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Assessing arsenic intake from groundwater and rice by residents in Prey Veng province, Cambodia

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ABSTRACT

We investigated total daily intake of As by residents in Prey Veng province in the Mekong River basin of Cambodia. Groundwater ($n = 11$), rice ($n = 11$) and fingernail ($n = 23$) samples were randomly collected from the households and analyzed for total As by inductively coupled plasma mass spectrometry. Calculation indicated that daily dose of inorganic As was greater than the lower limits on the benchmark dose for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$ equals to 3.0 μg d^{-1} $kg^{-1}{}_{body\ wt.}$). Moreover, positive correlation between As in fingernail and daily dose of As from groundwater and rice and total daily dose of As were found. These results suggest that the Prey Veng residents are exposed to As in groundwater. As in rice is an additional source which is attributable to high As accumulation in human bodies in the Mekong River basin of Cambodia.

1. Introduction

Chronic exposure to As in drinking water is a major public health concern among the developing countries in South Asia. High As concentrations have been reported in Bangladesh (Das et al., 2004; Ohno et al., 2007), India (Uchino et al., 2006; Roychowdhury, 2010), Taiwan (Liao et al., 2009; Cheng et al., 2010), China (Fujino et al., 2004; Kwok et al., 2007; Liu et al., 2009), Vietnam (Berg et al., 2001; Nguyen et al., 2009; Hanh et al., 2011) and Loa PDR (Chanpiwat et al., 2011). To date, many studies have also reported high As concentrations in shallow Cambodian groundwater (Polya et al., 2005; Berg et al., 2007; Buschmann et al., 2007; Benner et al., 2008; Kocar et al., 2008; Polizzotto et al., 2008; Robinson et al., 2009). Moreover, it was revealed that the highly contaminated area like Kandal province not only contaminated with As, but also Mn, Ba and Fe (Sthiannopkao et al., 2008; Luu et al., 2009; Phan et al., 2010). Our health risk assessment of inorganic As intake of people residing in the Mekong River basin of Cambodia revealed that 98.65% of residents in Kandal province study area were confronted to As toxicity through groundwater drinking pathway (Phan et al., 2010). Moreover, calculation of cancer risk was found in average 5 in 1000 exposures (Phan et al., 2010). In fact, arsenicosis patients have been discovered in the rural Cambodia (Sampson et al., 2008; Mazumder et al., 2009); some cases developed sever skin cancer and ulcer which required amputation (Gollogly et al., 2010). Although some high risk areas have been identified, much effort is needed to dress arsenic issues in the Mekong River basin of Cambodia. Recently, high As concentrations have been also reported in rice irrigated with As-enriched groundwater in Kandal (Phan et al., 2012). Therefore, it is of importance to investigate the total daily intake of As by residents living in the other contaminated areas in order to prevent the adverse health impacts resulting from ingestion of both As-contaminated groundwater and rice. The main objectives of the present study were to (1) determine a distribution of total As concentrations in groundwater, rice and fingernail of residents living in the Prey Veng province, Cambodia; (2) assess the daily intake of inorganic As from groundwater and rice by residents in Prey Veng province, Cambodia; (3) compare the daily intake of As from groundwater consumption to that from rice ingestion; (4) observe a correlation between As concentration in fingernail and that in groundwater and rice.

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2. Materials and methods

2.1. Field work

This is a cross-sectional study of 11 households, with groundwater ($n = 11$), rice ($n = 11$), and fingernail ($n = 23$, clipping from two family members) sampled from each household in Svay Chrum village, Koh Roka commune, Peam Chor district, Prey Veng province in the Mekong River basin of Cambodia (Fig. 1).

