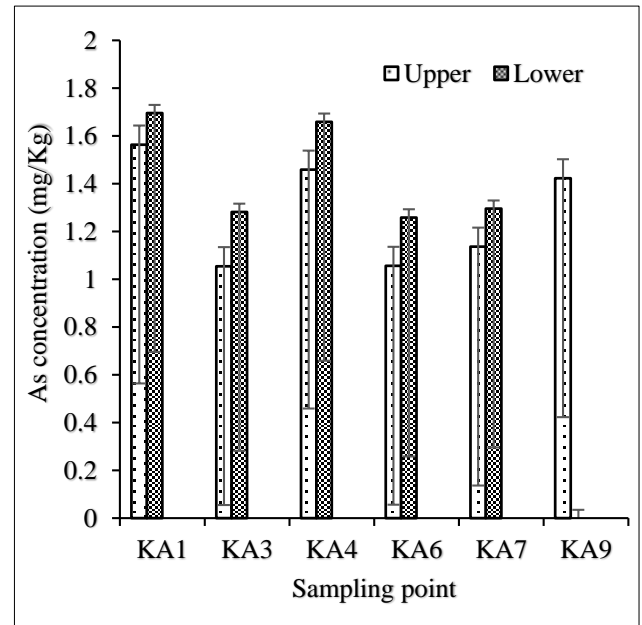


Fig.6. Arsenic concentration in sediments

Fig.6, shows that arsenic concentration in the upper layer of sediments ranged from 1.05mg/Kg to 1.56mg/Kg. In lower layer of sediments, arsenic concentration ranged from 1.25mg/Kg to 1.70mg/Kg. Through the in Fig.4, arsenic and iron concentration in lower layer were higher than the upper layer all locations in Kandal province studies areas. Refer to this result, the concentration of iron might be involved with increasing of arsenic in the sediment from upper to lower. Arsenic might penetrate in the sediment because of the concentration of arsenic in own sediment and arsenic flow from the surface of the water into the sediment. The important process is arsenic adsorbed to the Fe oxyhydroxides (Meharg *et al.*, 2006). The high concentration of arsenic in water is the strong influence of arsenic in groundwater by water-rock interaction and tendency in aquifers under the natural condition to be favorable for arsenic mobilization and accumulation (Smedley and Kinniburgh, 2002). Arsenic in sediment is mobilized probably following the dissolution of hydrous iron oxides causing elevated

arsenic concentration in the pore water relative to the water column (Elbaz-Poulichet *et al.*, 1987).

4. CONCLUSIONS

The assessment of arsenic concentration and its distribution in the Mekong River in Cambodia were conducted for water and sediment. The basic water chemistry parameters show that all values are respect to the standard set by Sub-decree, 1999. The arsenic concentration in water in Kandal Province is higher than Kratie and Kampong Cham province. This study might be giving a further understanding of the occurrence of arsenic in the Mekong River and Bassac River, especially in Kandal Province because literature has reported the high concentration of arsenic in groundwater in this province. The proof through the previous study about the high concentration of arsenic in Kandal province could explain by the higher presence of arsenic content in the bottom water in this study. In addition, the higher concentration in the lower sediment of the Bassac River in Kandal Province could be further a scientific proof, which is correlating to the enrichment of arsenic. However, this study could be more validated if a complete analysis of the interaction between arsenic migration together with the geological condition of soil and land use condition in the study as well as the riverbank study.

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