2.2. Sample preparation and analysis

Groundwater was sampled from a tube well after 5–10 min of flashing in order to remove any standing water from the tube. Groundwater was filled in a polyethylene bottle, acidified (with 70% HNO_3) and kept in an ice box during field work. Rice sample was collected from the same household where groundwater was collected and kept in a paper bag. Concurrently, fingernails of male and female family members were sampled from a household where groundwater and rice were collected. All samples were transported to a laboratory at the Department of Chemistry, Royal University of Phnom Penh for further treatment. Rice samples were washed with deionized water and dried in the open air under diffused sunlight for 24 h; next samples were oven-dried at 50 °C for several days to achieve complete dryness, and they were subsequently manually ground to a fine powder with a mortar and passed through 35-mesh sieve. Each sample was repacked in a labeled plastic ziplock bag and shipped to GIST, South Korea for chemical analyses. Analytical procedures were described in our previous reports of groundwater (Phan et al., 2010), rice (Phan et al., 2012) and fingernail (Phan et al., 2011). In brief, approximately 0.10 g of rice or fingernail was weighed into a 15 mL polyethylene tube. One mL of the concentrated HNO_3 (65%) was added into each tube. The tube was then capped and left in a hood at room temperature. After 48 h, 9.00 mL of deionized water was added and filtered (0.45 μm) into a fresh tube. All chemical measurements of the total As were made by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7500 ce).

2.3. Estimate of daily inorganic arsenic intake

As intake from groundwater (μg d^{-1}) is calculated by multiplying the As concentration in groundwater (μg L^{-1}) by the water consumption rate (L d^{-1}). The As intake from rice is calculated by multiplying the As concentration in rice (μg g^{-1}) by the rice consumption rate (g d^{-1}). The As concentrations in groundwater and rice are determined in this study. Daily inorganic As intake from groundwater and rice are estimated for individuals who participated in this study, based on the assumption that 100% of the total As in groundwater and 80% of the total As in rice are inorganic As

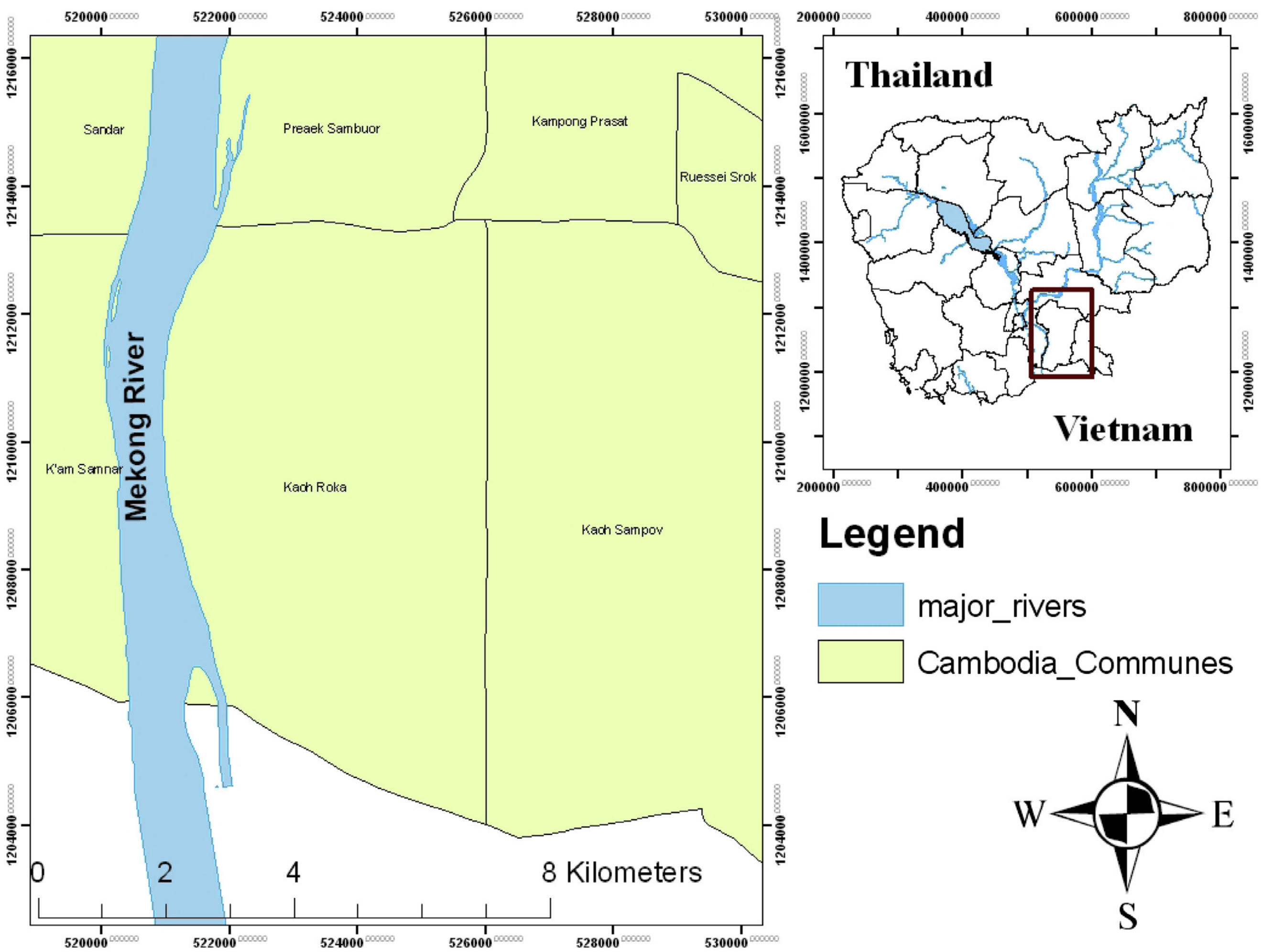

Fig. 1. Map of the sampling area.

(Williams et al., 2005; Sanz et al., 2005; Mondal and Polya, 2008; WHO, 2011; Hanh et al., 2011; Phan et al., 2012). Demographic information as well as groundwater and rice consumption rates were collected during the field work (Table 1). Daily dose of inorganic As ($\mu g\ kg^{-1}\ d^{-1}$) is calculated by dividing the inorganic As intake ($\mu g\ d^{-1}$) by the individual body weight (kg).

2.4. Statistical data analyses

All statistical data analyses were performed by SPSS for windows (Version 16.0). Mann–Whitney's U test was applied to verify the differences in male and female intake of inorganic arsenic whereas Wilcoxon Signed Ranks test was performed to certify the differences in daily intake of As from groundwater and rice. Concurrently, Mann–Whitney's U test was used to validate a difference in arsenic concentration in male and female fingernails. The strength of correlation between the As concentrations in fingernail with the daily dose of As from groundwater and rice and daily dose of inorganic arsenic were measured by Spearman's rho correlation coefficient (r_s). Significance was considered in circumstance where $p < 0.05$.

3. Results and discussion

Analytical results of groundwater, rice and fingernail samples are presented in Table 2. Approximately 63.6% of groundwater samples ($n = 11$) had As concentration higher than 10 $\mu g\ L^{-1}$, WHO's guideline for As in drinking water. However, all rice samples ($n = 11$) had As concentrations less than the maximum level for As (0.3 $\mu g\ g^{-1}$) proposed by Food and Agriculture Organization of the United Nations (FAO, 2012). The mean of the total arsenic in rice ($n = 11$, mean $= 0.201 \pm 0.050$ $\mu g\ g^{-1}$, median $= 0.209$ $\mu g\ g^{-1}$) is comparable to that in the arsenic-affected areas of Northern (Agusa et al., 2009) ($n = 10$, mean $= 0.225$ $\mu g\ g^{-1}$) and Southern Vietnam (Hanh et al., 2011) ($n = 39$, mean $= 0.225$ $\mu g\ g^{-1}$, median $= 0.201$ $\mu g\ g^{-1}$), Bangladesh (Smith et al., 2006) ($n = 46$, mean $= 0.358$ $\mu g\ g^{-1}$) (Ohno et al., 2007) ($n = 18$, mean $= 0.34 \pm 0.15$ $\mu g\ g^{-1}$) and India (Roychowdhury, 2009) ($n = 34$, mean $= 0.239$ $\mu g\ g^{-1}$). It is also quite close to the total arsenic in rice collected from different regions of Bangladesh (Williams et al., 2006) ($n = 330$, 0.08–0.51 $\mu g\ g^{-1}$) and Brazil (Batista et al., 2011) ($n = 44$, mean $= 0.223$ $\mu g\ g^{-1}$), as well as the total arsenic in rice in the markets of France ($n = 33$, mean $= 0.28$ $\mu g\ g^{-1}$, median $= 0.23$ $\mu g\ g^{-1}$) and the United States ($n = 163$, mean $= 0.25$ $\mu g\ g^{-1}$, median $= 0.25$ $\mu g\ g^{-1}$) (Meharg et al., 2009).

Analyses of acid-digested fingernail samples clipped from the residents in the Prey Veng province study area revealed that the As concentrations in fingernail ($n = 23$) ranged from 0.099 to 2.382 $\mu g\ g^{-1}$ with mean of 0.830 $\mu g\ g^{-1}$ and median of 0.707 $\mu g\ g^{-1}$. Among all the fingernail samples ($n = 23$), 26.1% had As concentration greater than 1.00 $\mu g\ g^{-1}$ (ATSDR, 2007), indicating As toxicity. Gault et al. (2008) reported that As concentrations in fingernail collected from Kandal province study area ranged from 0.2 to 6.50 $\mu g\ g^{-1}$ ($n = 70$, median $= 1.30$ $\mu g\ g^{-1}$ and mean $= 1.90$ $\mu g\ g^{-1}$) while Mazumder et al. (2009) subsequently presented that the As concentration in nail of the Preak Russey residents ranged from 1.06 to 69.48 $\mu g\ g^{-1}$ ($n = 93$). Our results showed that As concentrations in fingernails of the residents in Prey Veng province were much lower than those in the Kandal province. However, As concentration in fingernails of the residents in Prey Veng province were a bit higher those in Kratie ($n = 76$, mean $= 0.26$ $\mu g\ g^{-1}$, median $= 0.23$ $\mu g\ g^{-1}$, range $= 0.07$–0.73 $\mu g\ g^{-1}$) and Kampong Cham ($n = 83$, mean $= 0.13$ $\mu g\ g^{-1}$, median $= 0.12$ $\mu g\ g^{-1}$, range $= 0.03$–0.28 $\mu g\ g^{-1}$) (Phan et al., 2011).

Table 2
Summary of As concentrations in groundwater ($\mu g\ L^{-1}$), rice ($\mu g\ g^{-1}$) and fingernail ($\mu g\ g^{-1}$).

Statistics	As concentration		
	Groundwater	Rice	Fingernail
N	11	11	23
Mean	118.312	0.201	0.830
Median	31.180	0.209	0.707
SD	138.527	0.050	0.631
Min	0.972	0.091	0.099
Max	351.500	0.285	2.382

SD, standard deviation; Min, minimum; Max, maximum.

Calculation of daily intake (Table 3) indicated that the daily dose of inorganic As was greater that the lower limits on the benchmark dose for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$ equals to 3.0 $\mu g\ d^{-1}\ kg^{-1}{}_{body\ wt.}$). Recently, Hanh et al. (2011) reports that male and female residents of Southern Vietnam ingest inorganic arsenic from 28 to 102 $\mu g\ d^{-1}$, equivalent to the daily dose of 0.6–1.9 $\mu g\ d^{-1}\ kg^{-1}{}_{body\ wt.}$ after they stopped using groundwater in 2008. The present study clearly indicates that residents in the Prey Veng province of Cambodia ingest higher amount of inorganic arsenic than those in the Southern Vietnam. Likewise, the residents in Prey Veng ingest higher amounts of inorganic arsenic than those in Ronphibun of Thailand (Ruangwises and Saipan, 2010) (15.8–146 $\mu g\ d^{-1}$, average $= 82.4 \pm 27.8$ $\mu g\ d^{-1}$, equivalent to the daily dose of 0.31–2.01 $\mu g\ d^{-1}\ kg^{-1}{}_{body\ wt.}$, average $= 1.43 \pm 0.40$ $\mu g\ d^{-1}\ kg^{-1}{}_{body\ wt.}$ from a duplicate diet study), Bangladesh (Smith et al., 2006) (19–232 $\mu g\ d^{-1}$ from cooked rice only) and India (Roychowdhury, 2009) (141–179 $\mu g\ d^{-1}$, average of the daily intake of arsenic from only rice and vegetable in Bengal delta).

Comparisons indicated that there were no significant differences in daily intake of As from groundwater and rice and total daily intake of As among male and female residents in the Prey Veng province (Mann–Whitney's U test, $p > 0.05$). Likewise, there was no significant difference in daily intake of As from groundwater and rice (Wilcoxon Signed Ranks test, $p > 0.05$). Concurrently, As concentrations in male and female fingernails were not statistically

Table 1
Summary of gender, age, body weight, height, water rice and rice consumption from field survey.

	Female ($n = 12$)					Male ($n = 11$)				
	Mean	Median	SD	Min	Max	Mean	Median	SD	Min	Max
Age (y)	34.083	31	20.961	7	79	42.273	41	17.153	21	76
Body weight (kg)	42.500	45	11.091	13	59	55.364	56	4.843	48	66
Height (cm)	151.333	155	17.206	100	165	162.091	163	3.270	155	167
Water consumption rate ($L\ d^{-1}$)	1.375	1.25	0.433	1	2	1.818	2	0.337	1	2
Education level (y)	6.250	6.5	2.375	2[a]	10	6.273	7	2.149	3	10
Rice consumption rate ($g\ d^{-1}$)	429.167	450	72.169	200	450	450	450	0.000	450	450

[a] Four female participants did not go to school; SD, standard deviation; Min, minimum; Max, maximum.

Table 3
Summary of inorganic As concentration in groundwater (μg L^{-1}) and rice (μg g^{-1}), daily intake and daily dose of inorganic As from groundwater, rice and total consumption.

	Statistics	Inorganic arsenic	Daily intake (μg d^{-1})	Daily dose (μg kg^{-1} d^{-1})
Groundwater	Mean ± SD	118.312 ± 138. 527	196.455 ± 243.140	3.855 ± 4.846
	Median	31.18	46.77	0.843
	Range	0.972–351.500	0.97–703.00	0.035–17.575
Rice	Mean ± SD	0.167 ± 0.040	68.955 ± 20.886	1.459 ± 0.421
	Median	0.171	75.359	1.511
	Range	0.073–0.228	27.977–102.454	0.585–2.152
Total Consumption	Mean ± SD	–	265.41 ± 255.629	5.314 ± 5.016
	Median	–	103.198	2.242
	Range	–	28.950–779.872	1.159–19.497

SD, standard deviation; Inorganic As was calculated by assuming 100% of total As in groundwater and 80% of total As in rice are in inorganic form.

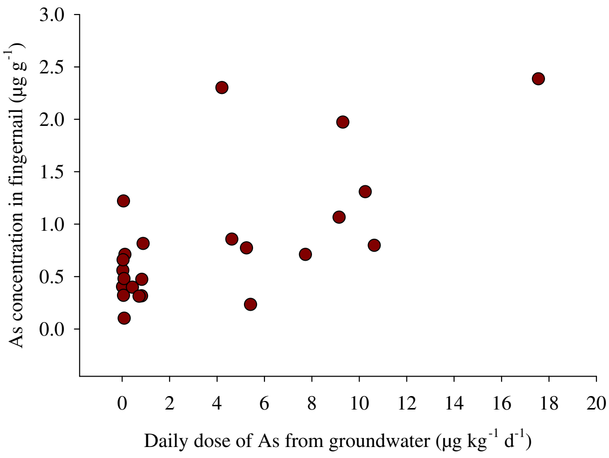

Fig. 2. Association between daily dose of As from groundwater and As concentration in fingernail.

significant different (Mann–Whitney's U test, $p > 0.05$). This was consistent with our previous report (Phan et al., 2011). However, plotting As concentration in fingernail versus daily dose of As from groundwater revealed a significant positive correlation ($r_s = 0.542$, $p < 0.01$; Fig. 2). In addition, non-significant positive correlation was found while plotting As concentration in fingernail with daily dose of As from rice ($r_s = 0.406$, $p > 0.05$; Fig. 3). The correlation was improved (more significant positive) while plotting As concentration in fingernail and total daily dose of inorganic As ($r_s = 0.555$, $p < 0.01$; Fig. 4). Inter-correlation between As concentrations in groundwater, rice and fingernail, daily dose of As from groundwater and rice and total daily dose of As are presented in Table 4. These findings suggested that As in rice could be an additional source for As intake among residents in Prey Veng province in the Mekong River basin of Cambodia. This study measured only As concentrations in groundwater and uncooked rice; additional exposure from cooking water might be possible because tube well waters were still used for cooking by some households.

A dozen of arsenicosis patients were found during field sampling. The rapid onset of arsenicosis symptoms in Prey Veng province might be due to the ingestion of excessive amounts of arsenic from either groundwater drinking pathway or daily food consumption, in particular rice irrigated with As-enriched shallow groundwater. Although some mitigating actions of arsenic risks from drinking arsenic-rich groundwater have been taken into account, arsenic in rice is substantially/equally dangerous. The development of information, education and communication (IEC) materials may play a vital role to educate people about their health risks from consumption of both As-enriched groundwater and As-laden rice. In addition, the change of agricultural practices may reduce the arsenic burden in rice. Therefore, more attention should be paid to the development of irrigation systems in the arsenic-affected areas.

4. Conclusions

Analytical results showed that 63.6% of groundwater in the study area of Prey Veng province was unsafe for drinking purpose. Calculation of daily inorganic As intake indicated that the daily dose of inorganic As was greater than the lower limits on the benchmark

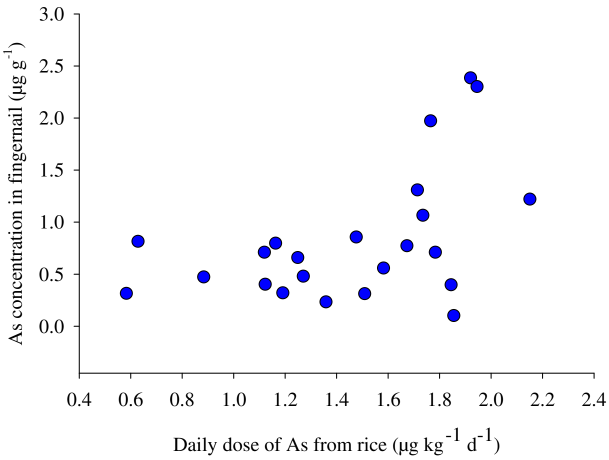

Fig. 3. Association between daily dose of As from rice and As concentration in fingernail.

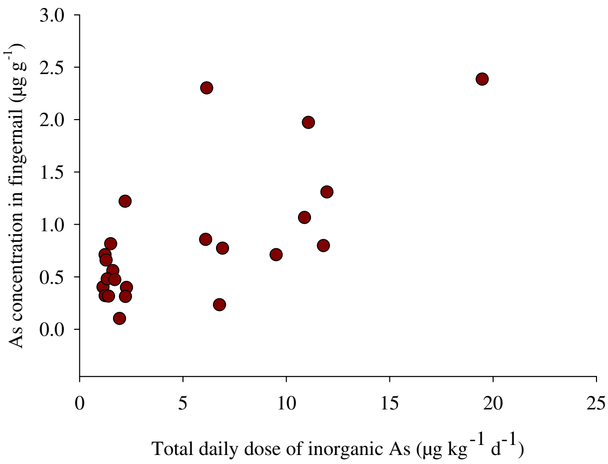

Fig. 4. Correlation between total daily intake and As concentration in fingernail.

Table 4
Inter-correlation between As concentrations in groundwater, rice, fingernail, daily dose of As from groundwater, rice and total daily dose of As.

Variables	Rice	Fingernail	Groundwater intake	Rice intake	Total intake
Groundwater	0.563**	0.455*	0.971**	0.164	0.847**
Rice	–	0.355	0.563**	0.646**	0.749**
Fingernail	–	–	0.542**	0.406	0.555**
Groundwater intake	–	–	–	0.238	0.893**
Rice intake	–	–	–	–	0.576**

*$p < 0.05$; **$p < 0.01$.

dose for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$ equals to 3.0 μg d^{-1} $kg^{-1}_{body\ wt.}$). About 26.1% of the participants were susceptible to As toxicity based on fingernail analysis. Moreover, positive significant correlations between groundwater As concentration, daily dose of As from groundwater and total daily dose of As with As concentration in fingernail were found. These results suggested that the residents in Prey Veng province study area are at risk of As in groundwater. As in rice is an additional source which is attributed to the high As accumulation in human bodies in the Mekong River basin of Cambodia.

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